Journal of Stored Products Research 58 (2014) 67–76

Contents lists available at ScienceDirect

Journal of Stored Products Research

journal homepage: www.elsevier.com/locate/jspr

A simple methodology for measuring profitability of on-farm storage pest management in developing countries

Michael Jones[a], Corinne Alexander[b,*], J. Lowenberg-DeBoer[c]

[a] Food and Resource Economics Department, University of Florida, P.O. Box 110240 IFAS, Gainesville, FL 32611, USA
[b] Department of Agricultural Economics, Purdue University, 403 W. State St., West Lafayette, IN 47907, USA
[c] Department of Agricultural Economics, Purdue University, 615 W. State St., West Lafayette, IN 47907, USA

ARTICLE INFO

Article history:
Received 23 April 2012
Accepted 10 December 2013
Available online 6 February 2014

Keywords:
Profitable storage
Financial model
Price seasonality
Opportunity cost of capital

ABSTRACT

We present a simple financial model for storage researchers to measure the profitability of storage protection for marketing producers in developing countries. We examine the relationship between the value of a stored commodity and required price seasonality for profitable storage under a range of possible fixed costs of storage and opportunity costs of capital. The cost of storage protection has a larger effect on storage profitability with low value commodities such as maize, while the opportunity cost of capital has a larger effect on storage profitability of high value commodities such as cowpeas and common beans. An example is drawn with maize in Malawi, contrasting the profitability of storage protection with hermetic Purdue Improved Crop Storage (PICS) bags versus government-subsidized chemical protectants. Results from this example show that while PICS bags financially outperform chemical protectants, profitability varies greatly both by year and region of the country. We additionally include a Microsoft Excel template and interactive website link along with an explanation of the financial model to facilitate incorporation of economics in storage research on insect losses and technology adoption.

1. Introduction

Storage pests cause substantial economic losses in developing countries (Boxall, 2001; World Bank, 2011). To combat pest threats, scientists strive to develop technologies which provide the highest level of effective and safe storage protection. However, highly effective protection is often expensive and few producers will adopt the technology unless it is profitable. Technically sound innovations may not become sustainable market goods, even after surpassing traditional hurdles to adoption such as product availability and producer capital constraints. Researchers must critically examine the potential demand for a technology, asking “Can this storage technology be profitable for smallholder producers?” and, if yes, “Are producers better off with this technology than with their current storage practices?” Producers may benefit from a technology because it is more profitable than their current practices, or the technology may offer additional health, environmental, or other benefits. The answers to these questions require a more robust understanding of economic losses from pest damage, from which we calculate the implicit value of preventing such losses. For example, is perfect protection with zero storage losses the best financial decision, or is the market willing to tolerate some damage? Profitable storage also depends on the relationship between the stored commodity’s value, price seasonality, and the cost of storage protection. Further, producers will evaluate investment in a particular storage technology relative to their alternative on-farm and off-farm investment opportunities.

Ex-ante analysis of storage technology transfer must contextualize each of these key economic concepts in order to reliably estimate adoption potential and profitability. The goal of this article is to present a useful and simple framework for researchers to estimate financial losses from insect damage and ultimately the profitability of storage technologies for low-resource producers. We provide an application of this methodology based on a real screening process for the introduction of a storage technology in Sub-Saharan Africa.

1.1. Defining ‘losses’ from the producer’s perspective

Grain protectants allow producers to store for long periods without facing potentially massive losses from storage pests.

---

* Corresponding author. Tel.: +1 765 494 4249.
E-mail address: cealexan@purdue.edu (C. Alexander).

0022-474X/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jspr.2013.12.006

However, the term ‘storage loss’ is poorly defined in the stored products literature. While economic and life science storage research evaluates ‘losses’ primarily through ‘dry weight losses’ (DWL) (see: Babarinde et al., 2008; Kimenju and DeGroote, 2010; Stephens and Barrett, 2011), Boxall (2002) emphasizes that there are other forms of ‘loss’ associated with pest damage which must be considered and which depend on the producer’s end use of the grain. A producer storing grain for household consumption may measure pest ‘losses’ primarily through DWL, though losses also occur in relative nutritive value (Magrath et al., 1996). Producers storing grain for seed must consider DWL as well as depressed seed viability in damaged grains (Baier and Webster, 1992; Moino et al., 1998; Paul et al., 2009). Marketing producers are an especially important case, as DWL is compounded by price discounts for pest-damaged grains (Compton et al., 1998; Langyintuo et al., 2004; Mishili et al., 2011). When a marketing producer’s revenue is eroded due to the combination of DWL and price discounts for damage, the result is a ‘total value loss’ which can far exceed the traditional metric of DWL. This article focuses on marketing producers and demonstrates how focusing on DWL alone can lead to serious underestimation of the value of storage protection when producers face price discounts for low quality grain. Instead, we argue that the correct metric is ‘total value loss’.

1.2. The economics of ‘total value loss’ prevention

To determine ‘total value loss’, it is necessary to know (i) DWL, (ii) the percentage of grains damaged, and (iii) the price discounts for each percentage of damaged grain. Since revenue is the product of quantity and price, the resulting revenue loss or ‘total value loss’ from insect damage is the compound effect of DWL and price discounts for damaged grain. In developed countries, grain quality grades are formalized with strict thresholds on insect infestation and grain damage. Discount schedules are generally published by grain buyers and are openly available, providing developed-country producers with a clear understanding of the economic losses associated with reduced quality due to damage in storage (Yigezu et al., 2010). In contrast, many developing-world grain marketing transactions are informal. Grain prices are commonly negotiated between traders and producers on the spot. Thus thresholds and discount schedules for damaged grain are less clear, complicating measures of economic loss.

Among the limited literature on informal discount schedules in Sub-Saharan Africa, price discounts for grain damage are best documented for cowpeas in hedonic pricing studies throughout West and Central Africa (Langyintuo et al., 2003, 2004; Faye et al., 2004, 2006; Mishili, 2005; Mishili et al., 2009; Ibro, 2011). Cowpea damage discount estimates range from 0.17% to 2.3% of average price for each bruchid hole in a sample of 100 grains (Langyintuo et al., 2003; Mishili, 2005). While researchers originally hypothesized that West and Central Africans would tolerate a certain level of damage before demanding a price discount, data indicate that consumers discount from the very first bruchid hole.

Discounts for insect grain damage also have been documented for common beans (Mishili et al., 2011) and maize (Compton et al., 1998). Using hedonic price analysis, Mishili et al. (2011) find a 2.3% reduction in price for every insect emergence hole in 100 grains in a major market of Dar es Salaam, Tanzania. Compton et al. (1998) use trader focus groups throughout the marketing season to find a 0.60%–0.97% price reduction for every 1% of damaged maize kernels in Ghana. Maize damage discounts decrease as grain becomes scarcer later in the marketing season and there is a threshold of 5–7% grain damage in the lean or “hunger” season before discounts are applied (Compton et al., 1998). At the highest rates of grain damage, traders may also refuse to purchase. The larger discounts for legumes compared to maize may reflect preparation methods, as legumes are cooked whole and maize is generally milled before consumption. Quantifying value loss for damaged grain consumed in the home becomes more difficult to specify, as research indicates smallholder producers value and handle grain for market and grain for consumption differently (Hoffmann et al., 2013). To avoid misspecification of quality discounts for home-consumed maize, we will focus only on smallholders who store for the purpose of sale so that we can utilize the explicit market-based damage discounts from the literature.

Based on the literature on maize storage damage in Sub-Saharan Africa, we quantitatively link DWL, the percentage of grains damaged, and applicable price discounts for damaged grains to estimate total value loss for marketing producers. Price discounts depend on the percentage of grains damaged and are not directly related to DWL. To link DWL to insect-damaged maize kernels, we utilize the exponential relationship documented by Holst et al. (2000) under infestation of both maize weevil (*Sitophilus zeamais*) and larger grain borer (*Prostephanus truncatus*) complexes (for more detail see Appendix A). Utilizing Ghanaian price discount schedules from Compton et al. (1998), conservative six month DWLs of 10–15% from maize storage pests such as the larger grain borer (Dick, 1988; Golob and Hanks, 1990; Boxall, 2002) may result in total value losses of 36.7%–51.1%. The relationship between maize DWL and total value loss is depicted in Fig. 1 for storage into the lean or ‘hunger’ season. Following Compton et al. (1998), we assume a conservative 7% grain damage threshold before price discounts become applicable, corresponding to a traditionally “low” DWL of 1.45% (Holst et al., 2000). Figure 1 illustrates that when defining “losses”, total value loss can easily triple DWL above the 7% grain damage threshold. Therefore, it is crucial to include price discounts for grain damage in estimating economic losses or the potential benefit of adopting a storage technology. To the best of our knowledge, Meikle et al. (2002), and Jones et al. (2011) are the only economic evaluations of maize storage protection in Africa that utilize total value loss rather than DWL.

1.3. Indirect costs of storage for small producers

Storage cost analysis typically focuses on direct costs of storage technologies (Adda et al., 2002; Meikle et al., 2002; Adetunji, 2009; Sekumade and Oluwatayo, 2009; Kimenju and DeGroote, 2010). In addition to direct costs of storage, a producer also faces a significant opportunity cost of capital (OCC). Economists use OCC to measure this indirect cost of storing a commodity by evaluating the return on commodity storage relative to other investment options. OCC is often estimated as (i) the rate of return on alternative investments, or as (ii) the interest rate on acquiring capital through a loan. For example, if a low-resource producer is considering storing maize, the direct investment would include the sack or storage container, grain protectants purchased, and also the value of the maize itself. The producer could sell the maize at harvest and invest the revenue plus the saved cost of sacks and grain protectants in a venture such as livestock rearing or small-scale vending which earns a certain return. Therefore, the producer who stores maize must expect returns from maize storage will be greater than his or her alternative investment opportunities.

In the context of developed-country markets, the OCC is generally measured as the foregone interest from investing capital in financial markets or institutions (Perloff, 2008), and may range between 2 and 10% (Williams and Wright, 1991). However, this is not a realistic OCC measure for a rural African small-holder with no access to developed capital markets. The estimates of OCC are

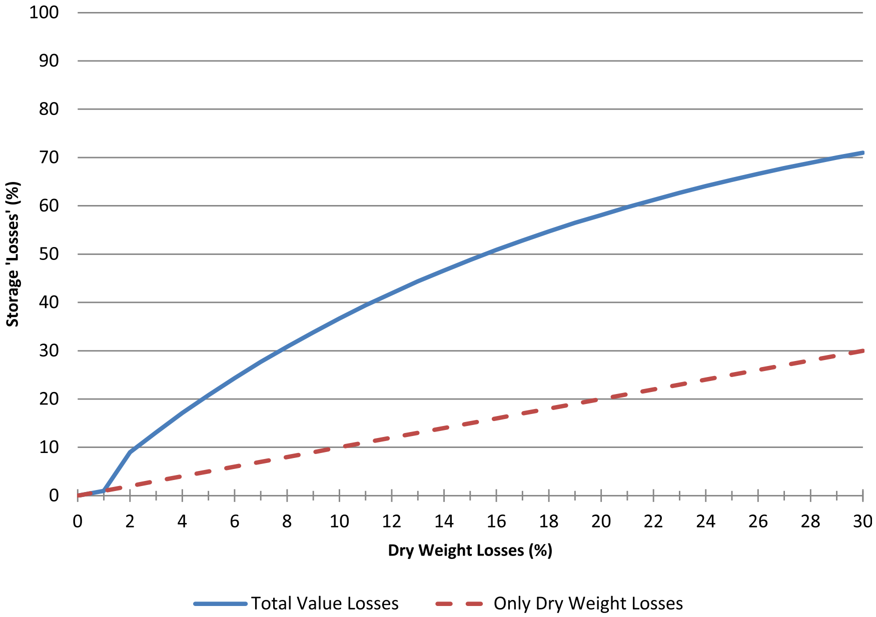

Fig. 1. Disparity between Maize Dry Weight Losses and Total Value Losses. Sources: Conversion of DWL to percentage of grains damaged: Holst et al. (2000); Price discounts from grain damage: Compton et al. (1998), normal lean season.

significantly higher in developing countries due to the high cost of capital faced by many producers in Sub-Saharan Africa (Lowenberg-Deboer et al., 1994). If credit is available, microloans in Sub-Saharan Africa commonly have annual interest rates between 25 and 50%, and informal lending may have annualized rates over 100% (Buckley, 1997; Stewart et al., 2010). However, access to formal credit sectors is extremely limited and most low-resource producers rely on personal savings or informal borrowing (Gulde et al., 2006).

There are two important consequences of limited access to credit which are relevant to storage investment. Many debts such as school and social obligations are generally due in the immediate post-harvest period. To store grain for marketing purposes, a producer must be able to meet debts in the harvest season through credit or sufficient personal savings, rather than needing to sell grain to cover these obligations (Stephens and Barrett, 2011). Secondly, storing for future sale requires a producer to forego investing post-harvest grain sales in other revenue-generating activities that may generate very high rates of return which could very well outpace returns from commodity storage (Lowenberg-Deboer et al., 1994).

For an individual producer, the opportunity cost of storing a particular commodity depends on the value of the commodity and the annual rate of OCC. The magnitude of the OCC increases as the value of the commodity increases and as the rate of OCC increases. To understand the impact of varying rates of OCC, Table 1 presents an example from the Southern African country of Malawi with sensitivity analysis over developed world rates of 2–10% and developing world rates of 25–50%. To understand the impact of the value of the commodity, Table 1 compares the opportunity cost associated with storing maize, a relatively low value crop, to storing common bean, a relatively high value crop. In the Lunzu market of Blantyre, Malawi during the May 2010 harvest period, the price of a 50 kg bag of maize was 1500 Malawian Kwacha (MK) ($10.13 USD[1]) and the price of a 50 kg bag of common beans was 10,000 MK ($67.62 USD). According to the World Bank, this 50 kg of maize and beans would represent 3.1% and 20.9%, respectively, of the average 2010 per capita Gross Domestic Product ($323). Bean storage is expensive in this context, as this large portion of a producer's income would be inaccessible until the time of sale. The opportunity cost of storing 50 kg of maize or beans for eight months (0.67 years), evaluated at an annual OCC rate of 25%, would thus be 248 MK and 1650 MK ($1.68 and $11.16), respectively.

Table 1
Opportunity Cost of Capital (OCC) for storing 50 kg of grain for eight months.[a]

Annual rate of OCC (%)	Maize	Common beans
2	20 MK[b]	132 MK
10	99 MK	660 MK
25	248 MK	1650 MK
50	495 MK	3300 MK

[a] Lunzu market, Blantyre, Malawi; nominal May 2010 harvest season prices.
[b] Malawian Kwacha (MK).
Malawian Ministry of Agriculture (2011).

2. Estimating returns to storage

A profit-maximizing producer only has an incentive to store if they expect the sale of a commodity to be more profitable in the future than in the present. Therefore, an analysis of storage returns must be measured against the benchmark option to sell in the immediate post-harvest period ($t = 0$). The variables required to measure returns to storage are:

1) commodity price at harvest period
2) quantity of grain to be stored
3) length of storage period
4) price seasonality (increase or decrease) across the storage period
5) cost of storage technology
6) DWL

---

[1] MK/USD conversion based on January 1, 2011 exchange rates.

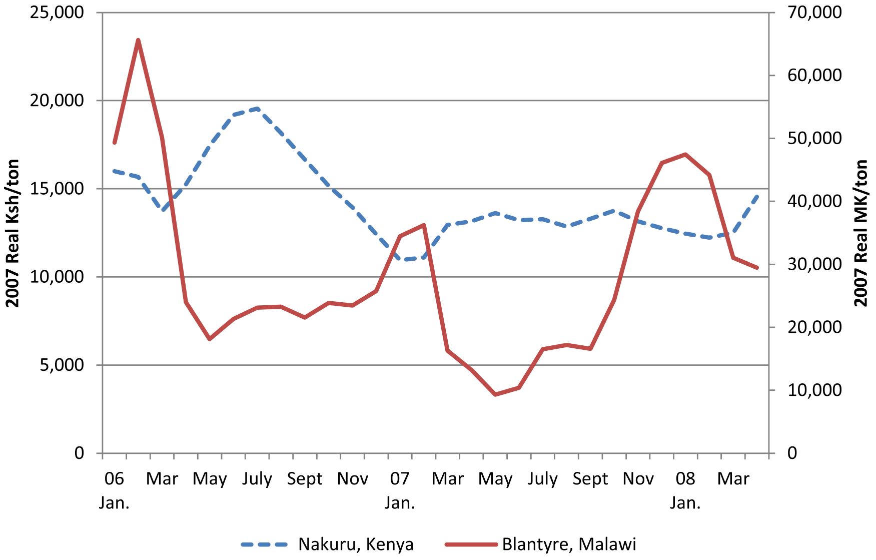

Fig. 2. Maize prices, 2006/07 and 2007/08 marketing seasons: Blantyre, Malawi and Nakuru, Kenya (real prices, base 2007). Source: Adapted from Chapoto and Jayne (2010). Note: Ksh = Kenyan Shilling; MK = Malawian Kwacha.

7) percentage of damaged grains
8) price discount for damaged grains
9) rate of OCC (or range for sensitivity analysis)

To compute the return to storage, future revenue at time (t) is computed net of investment costs and associated opportunity costs. The investment costs represent both the investment in storage protection and the value of the commodity at harvest. The return to storage is simply the gain divided by the investment cost.

Equation (1) calculates the returns to storage (%R) as follows:

$$\%R = \frac{p_t q_t - [1 + r_t](p_0 q_0 + c)}{p_0 q_0 + c} \tag{1}$$

Where (p_0) and (q_0) are the price received and quantity sold in the immediate post-harvest month, (p_t) and (q_t) are the price received and quantity sold (t) months after the immediate post-harvest month ($t = 0$), (c) is the cost of the storage technology, and (r_t) is the time-adjusted rate of OCC (or loan interest rate). The time-adjusted annual rate of OCC is evaluated as a percentage of the annual rate of OCC (r). For example, for (t) months of storage, the simple interest time-adjusted rate of OCC is evaluated as (t/12)*r. Equation (2) relates the price and quantity (t) months after harvest relative to the harvest period.

$$p_t q_t = (1 + x)(1 - v)(p_0)^*(1 - w)(q_0) \tag{2}$$

Where (x) is the percent commodity price increase over (t) months, (v) is the percent price discount applied for grain damage, and (w) is the percent DWL in storage. Substituting equation (2) into equation (1) results in equation (3).

$$\%R = \frac{[(1 + x)(1 - v)(1 - w) - 1]p_0 q_0 - c}{p_0 q_0 + c} - r_t \tag{3}$$

Equation (3) shows that the return to storage depends on the difference between two rates: the financial rate of return to storage and the time-adjusted rate of OCC. A positive return to storage (%$R > 0$) indicates that storage profit is greater than potential returns from other investments, and thus the producer should choose to store. A negative return to storage (%$R < 0$) means other investments are more profitable or the loan interest rate exceeds returns from storage, and the producer should not choose to store. The producer is indifferent between storing and investing in other activities if the two rates are equal, or %$R = 0$.

2.1. Price seasonality

For storage to be profitable across (t) months, the price needs to increase through the storage period. Regional harvest cycles have a large influence on seasonal price patterns. Therefore, it is imperative to understand the commodity's price seasonality (x) in the locations of potential storage technology introduction.

An estimated 90% of Sub-Saharan Africa agriculture is still under rain-fed production and small producers are extremely dependent on climate patterns (Rosegrant et al., 2002). Regions with a single harvest season in unimodal rainfall zones generally experience much greater price seasonality than regions with dual harvests in bimodal rainfall zones. As illustrated by Fig. 2, the Blantyre market region in unimodal Malawi displays very pronounced seasonal maize price patterns, with inflation-adjusted (real) price increases between harvest in May and December of 99.7% and over 400% in the 2006/07 and 2007/08 marketing seasons. Western Kenya, in contrast, has bimodal rainfall which helps moderate this price seasonality. The market region of Nakuru in the southwestern "grain basket" region of Kenya had seasonal price increases of 42.4% and 25.7% in the 2006 and 2007 marketing seasons. In addition to climate variation, the policy environment is very different in the two regions. The Malawian government's discretionary policies of imposing export bans and attempting price controls in the 2007/08 marketing season is blamed for some of the exacerbated price variance, while Kenya has been committed to stronger free-market policies since 2005 (Chapoto and Jayne, 2010).

While both regions are major maize growing zones with pest pressure from the larger grain borer (Kamanula et al., 2010; Omondi et al., 2011), price data indicate that the average return to storage in southern Malawi is significantly higher than in bimodal zones of western Kenya (Jones et al., 2011). Thus, profit-

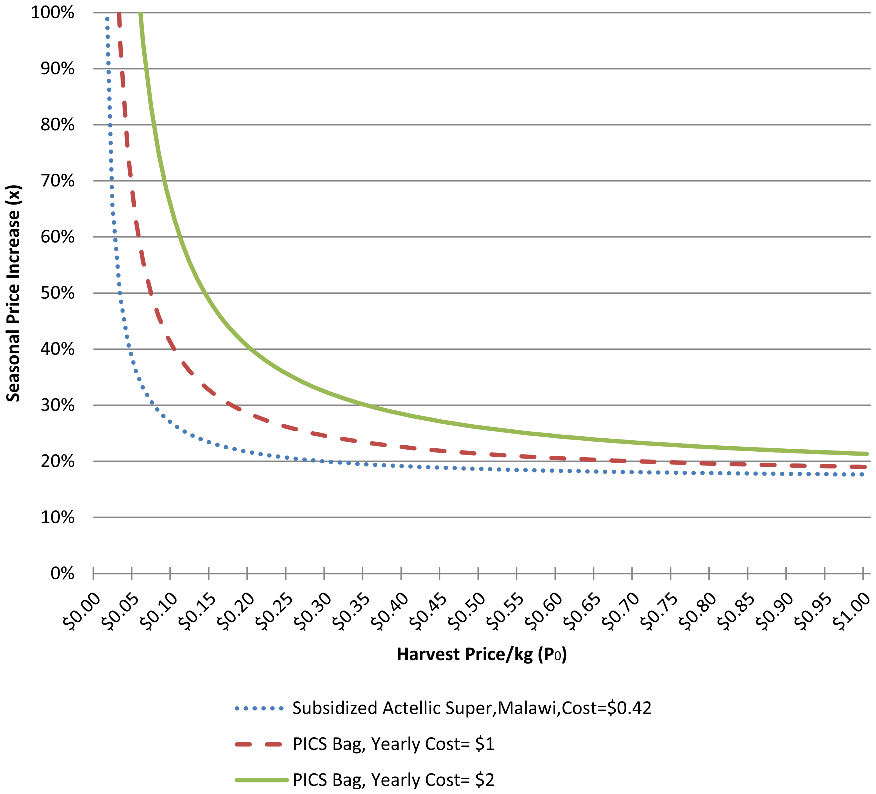

Fig. 3. Financial Threshold for Storage Profit for Any Crop (Best-case Scenario: Perfect Protection- no weight or value loss) 50 kg, 8 months, OCC (r) = 0.25.

maximizing marketing producers in Malawi have greater incentives to adopt storage technologies.

Economic theory suggests that the difference between present and future commodity prices should equal the cost of storage (Working, 1949). However, throughout the world and particularly in Sub-Saharan Africa, frequent shocks disturb this natural price seasonality. Shocks may be domestic or international, including regional drought, discretionary government policy such as government purchase, export bans, and price controls (Chapoto and Jayne, 2010), or price pressures from world markets (Abbot et al., 2008; Minot, 2009). Low-resource marketing producers operate in these uncertain price environments, and shocks may cause price movements which favor or disfavor returns to storage in any particular year. This price uncertainty which derives from the supply uncertainty drives the demand for storage (Williams and Wright, 1991). When data are available, incorporating price risk analysis into storage profitability estimates will help capture this price uncertainty facing marketing producers. However, this article will not incorporate this price risk component, as sufficient data are not available in the developing world context.

2.2. Is this new storage technology profitable?

To determine if storage of a particular commodity is profitable, for a given harvest price we calculate the minimum level of expected price seasonality for a positive return to storage. This minimum expected price seasonality can be compared with historical data and future price expectations to estimate whether storage is potentially profitable for marketing producers in a particular region. We solve equation (3) for the expected price seasonality variable (x) required for profitable storage across (t) months, incorporating DWL and price discounts for damaged grain:

$$x = \frac{1}{(1-v)(1-w)}\left[1 + r_t + \frac{c(1+r_t)}{p_0 q_0}\right] - 1 \tag{4}$$

Equation (4) shows that dry weight losses (w) and price discounts for grain damage (v) incurred during the storage period will erode gains and require greater expected seasonal price increases (x) to make storage profitable. Similarly, higher storage technology costs (c) and producer OCC (r_t) will also require more significant expected seasonal price increases. Increasing the quantity stored (q_0) or harvest price (p_0), i.e. storing higher-value crops, conversely requires smaller expected seasonal price increases.

If a storage technology provides “perfect” protection, i.e. negligible weight loss and no price discounts ($v = w = 0$), equation (4) reduces to equation (5).

$$x = r_t + \frac{c(1+r_t)}{p_0 q_0} \tag{5}$$

Figure 3 is based on equation (5) and illustrates the minimum threshold for storage profitability for two storage technologies on the market in Sub-Saharan Africa for a 50 kg sack of grain, given the commodity’s harvest price and expected seasonal price increase assuming zero DWL, no price discounts for grain damage ($v = w = 0$), 8 months of storage and an OCC of 25%, for storage technologies that have different costs. While the literature shows recommended doses of Actellic Super (permethrin (0.3%) + pirimiphos-methyl (1.6%)) would not provide zero DWL over eight months in larger grain borer zones, if the seasonal price increases are not large enough to make storage profitable under the assumption of “perfect” efficacy then producers would be unlikely to adopt them.

Figure 3 compares two storage technologies, at three different costs. First, Actellic Super is the lowest-cost storage investment of

$0.42. This case represents storage in woven polypropylene sacks with recommended doses of deltamethrin and permethrin-based chemical insecticides subsidized by the Malawian government's Agricultural Input Subsidy Program. Insecticide cost is evaluated at $0.084/50 kg treated, as bottles were sold by extension offices in 2011 at subsidized prices of 100 Malawian Kwacha (MK)/200 mg. A non-subsidized bottle of the same product would cost between 250 and 350 MK/200 mg on the retail market. Therefore, if storage at the subsidized price is not profitable, then it is likewise not profitable at the full retail price. The 50 kg capacity woven bag is evaluated at $0.337, based on a purchase price of 100 MK and depreciated for two years of use (author's observation (2011), producer interviews).[2] While the Malawian government has included several different storage chemicals in the subsidy program since this component's inception in 2005 (Dorward and Chirwa, 2011), we assume Actellic Super (permethrin (0.3%) + pirimiphos-methyl (1.6%)) because it is often included in the subsidy program. Second, we consider Purdue Improved Crop Storage (PICS) triple-layer hermetic storage bags.[3] PICS bags are currently manufactured and distributed in West and Central Africa, with retail prices of $2–4 (Baributsa et al., 2010). We assume the PICS bags are used for two years, resulting in the depreciated $1 and $2 annual cost.

In Fig. 3, each curve defines the threshold at which storage becomes profitable for a technology. For a given commodity harvest price, storage is profitable if the expected seasonal price increase is above the threshold for that technology; if the expected seasonal price increase is below the threshold then storage is not profitable. For example, if PICS bags have a $1 annual cost, maize with a harvest price of $0.1/kg to $0.2/kg would require at least a 40%–28.3% expected seasonal price increase for profitable storage, respectively. If PICS bags cost $2, profitable storage of maize with a harvest price of $0.1/kg to $0.2/kg would require a larger seasonal price increase of at least 63.3%–40%, respectively. While low-value maize requires large seasonal price increases for profitable storage with these technology costs, high-value commodities such as cowpeas and common beans would require much lower seasonal price increases. For cowpea in West Africa, both harvest prices and seasonal price increases are very high, resulting in exceptionally profitable storage with highly effective technologies. For example, from 2005 to 2009 in cowpea-intensive south-central Niger, harvest prices ranged from $0.3/kg to $0.6/kg with inflation-adjusted seasonal price increases of 31%–196%.

For each storage technology, low-value commodities require larger expected seasonal price increases than high-value commodities. Furthermore, the profitability of storing low-value commodities is especially sensitive to the cost of storage, as this cost represents a larger percentage of the stored commodity's total value. In contrast, high-value commodities with a harvest price above $0.50/kg are much less sensitive to storage costs and the OCC becomes a much larger component of total storage cost. As the value of the commodity increases, the minimum expected seasonal price increase for profitable storage will approach the OCC. With storage technologies with fixed capacities, such as metal silos or PICS hermetic bags, producers must choose the most profitable commodity to store based on harvest price and expected price seasonality. If a producer is choosing between storing a low-value commodity such as maize and a high-value commodity such as cowpea, the producer would choose to store cowpeas when the price of both commodities is expected to increase by 50%.

3. Comparing profitability of storage technologies: application of the methodology for maize storage in Malawi

This methodology can be used to determine the relative profitability of storage technologies with different costs and efficacy. We provide an example which the Purdue Improved Crop Storage (PICS) research team has used to investigate the potential profitability of hermetic storage in triple-layer bags for various crops. The first stage of the PICS project (2006–2011) yielded widespread adoption of the triple-bagging system for cowpea storage in West and Central Africa; as of April 2012, over 1.8 million PICS bags have been manufactured and sold in 10 countries. PICS triple-bagging has proven very effective at minimizing bruchid grain damage for reliable medium- and long-term storage of this high-value crop (Sanon et al., 2011; Bauoa et al., 2012), leading to significant income gains for producers (Baributsa et al., 2010). The 100 kg bagging system has retail cost between $2–4, units and can be re-used if the integrity of the high-density polyethylene liners is not compromised (Baributsa et al., 2010). In the second phase of the PICS project, we are responding to considerable interest from producers, researchers and policy makers as to the potential effectiveness and profitability of the triple-bagging system for other crops throughout Sub-Saharan Africa, including maize, common bean, and pigeon pea (Obeng-Ofori, 2011). An independent trial by Hell et al. (2010) showed promising initial results for 3 and 6 months of maize storage, with dry weight losses in the presence of the larger grain borer of 0.29% and 0.31%, respectively. The 0.02% increase in dry weight loss from 3 to 6 months was not statistically significant. Larger trials are currently underway at various East and West African institutions, but this analysis will include the Hell et al. (2010) initial results to simply illustrate an application of the storage profitability methodology.

The PICS project is investigating the important questions of whether storage of low-value crops such as maize is profitable, and, if so, whether PICS bags increase storage profits compared with competing storage technologies. The PICS project identified Malawi as a region where the bags may be profitable because there is significant maize price seasonality as well as major storage challenges posed by the larger grain borer and maize weevil. This example represents part of the ex-ante assessment for potential PICS bags profitability when compared to government-subsidized storage chemicals.

To address these research questions, equation (4) is modeled in Fig. 4 to include DWLs and price discounts for grain damage for PICS bags and Actellic Super. Since reliable DWL estimates are not available for insecticide-treated maize in Malawi, Actellic Super DWLs are modeled with eight-month losses of 8.4% under larger grain borer presence in shelled maize. This intentionally conservative eight-month estimate is based on a six-month recorded DWL in CIMMYT studies detailed by Kimenju and DeGroote (2010) and George (2011). Maize DWL is converted to "percentage of grains damaged" using the relationship from Holst et al. (2000). Then price discounts are applied at the lean-season rate from Compton et al. (1998), which is the most conservative study to have estimated price discounts for insect damaged maize. Consumer preferences and thus price discounts from grain damage can and will vary geographically (as seen from cowpea hedonic pricing studies). Using these assumptions, a DWL of 8.4% translates to 34.4% of grains damaged and a price discount of 25.7% for a total value loss with Actellic Super of 32.1%. For sensitivity analysis, we also examine storage profitability when Actellic Super is 25% more effective, with an eight-month DWL of 6.3%. When DWL is assumed to be only 6.3%, total value loss is 18.3%. The total price of Actellic Super use in bagged maize is modeled at subsidized rates of $0.42/50 kg of grain. PICS bags with 50 kg volume are anticipated to have

---

[2] MK/USD conversion based on January 1, 2011 exchange rates.

[3] See: http://www.ag.purdue.edu/ipia/pics/Pages/Home.aspx.

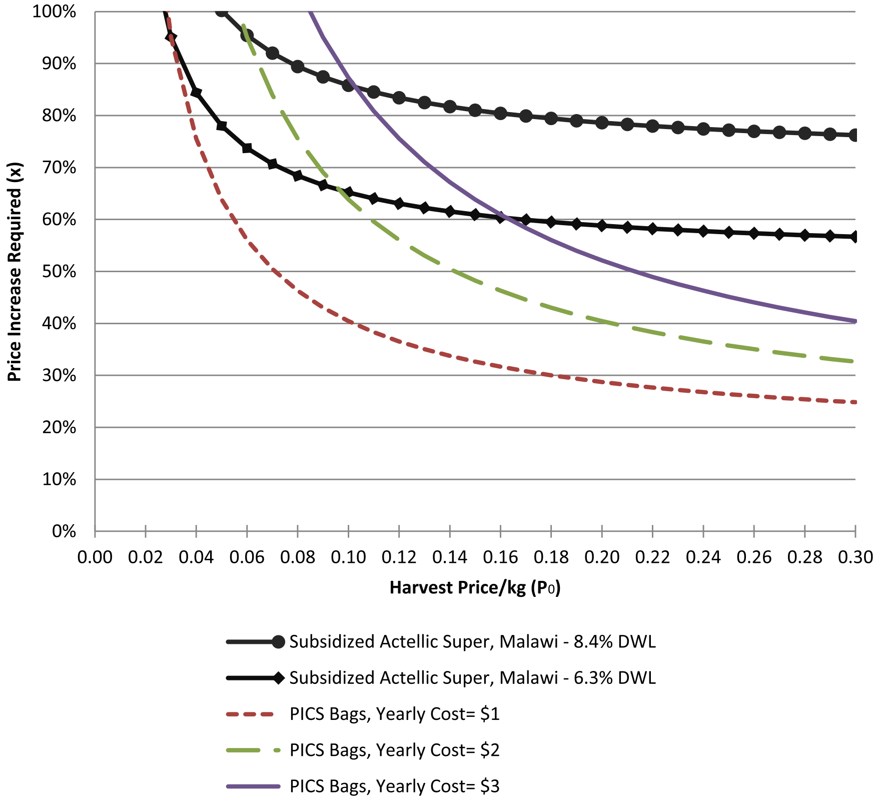

Fig. 4. Comparing Profitability of Storage Products in Malawi for 50 kg of Maize, storing for 8 months with an opportunity cost of capital (r) of 25%.

a retail cost of $2–$2.5, based on manufacturing capacity and distribution channels in Malawi. If a second year of use is possible, bag cost per season would depreciate to $1–1.25.

Maize price data were collected from the Malawian Ministry of Agriculture office for 21 markets throughout the country with complete or nearly complete price series from January 2006 to April 2011. These price data were grouped into regions with 7 markets in the Northern region, 6 markets in the Central region and 8 markets in the Southern region. Prices were converted to real January 2011 prices, adjusting for inflation using the monthly consumer price index from the National Statistics Office of Malawi. Farm-gate prices are assumed to represent 79% of listed retail prices in the post-harvest season based on trader interviews during June and July, 2011. Table 2 shows that real national average harvest prices increased from $0.10–$0.13/kg in 2006 and 2007 to $0.19–$0.21/kg in 2008, 2009, and 2010. Price seasonality varies considerably by year and by market, with the largest seasonal increases in 2007 and 2008. The dramatic price variation between markets highlights the value of market-level analysis rather than using national averages. Projects in other countries should seek market-level data as well to identify regional and yearly variance in potential returns.

Figure 4 illustrates the expected seasonal maize price increases at which PICS bags become more profitable than subsidized Actellic Super, using estimates of DWL and price discounts from the literature. In Fig. 4, the most cost-effective storage technology requires the lowest expected price seasonality to be profitable for a given harvest price. As in Fig. 3, for each maize harvest price and the curves represent the minimum expected price seasonality for profitability of each technology. Thus, the intersections between curves represent the maize harvest price and price seasonality at which PICS bags and subsidized Actellic Super are equally profitable. For example, when PICS bags cost $2, they are more profitable than Actellic Super with 8.4% and 6.3% DWL when maize harvest prices exceed $0.060 and $0.096/kg, respectively. However, if Actellic Super has 6.3% expected DWL and PICS bags retail at $3, Actellic Super will be more profitable when harvest prices are below $0.16. If the $3 PICS bag can be used for 2 or 3 years, reducing

Table 2
Malawian Harvest Season Maize Prices and 8-month real price increases (National, real prices in Jan 2011 Malawian Kwacha (MK)).

Prices (Jan' 11 MK)	2006	2007	2008	2009	2010
Min	0.10	0.07	0.11	0.11	0.11
Avg	0.13	0.10	0.20	0.21	0.19
Max	0.17	0.14	0.25	0.29	0.28
% Increase	2006	2007	2008	2009	2010
Min	−11%	38%	42%	−23%	−32%
Avg	29%	149%	117%	32%	6%
Max	63%	326%	260%	97%	56%

Malawian Ministry of Agriculture (2011).

Table 3
Percentage of Malawian markets with positive returns to storing maize in 50 kg capacity PICS bags for eight months.

OCC	Years of use	2006	2007	2008	2009	2010
25%	1	0%	100%	100%	33%	0%
	2	33%	100%	100%	48%	14%
50%	1	0%	86%	90%	5%	0%
	2	0%	95%	90%	19%	0%

Note: Profitability modeled with anticipated costs based on local manufacturing and distribution channels.

Table 4
Threshold Maize Harvest Price (Jan 2011 USD/kg) for Superior Profitability with PICS Bags vs. Subsidized Actellic Super (storing 50 kg of grain for 8 months).

Subsidized Actellic Super	PICS bag cost (per season)								
	$1.00	$1.25	$1.50	$1.75	$2.00	$2.25	$2.50	$2.75	$3.00
8.4% DWL	0.016	0.027	0.038	0.049	0.059	0.070	0.081	0.092	0.102
6.3% DWL	0.030	0.047	0.063	0.080	0.096	0.112	0.129	0.146	0.162

the yearly cost to $1.50 or $1, the PICS bag would become more profitable than Actellic Super at reported maize harvest prices of $0.10 and higher.

Since both maize harvest prices and price seasonality vary by year and by market, it is important to understand how often we would expect maize storage in PICS bags to be profitable. Table 3 reports the percentage of markets in which PICS bags would yield positive storage returns when the OCC is 25% and 50% and for 1 and 2 years of use. At 25% OCC, PICS bags in the anticipated cost range for one year of use ($2–$2.5) would be profitable in all 21 markets in 2007 and 2008, 7 of 21 markets (33%) in 2009, and not profitable in any markets in 2006 or 2010. When used for two years ($1–$1.25), PICS bags would be profitable in all markets in 2007 and 2008, 10 of 21 markets (48%) in 2009, 7 of 21 markets (33%) in 2006, and 3 of 21 markets (14%) in 2010. At an annual OCC of 50%, PICS bags would be profitable in most markets in 2007 and 2008, fewer in 2009, and not profitable in 2006 or 2010.

When introducing a new storage technology, it is important to compare the expected profitability of the new technology to the profitability of the current storage technology. Table 4 presents the harvest price thresholds beyond which maize storage is more profitable with PICS bags costing $1–$3 per season per 50 kg of grain stored, assuming the minimum seasonal price increases are achieved for profitable storage with any technology. After 2007, Malawian maize prices have averaged about $0.20/kg at harvest, with a low of $0.11/kg. Assuming this price pattern continues and Actellic Super results in 6.3% DWL after 8 months, PICS bags are more profitable than Actellic Super even at $3 per bag. If the PICS bags can be used for multiple years, this would improve their profitability and therefore the likelihood of adoption, even if real harvest prices drop to 2005/06 levels (see Appendix B).

On average, one year of use at anticipated PICS retail prices also has the potential to be competitive with subsidized storage chemicals. This comparative profitability may reverse if maize harvest prices fall below $0.10/kg. Overall profitability in maize storage will vary by region and by year. This is not surprising, since storage profitability also fluctuates from year to year in developed country contexts. During years of dramatic food price increases like 2007 and 2008, PICS bags used for any length of time could provide substantial returns, which, on average, may outweigh years with weaker price seasonality. Years of more moderate seasonal price increases like 2006 and 2009 may also have storage profits when bags are used multiple years. In periods like 2010 when the price of maize declined through the storage season because the Malawian government banned maize exports, storage would not be profitable with any technology. As the OCC increases, it is even more difficult for any storage technology to be profitable. Producers with an OCC of 50% will be much less likely to adopt the PICS storage technology, except in periods of significant price seasonality.

With this information, our team can approach maize storage in Malawi with a much better understanding of the opportunities and challenges for profitable storage. In particular, we now understand the extent of the financial advantage when bags can be used for more than one season and the variability of storage returns in a grain market with a history of discretionary government intervention. Furthermore, we can use this financial information when working with plastics manufacturers and agricultural input retailers to build a local supply chain for this new technology.

4. Conclusion

Understanding the financial returns to crop storage is imperative to successful introduction of new storage technologies. Omission of key components such as price discounts for grain damage when modeling economic losses may lead to serious underestimation of the value of storage protection. Modeling economic losses is a particular challenge, as there are very few estimates for price discounts associated with low grain quality in the literature. Yearly and geographic variance in commodity price seasonality requires market-level data when conducting storage profitability analyses. By utilizing generalized relationships such as equations (4) and (5), researchers can estimate the returns to storage and determine if storage is profitable for high- and low-value commodities. Researchers seeking to increase total welfare through improved storage protection can prioritize commodities which most dramatically increase producer incomes. Equation (4) can be adapted to any product, storage volume, storage technology cost, or OCC to customize a storage technology profitability analysis to local situations. Appendix B is an Excel template to estimate Equation (4) and is also available in an interactive format. The template is structured to compare two storage technologies against the producer's benchmark option of selling immediately at harvest. The template can also be used to compare the storage profitability for two commodities stored with the same storage technology. In this case, (p_0), (x), and (t) will also vary by commodity and the technology cost (c) would remain static (unless time dependent).

This article focused on producers who market their grain. However, Malawians commonly purchase storage technologies to preserve grain destined solely for household consumption (producer interviews, 2011 and 2012). Discussions with producers also indicate that households may place an extra value on chemical-free storage options, as many expressed concern about suspected health side-effects. The premium which some households may be willing to pay for chemical-free maize storage is an important area of further research.

Additional opportunities for further research in developing-world storage economics are extensive. Dry weight losses from insect damage must be accurately translated into total value losses. Modeling the relationship between dry weight losses and the percentage of insect damaged grains for commodities besides maize, similar to the work of Holst et al. (2000), would provide an extremely valuable link in the literature. Further examination of value loss from damaged grains is needed for many commodities including sorghum, millet, wheat, cassava chips, and pigeon peas. In addition, more research is needed to understand the role of risk and the effect of credit constraints in developing world storage behavior.

Appendix A. Derivation of maize total value loss.

Dry weight losses (%) (w)	Grain damaged (%)	Price discount (%) (lean season) (v)	Total value loss (%) $1 - (1 - w)^*(1 - v)$
0.0	0.0	0.0	0.0
1.0	4.9	0.0	1.0
2.0	9.5	7.1	9.0
3.0	13.9	10.4	13.1
4.0	18.2	13.6	17.1
5.0	22.2	16.6	20.8
6.0	26.0	19.5	24.3
7.0	29.6	22.2	27.7
8.0	33.1	24.8	30.8
9.0	36.4	27.3	33.8
10.0	39.5	29.7	36.7
11.0	42.5	31.9	39.4
12.0	45.4	34.0	41.9
13.0	48.1	36.0	44.4
14.0	50.6	38.0	46.6
15.0	53.1	39.8	48.8
16.0	55.4	41.5	50.9
17.0	57.6	43.2	52.8
18.0	59.7	44.8	54.7
19.0	61.7	46.3	56.5
20.0	63.6	47.7	58.1
21.0	65.4	49.0	59.7
22.0	67.1	50.3	61.2
23.0	68.7	51.5	62.7
24.0	70.3	52.7	64.1
25.0	71.7	53.8	65.4
26.0	73.1	54.9	66.6
27.0	74.5	55.9	67.8
28.0	75.7	56.8	68.9
29.0	76.9	57.7	70.0
30.0	78.1	58.6	71.0

Lean Season Price Discounts from "recommended" equations in Compton et al. (1998).
DWL to % Grain Damaged from Holst et al. (2000) [regressions I&II pooled].

Appendix B. Simplified spreadsheet template for use in data analysis software (Cells simulated).

	A	B	C	D
1		Sell at Harvest	Storage Product A	Storage Product B
2	Harvest (kg)	q_0	B2	B2
3	Months Stored	–	t	t
4	Dry weight losses (%)	–	W_A	W_B
5	Quantity Marketed (kg)	*B*2	C2*(1–C4)	D2*(1–D4)
6	Total Price Discount for Grain Damage Present [compared to clean grain] (%)	–	v_A	v_B
7	Commodity Price for undamaged grain (t) Months after Harvest	–	p_t	p_t
8	Final Price Received	p_0	C7*(1–C6)	D7*(1–D6)
9	Commodity Revenue	B5*B8	C5*C8	D5*D8
10	Total Technology cost (per q_0 protected for entire storage period)	–	C_A	C_b
11	Rate of OCC	–	r	r
12	Total OCC	–	*C11**(*C3*/12)*(*B*9 + *C*10)	*D11**(*D3*/12)*(*B*9 + *C*10)
13	Financial Gain on Storage	–	C9–*B*9–*C*10–*C*12	*D*9–*B*9–*D*10–*D*12
14	Financial Return to Storage	–	C13/(*B*9 + *C*10)	D13/(B9 + D10)

Appendix C. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jspr.2013.12.006.

References

Abbot, P.C., Hurt, C., Tyner, W.E., 2008. What's Driving Food Prices? Farm Foundation, Oak Brook (IL).

Adda, C., Borgemeister, C., Biliwa, A., Meikle, W.G., Markham, R.H., Poehling, H.-M., 2002. Integrated pest management in post-harvest maize: a case study from the Republic of Togo (West Africa). Agric. Ecosyst. Environ. 93, 305–321.

Adetunji, M.O., 2009. Profitability evaluation of Maize storage techniques by farmers and traders in Kwara State, Nigeria. J. Food Prod. Mark. 15, 392–405.

Baier, A.H., Webster, B.D., 1992. Control of *Acanthoscelides obtectus* Say (Coleoptera: Bruchidae) in *Phaseolus vulgaris* L. seed stored on small farms-II. Germination and cooking time. J. Stored Prod. Res. 28, 295–299.

Babarinde, S.A., Sosina, A., Oyeyiola, E.I., 2008. Susceptibility of the selected crops in storage to *Sitophilus Zeamais* Motchulsky in Southwestern Nigeria. J. Plant Prot. Res. 48, 541–549.

Baributsa, D., Lowenberg-DeBoer, J., Murdock, L., Moussa, B., 2010. Profitable chemical-free cowpea storage technology for smallholder farmers in Africa: opportunities and challenges. In: 10th International Working Conference on Stored Product Protection, Lisbon, Portugal, pp. 1046–1052.

Bauoa, I.B., Amadou, L., Margam, V., Murdock, L.L., 2012. Comparative evaluation of six storage methods for postharvest preservation of cowpea grain. J. Stored Prod. Res. 49, 171–175.

Boxall, R.A., 2001. Post-harvest losses to insects: a world overview. Int. Biodeterior. Biodegrad. 48, 137–152.

Boxall, R.A., 2002. Damage and Loss caused by the larger grain borer *Prostephanus truncatus*. Integr. Pest Manag. Rev. 7, 105–121.

Buckley, G., 1997. Microfinance in Africa: is it either the problem or the solution? World Dev. 25, 1081–1997.

Chapoto, A., Jayne, T.S., 2010. Maize price instability in Eastern and Southern Africa: the impact of trade barriers and market interventions. In: Paper Prepared for the COMESA Policy Seminar on 'Variation in Staple Food Prices: Causes, Consequences, and Policy Options', Maputo, Mozambique, 25–26 January, 2010.

Compton, J.A.F., Floyd, S., Magrath, P.A., Addo, S., Gbedevi, S.R., Agbo, B., Bokor, G., Amekupe, S., Motey, Z., Penni, H., Kumi, S., 1998. Involving grain traders in determining the effect of post-harvest insect damage on the price of maize in African markets. Crop Prot. 17, 483–489.

Dick, K., 1988. A Review of Insect Infestation of Maize in Farm Storage in Africa with Special Reference to the Ecology and Control of Prostephanus Truncatus. Natural Resources Institute, Bulletin No. 18. NRI, Chatham Maritime, Kent, ME4 4TB, UK.

Dorward, A., Chirwa, E., 2011. The Malawi agricultural input subsidy programme: 2005/06 to 2008/09. Int. J. Agric. Sustain. 9, 232–247.

Faye, M., Jooste, A., Lowenberg-DeBoer, J., Fulton, J., 2004. The influence of cowpea characteristics on cowpea prices in Senegal. Agrekon 43, 418–425.

Faye, M., Jooste, A., Lowenberg-DeBoer, J., Fulton, J., 2006. Impact of sucrose contents and cooking time on cowpea prices in Senegal. South Afr. J. Econ. Manag. Sci. 9, 207–212.

George, Maria, 2011. Effective Grain Storage for Better Livelihoods of African Farmers Project. Completion Report Submitted to The Swiss Agency for Development and Cooperation (SDC), International Maize and Wheat Improvement Center, May 2011. www.sdc-ruraldevelopment.ch/media/grain_storage_africa.pdf.

Golob, P., Hanks, C., 1990. Protection of farm stored maize against infestation by *Prostephanus truncatus* (Horn) and *Sitophilus* species in Tanzania. J. Stored Prod. Res. 26, 187–198.

Gulde, A.M., Pattillo, C.A., Christensen, J., Carey, K.J., Wagh, S., 2006. Sub-Saharan Africa: Financial Sector Challenges. International Monetary Fund, Washington.

Hell, K., Ognakossan, K.E., Tonou, A.K., Lamboni, Y., Adabe, K.E., Coulibaly, O., 2010. Maize stored pests control by PICS-bags: technological and economic evaluation. In: Presentation at the 5th World Cowpea Conference, Saly, Senegal, 27 September–1 October 2010.

Hoffmann, V., Mutiga, S., Harvey, J., Nelson, R., Milgroom, M., 2013. Aflatoxin contamination of maize in Kenya: observability and mitigation behavior. In: Selected Paper Prepared for Presentation at the Agricultural & Applied Economics Association's 2013 AAEA & CAES Joint Annual Meeting, Washington, DC, August 4–6.

Holst, N., Meikle, W.G., Markham, R.H., 2000. Grain injury models for *Prostephanus truncatus* (Coleoptera: Bostrichidae) and *Sitophilus zeamais* (Coleoptera: Curculionidae) in rural maize stores in West Africa. J. Econ. Entomol. 93, 1338–1346.

Ibro, G., 2011. Analyse de l'effet des caractéristiques physiques et chimiques de niébé sur le prix au consommateur au Niger (Doctoral dissertation). University of Ouagadougou, Burkina Faso.

Jones, M., Alexander, C., Lowenberg-DeBoer, J., September 2011. An Initial Investigation of the Potential for Hermetic Purdue Improved Crop Storage (PICS) Bags to Improve Income for Maize Producers in Sub-Saharan Africa. Purdue University Working Paper 11-3. Department of Agricultural Economics, Purdue University.

Kamanula, J., Sileshi, G.W., Belmain, S.R., Sola, P., Mvumi, B.M., Nyirenda, K.C., Nyirenda, S.P., Stevenson, P.C., 2010. Farmers' insect pest management practices and pesticidal plant use in the protection of stored maize and beans in Southern Africa. Int. J. Pest Manag. 57, 41–49.

Kimenju, S., DeGroote, H., 2010. Economic analysis of alternative Maize storage technologies in Kenya. In: Paper Contributed to the Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa, September 19–23, 2010.

Langyintuo, A., Lowenberg-DeBoer, J., Faye, M., Lambert, D., Ibro, G., Moussa, B., Kergna, A., Kushwaha, S., Ntoukam, G., 2003. Cowpea supply and demand in West Africa. Field Crops Res. 82, 215–231.

Langyintuo, A.S., Ntoukam, G., Murdock, L., Lowenberg-DeBoer, J., Miller, D.J., 2004. Consumer preferences for cowpea in Cameroon and Ghana. Agric. Econ. 30, 203–213.

Lowenberg-DeBoer, Abdoulaye, J.,T., Kaboré, D., 1994. The Opportunity Cost of Capital for Agriculture in the Sahel: Case Study Evidence from Niger and Burkina Faso. Staff Paper 94-2. Purdue University.

Magrath, P.A., Compton, J.A.F., Motte, F.F., Awuku, M., 1996. Coping with a New Storage Insect Pest: the Impact of the Larger Grain Borer in Eastern Ghana. National Resources Institute, Chatham UK.

Malawi Ministry of Agriculture and Food Security, 2011. Monthly Commodity Retail Price Data for Major Malawian Market Centers (Jan. 2006–March 2011).

Meikle, W.G., Markham, R.H., Nansen, C., Holst, N., Degbey, P., Azoma, P., Korie, S., 2002. Pest management in traditional maize stores in West Africa: a farmer's perspective. J. Econ. Entomol. 95, 1079–1088.

Minot, N., 2009. Transmission of world food price changes to African markets and its effect on household welfare. In: Paper Contributed to the Comesa Policy Seminar "Food Price Variability: Causes, Consequences, and Policy Options" on 25–26 January 2010 in Maputo, Mozambique under the Comesa-MSU-IFPRI African Agricultural Markets Project. International Food Policy Research Institute, Washington, DC.

Mishili, F., May 2005. Cowpea Markets and Consumer Preferences in Ghana (Master thesis). Department of Agricultural Economics, Purdue University.

Mishili, F., Fulton, J., Shehu, M., Kushwaha, S., Marfo, K., Jamal, M., Chergna, A., Lowenberg-DeBoer, J., 2009. Consumer preferences for quality characteristics along the cowpea value chain in Nigeria, Ghana, and Mali. Agribus. Int. J. 25, 16–35.

Mishili, F., Temu, A., Fulton, J., Lowenberg-Deboer, J., 2011. Consumer preference as drivers of the common bean trade in Tanzania: a marketing perspective. J. Int. Food Agribus. Mark. 23, 110–127.

Moino, A., Alves, S.B., Pereira, R.M., 1998. Efficacy of *beauveria bassiana* (Balsamo) Vuillemin isolates for control of stored-grain pests. J. Appl. Entomol. 122, 301–305.

Obeng-Ofori, D., 2011. Protecting grain from insect pest infestations in Africa: producer perceptions and practices. Stewart Postharvest Rev. 3, 10.

Omondi, B.A., Jiang, N., van den Berg, J., Schulthess, F., 2011. The flight activity of *Prostephanus truncatus* (Horn)(Coleoptera: Bostrichidae) and *Teretrius nigrescens* Lewis (Coleoptera: Histeridae) in Kenya. J. Stored Prod. Res. 47, 13–19.

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

Perloff, J.M., 2008. Microeconomics: Theory and Applications with Calculus. Pearson, Addison, Wesley, Boston, MA.

Rosegrant, M.W., Cai, X., Cline, S.A., 2002. World Water and Food to 2025: Dealing with Scarcity. IFPRI-2020 Vision/International Water Management Book. IFPR, Washington, D.C.

Sanon, A., Dabiré, L.C., Ba, N.M., 2011. Triple-bagging of cowpeas within high density polyethylene bags to control the cowpea beetle *Callosobruchus maculatus* F. (Coleoptera: Bruchidae). J. Stored Prod. Res. 47, 210–215.

Sekumade, A.B., Oluwatayo, I.B., 2009. Comparative analysis of maize storage technologies in Kwara, State, Nigeria. Int. J. Sustain. Crop Prod. 4, 24–31.

Stephens, E., Barrett, C., 2011. Incomplete credit markets and commodity marketing behavior. J. Agric. Econ. 62, 1–24.

Stewart, R., Van Rooyen, C., Dickson, K., Majoro, M., De Wet, T., 2010. What is the Impact of Micro-finance on Poor People? A Systematic Review of Evidence from Sub-Saharan Africa. Technical Report. EPPI-Centre, Social Science Research Unit, Institute of Education, University of London, ISBN 978-1-907345-04-3.

Williams, J., Wright, B., 1991. Storage and Commodity Markets. Cambridge University Press, Cambridge, MA.

Working, H., 1949. The theory of price of storage. Am. Econ. Rev. 39, 1254–1262.

World Bank, 2011. Missing Food: the Case of Postharvest Grain Losses in Sub-Saharan Africa. World Bank. Report 60371-AFR, April 2011. http://siteresources.worldbank.org/INTARD/Resources/MissingFoods10_web.pdf.

Yigezu, Y., Alexander, C., Preckel, P.V., Maier, D.E., Woloshuk, C.P., Mason, L.J., Lawrence, J., Moog, D., 2010. The economics of integrated insect management in stored corn. J. Econ. Entomol. 103, 1896–1908.