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PICS or poly sack: Traders' willingness to invest in storage protection technologies

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ABSTRACT

This study applies a simple financial model to compare the profitability of selected grain storage protection technologies (PICS and Poly sacks) in Ghana. To address the objectives, market survey data of soybean traders who represent a section of the soybean supply chain was used. Per the model, the price seasonality for profitable soybean storage was estimated by accounting for costs related to storage (protectants, maintenance, supervision, and labor), the opportunity cost of capital, and storage technologies (PICS and Poly sacks). Results indicated that the profitability associated with poly sacks was higher than the PICS bags over the entire support of seasonal harvest prices and consistent across the different trader types. Secondly, less than 20% of the traders were willing to invest in storage protection technologies since the value of their storage losses is higher than the value of the investment cost.

1. Introduction

Are traders incentivized to invest in storage technologies to reduce postharvest losses given the urgent call to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture (SDG 2)? This study aims to understand traders' willingness to invest in storage protection technologies and the level of postharvest price that will incentivize them to invest in storage protection practices. Storage plays a significant role in the food supply chain as there is evidence that maximum postharvest losses often happen during storage. Storage losses can be either direct, as a result of physical loss of commodity, or indirect, owing to loss in quality and nutrition [1]. Direct and indirect storage losses can be occasioned by both biotic (insect, pest, rodents, fungi) and abiotic factors (temperature, humidity, rainfall) [2].

Improved storage technology is one of the strategies employed to reduce post-harvest losses, conserve product quality, and increase the longevity of product storage [2–4]. Traditional storage structures host nearly 60% of the grains produced in developing countries [2] and consist of floor and crib storage mainly at the village and market centres [5,6]. These indigenous storage structures are usually constructed with locally available materials (straw, wood, mud, etc.) without any scientific design and thus cannot serve as guaranteed protection against pests. Traditional storage structures cannot regulate moisture content and temperature, two crucial factors that influence the growth of molds and storage life.[1] In Ghana and the rest of West Africa, grains usually are stored in bulk or poly sacks in simple traditional raised platforms, conical structures, and baskets [2]. However, there is inefficient use of improved storage techniques due to high costs, credit constraints, lack of information, unavailability of good products, and risk aversion [7,8], leading to about 10%–40% grain loss in storage due to insect damage [2, 9–11].

Modern storage technologies are also under-utilized due to high cost and limited availability [1,12]. revealed that storage technologies such as hermetic bags, metal silos, and super grain bags are very effective in controlling maize weevils and the larger grain borer. Traders in Ghana predominantly store their grains in poly sacks due to the relative cost of using hermetic bags. Poly sacks[2] are made from woven strips of polypropylene and are light, easy to use, very affordable, and easily

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[1] It is important to note that fungi respond to individual soybean moisture levels, and not to the average moisture of a soybean lot. Moisture content is arguably the most important property of soybeans associated with their harvesting, drying, handling and storing [32].

[2] For more detail about the poly sack, refer to: https://sesitechnologies.com/comparing-the-effectiveness-of-different-grain-storage-bags/.

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accessible. However, they are not durable and susceptible to insect pests and rodents. They are used for short term storage of grains. A common hermetic storage bag widely promoted in Africa is the Purdue Improved Cowpea Storage (PICS) which is considered to be cost-effective [13]. The PICS bag has a three liner with two liners (high density polyethylene bags) fitted inside a woven sack (polypropylene bag) and enable grains to be stored for more than one year [14]. Since the introduction of the PICS bag, there have been several studies that assess the effect of PICS bag on postharvest losses (PHL), food security, and aflatoxin control (see Refs. [15–22]. These studies show that PICS bags are highly effective and efficient in protecting grains from storage insect infestation. However, what is not known is the factors influencing the slow pace at which the technology is catching up with traders and what will incentivize traders to invest in such technology. Our study employed a simple financial model for storage developed by Ref. [21] to investigate why traders are not investing in PICS bag. Similarly, at what level of price regimes will incentivize traders to invest in PICS bags relative to poly sacks?

The study analyzed the price regimes at which PICS bags is more profitable than poly sacks in northern Ghana. Poly sacks is mostly used by smallholder farmers and traders due to their lower cost when compared to the PICS bags. An economic agent such as traders will not invest in a technology if the short- and long-term benefits are lower than the cost of investment taking into consideration the time horizon of the technology use. Traders typically sell their grains within a short period after harvest especially where they have contractual agreement with buyers, so are more likely to invest in low-cost storage materials such as poly sacks. We test this hypothesis by employing a simple methodology that indicates the seasonal price regimes that will incentivize traders to invest in PICS bags.

The study's contribution to the literature is in three folds. First, the study is among the first to address the challenge of low adoption of improved storage protection technology among traders using northern Ghana as a case study. Second, the study explores the heterogeneity in the level of storage protection investment across trader types (wholesalers and retailers). Finally, the study assessed the seasonal price gap at which grain storage is profitable. The study's findings will inform researchers and development organizations seeking to increase welfare (food security and income) through the promotion of storage protection technologies that guarantee high economic returns.

2. Methodology

2.1. Study area and sampling

The study location is the Northern and Upper East regions of Ghana. The Upper East Region is situated in the North-Eastern corner of the country, between longitude 00 and 10 West and latitudes 100 30" N and 110 N. It is bounded to the north by Burkina Faso, the East by the Republic of Togo, the West by Sissala District in Upper West, and the south by West Mamprusi District in the North East Region. The population of the Region is 1,046,545. The land is comparatively flat, with few hills to the East and southeast. The overall land area is about 8,842 sq. km, which is 2.7% of the country's total land area. The typical vegetation is that of the savannah woodland, characterized by short-distributed drought-resistant trees and grass burnt by bushfires or scorched by the sun during the long dry season. Shea nut, dawadawa, boabab, and acacia are the most common economic fruit trees. The province's climate is characterized by a single rainy season from May–June to September–October. The mean annual rainfall during this period is between 800 mm and 1,100 mm. The rainfall is irregular spatially and in duration. There is a long dry spell from November to mid-February, characterized by cold, dry, and dusty harmattan winds. Agriculture, hunting, and forestry are the key economic activities in the Region. About 80% of the economically active population engages in agriculture. The main crops cultivated include millet, guinea corn, maize, groundnut, beans, soybean, sorghum, and dry-season tomatoes and onions. A high potential for cash crop production and fish farming due to the existence of several irrigation sites located in the region.

The Northern Region occupies about 70,384 square kilometers; it was the largest Region in Ghana in terms of landmass until 2018, when the Savannah and North East Region were carved out of the region. The Northern Region is bordered on the north by the North East Region, on the East by the eastern Ghana-Togo international border, south by the Oti Region, and west by the Savannah Region. The Northern Region has a population of about 1,948,913 and has a low population density. The climate of the Region is comparatively dry, with a single rainy season that commences in May and ends in October. The volume of rainfall recorded annually differs between 750 mm and 1,050 mm. The dry period begins in November and ends in April, with maximum temperature occurring near the end of the dry season and minimum temperature occurring in December or January. The primary vegetation is grassland, interspersed with guinea savannah woodland, characterized by drought-resistant trees. People in the Region are engaged in agriculture, accounting for about 75% of economic activity. The low population density is partially caused by emigration, geography, and climate. Cultivated crops cultivated include yam, maize, millet, guinea corn, rice, groundnuts, beans, soybeans, and cowpea.

Sampling of the traders was based on purposive, stratified, and snowball sampling methods. Districts within the Northern and Upper East regions were purposively sampled due to the annual volume of soybean transactions and were grouped into different clusters to accommodate different trader types (wholesalers and retailers). Given that a large section of retailers were in the Upper East Region, a higher sampling weight was assigned to that region. Within each cluster, a stratified sampling approach was used to group traders based on the storage duration of soybean and frequency of transactions. In the final stage, the snowball sampling technique was used to enumerate large and small traders. In summary, 70 traders were sampled from 3 districts within the Guinea Savannah agroecological zone of Ghana.

2.2. Data

This study employed primary and secondary data to address the research question. The primary data was obtained through an interview with sampled traders using a structured questionnaire. Data captured per the interview were trader location, household characteristics, timing and outlets of purchased grains, grain flow from the point of purchase to delivery, and grain storage (type of structure, location, quantity of grain held, postharvest losses, practices such as use of pesticides/rodenticides, and frequency of use), specific costs (labor, chemical, maintenance, and supervision), working capital for holding grains in storage, quantities of grains sold to buyers, and constraints associated with soybean trading. The secondary data captured information on soybean wholesale and retail prices (2010–2019) and were obtained from the Ministry of Food and Agriculture (MoFA).

2.3. Conceptual model: analyzing profitability of soybean storage

An economic agent (soybean trader) will minimize postharvest losses by investing in good storage practices, especially when they have the financial motivations to do so [23]. Generally, loss reduction increases the grain for sale and gross revenue from trade. Like farmers, the quantity of grain traders retains by reducing storage losses plays an essential role in their decisions.

The estimation of soybean storage returns followed the model proposed by Ref. [21]. A profit-maximizing trader will decide to hold grains (i.e., the quantity and longevity) in storage if the returns (which comes from a price increase between harvest and later in the storage season) cover variable costs. Given that traders use commercial storage facilities, they compare the returns on storage to the facility variable costs, including the rental cost (A), duration (t), technology cost (C), dry weight losses (DWL) or shrinkage cost from handling and moisture loss (φ), price discount for damaged grains (ω), and rate of opportunity cost of capital (OCC[3]) (r) based on the simple interest time-adjusted rate of opportunity cost of capital is evaluated as $r_t = (t/12 * r)$. The variable cost is a function of the quantity of grain and duration of the storage period.

In addition, traders make storage investment decisions by comparing their associated fixed costs (M) with the expected annual returns over variable costs [24]. The annual fixed cost is a function of the size of the investment in storage facilities such as type of structure, monitoring and conveyance equipment, aeration, site preparation, concrete pad, and construction. The annual fixed costs of storage are interest, depreciation, taxes, insurance, and maintenance. Other variables required to measure the return of storage are commodity price (p_o) at harvest ($t = 0$), quantity of grains stored (q_o), price seasonality (increase or decrease across the storage period).

Following from the above, the traders' revenue generated during harvest (period of abundance of soybean) is computed as $R_0 = p_o * q_o$ while the revenue generated in the immediate postharvest season is $R_t = p_t * q_t$. The total cost of investment (K) is computed as the value of the grain in storage plus the associated opportunity cost:

$$K = (1 + r_t)(p_o q_o + C) \tag{1}$$

The return on investment (ROI) is computed as:

$$ROI\ (\%) = \frac{R_t - K}{K} \tag{2}$$

Substituting equation (1) into equation (2) yields:

$$ROI\ (\%) = \frac{p_t q_t - (1 + r_t)(p_o q_o + C)}{(1 + r_t)p_o q_o + C} \tag{3}$$

Alternatively, profit (π) earned from storing grains is given by equation (4):

$$\pi = p_t q_t - (1 + r_t)(p_o q_o + C) \tag{4}$$

However, the revenue generated in the immediate postharvest season (R_t) can be expressed in terms of the price discounting (ω), percent soybean seasonal price gap[4] (s) over (t) months, and percent DWL (φ) in storage as:

$$R_t = (1 + s)(1 - \omega)(1 - \varphi)p_o q_o \tag{5}$$

Substituting equation (5) into equations (3) and (4) yield:

$$ROI\ (\%) = \frac{[(1 + s)(1 - \omega)(1 - \varphi) - 1]p_o q_o - C}{(1 + r_t)p_o q_o + C} - \frac{r_t}{(1 + r_t)} \tag{6}$$

Based on equation (6), the return to storage depends on the financial rate of return to storage $\left(\frac{[(1+s)(1-\omega)(1-\varphi)-1]p_o q_o - C}{(1+r_t)p_o q_o + C}\right)$ and the time-adjusted rate of OCC $\left(\frac{r_t}{(1+r_t)}\right)$. The trader will invest in storage (i.e. $ROI\ (\%) > 0$) if storage profit is greater than the potential returns from other investments and vice versa. Similarly, the trader will be indifferent between investing and storing if ROI (%) $= 0$.

Similarly, the profitability of storage is determined for a given harvest price by calculating the minimum level of expected price seasonality (s) for a positive return to storage. Solving for the seasonal price gap (appendix A shows the detailed derivation) based on equation (6) yields:

$$s = \frac{1}{(1 - \omega)(1 - \varphi)}\left[1 + r_t + \frac{c(1 + r_t)}{p_o q_o}\right] - 1 \tag{7}$$

Equation (7) shows that the dry weight loss, price discounting, quantity stored, and harvest is inversely related to the seasonal price gap, which suggests that an increase in these parameters will require greater expected seasonal price increase to make soybean storage profitable. Likewise, storage technology cost and OCC are directly related to the seasonal price gap, suggesting that an increase in these parameters will require a more significant increase in the seasonal price gap. Assuming the price discounting and dry weight loss is zero due to the effectiveness of the storage structure, then equation (7) reduces to:

$$s = r_t + \frac{c(1 + r_t)}{p_o q_o} \tag{8}$$

3. Results and discussion

3.1. Traders' willingness to invest in storage

This section highlights the storage investment cost required to mitigate the losses and the number of traders willing to invest in storage protection technologies. Based on the utility theory, traders will be willing to adopt a storage protection technology if the utility or the expected profit from adopting the technology is higher than the utility or expected profit from not adopting the technology. We estimated the value of soybean losses in storage using the current market price at the time of the data collection and the value of the PICS bag required to prevent soybean losses. However, there is limited information regarding the sources of losses, which the PICS bag may not be the only solution to the losses. The outcomes of the interviews with the traders suggest that potential sources of losses in storage may be due to loading and offloading of the grains, rodent attack, theft, and poor structure of the multi-purpose storage shed. For example, the data shows that about 36% of the traders recorded theft in storage. The study estimated the total investment required to prevent soybean losses, including the cost of the PICS bag, purchase of chemicals for warding off rodents and pests, and cost of security to prevent theft. The total estimated cost for the security and the chemical is US$108.40, and the average cost of the PICS bags is US$4.79. Nevertheless, the cost of the PICS bags varies with the quantity of losses in storage.

Following the estimation of the cost of investment and the value of soybean losses in storage, we plotted a demand curve for the investment cost and the value of soybean losses against the percentage of respondents (Fig. 1). The graph shows that 23% of the traders are willing to invest in storage to prevent soybean losses given that the value of soybean losses is greater than the cost of investment in storage. Comparatively, traders who were willing to invest in storage practices store a relatively large quantity of soybean for one month longer than those who are not willing to invest in storage. Figs. 2 and 3 show the disaggregated data based on trader types (wholesalers and retailers). The figure shows that 21% (Fig. 2) and 19% (Fig. 3) of the wholesalers and retailers were willing to invest in storage practices to mitigate losses, respectively. However, wholesalers store soybean more than the retailers for 0.6 months. Generally, traders who were more likely to invest in good storage practices recorded higher volumes of storage than traders who were not likely to use improved storage practices. The study's findings suggest that traders who store large volumes of their purchases are more likely to incur losses in storage and thus are more likely to invest in good storage practices to prevent losses and insure against their investment.

3.2. Soybean price volatility and storage cost

In this section, we describe the relationship between the national wholesale and retail price data collected from retail and wholesale

[3] Opportunity cost of capital (OCC) is used as a proxy for indirect cost measure of grain storage by evaluating the return on soybean storage relative to other investment.

[4] Seasonal price gap is measured as the difference between the maximum and the minimum soybean prices.

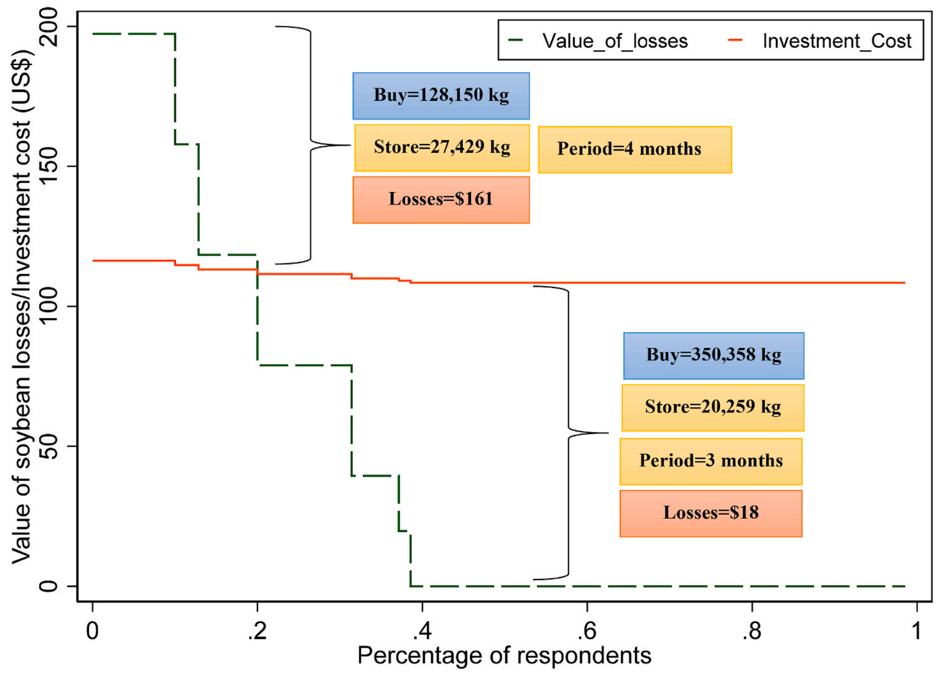

Fig. 1. Value of losses and storage investment cost (pooled sample).

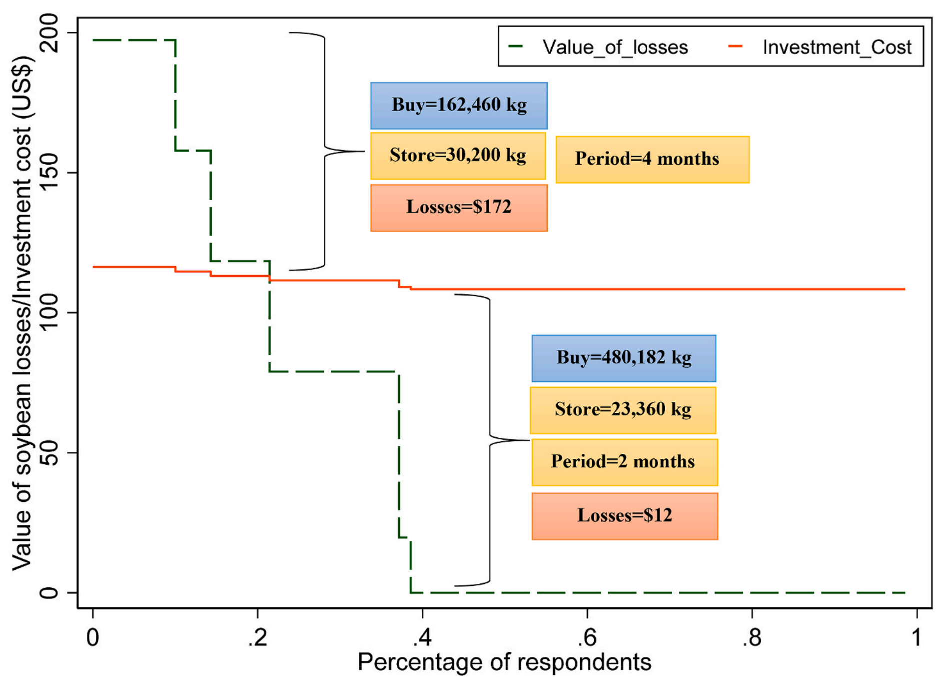

Fig. 2. Value of losses and storage investment cost (wholesalers).

markets across Ghana. Fig. 4 shows an upward movement of wholesale and retail soybean prices from 2010 to 2019 [25,26]. Consistent with the a priori expectation, retail prices were equal to or above the wholesale prices except for three occasions during the study period. The price series between the wholesalers and retailers was highly correlated ($r = 0.94$) (IFPRI, 2020) despite the high fluctuations, which suggest that soybean prices are volatile. Generally, retail and wholesale prices have witnessed an upward movement and a positive trend. The average price gap (retail markup) over the period was 41% (IFPRI, 2020). The period between 2014 and 2018 recorded a relatively high retail markup and contributed significantly to the average for the entire period.

Table 1 shows the cost variables required to compute the returns to storage for wholesalers and retailers (based on 100 kg of soybean) for PICS and Poly sacks. Both users and non-users of PICS bags recorded the exact costs except for the PICS bag. The PICS and poly bags cost $1.58/bag and $0.54/bag, respectively. Comparatively, the wholesalers recorded higher storage costs and lower storage losses than the retailers. The duration of storage is higher among retailers than wholesalers. The discounting price value was obtained from a previous study by Ref. [28]. To summarize briefly, both retail and wholesale traders generally discounted a bag of soybean by 11% for failure to meet the basic level of soybean quality (color, foreign materials, size, and oil content)

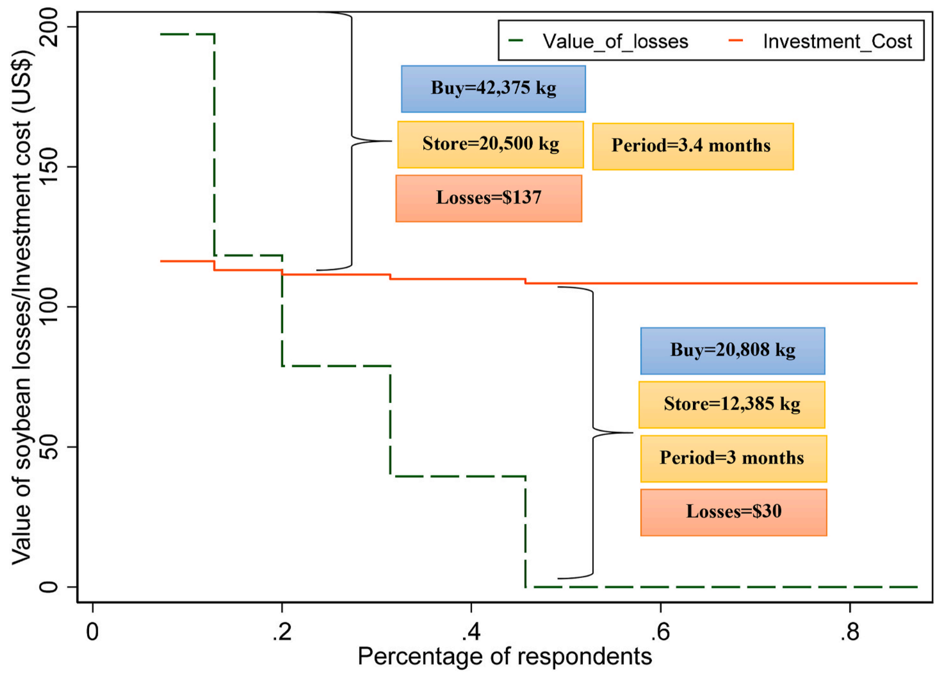

Fig. 3. Value of losses and storage investment cost (retailers).

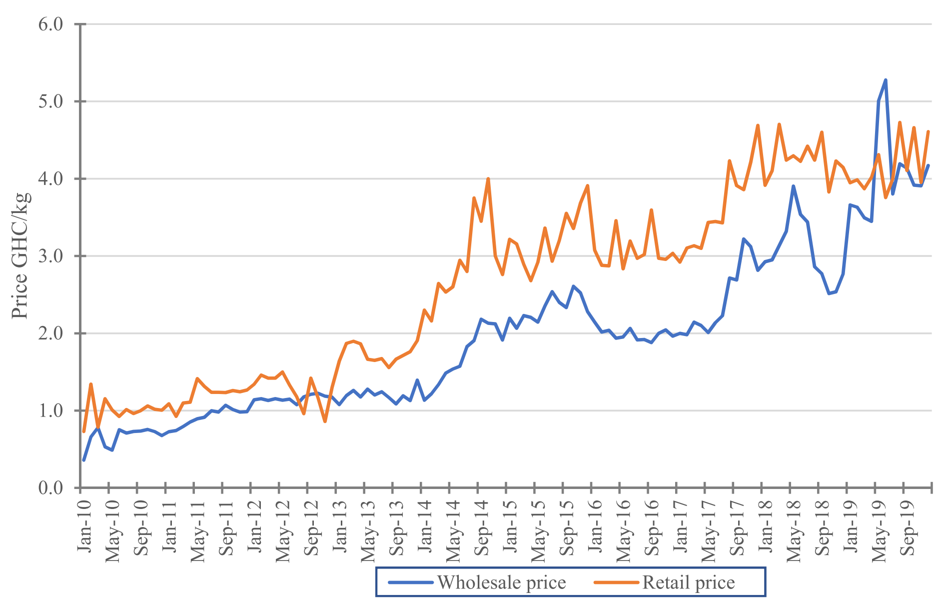

Fig. 4. National average soybean prices (GHS/kg) in wholesale and retail markets in Ghana, 2010 to 2019.
Source: Statistics, Research and Information Directorate [27].

Table 1
Variables for computing seasonal price gap.

	Retailers		Wholesalers	
	PICS Bag	Poly Bag	PICS Bag	Poly Bag
Facility cost ($)	1.260	1.260	1.310	1.310
Interest cost of storage ($)	0.246	0.246	0.218	0.218
Opportunity cost of capital (%)	11.55	11.55	11.55	11.55
PIC/Poly bag ($)	1.580	0.540	1.580	0.540
Price discounting (%)	11	11	11	11
Quantity losses (%)	0	0.709	0	0.401
Length of storage (months)	4	4	3	3

regardless of the bag used. However, this study assumed that using PICS bags have no grain losses in storage due to weevil infestation.

3.3. Estimation of profitability of storage technologies: PICS bag vs. poly sack

3.3.1. Profitability of storage based on zero losses and price discounting

According to Working [29], "economic theory indicates that the difference between present and future commodity prices should equal the cost of storage." However, external shocks may destabilize the natural price seasonality. Figs. 5 and 6 show the soybean storage profitability analysis based on equation (8) for retailers and wholesalers, respectively. The figures illustrate the minimum threshold for storage

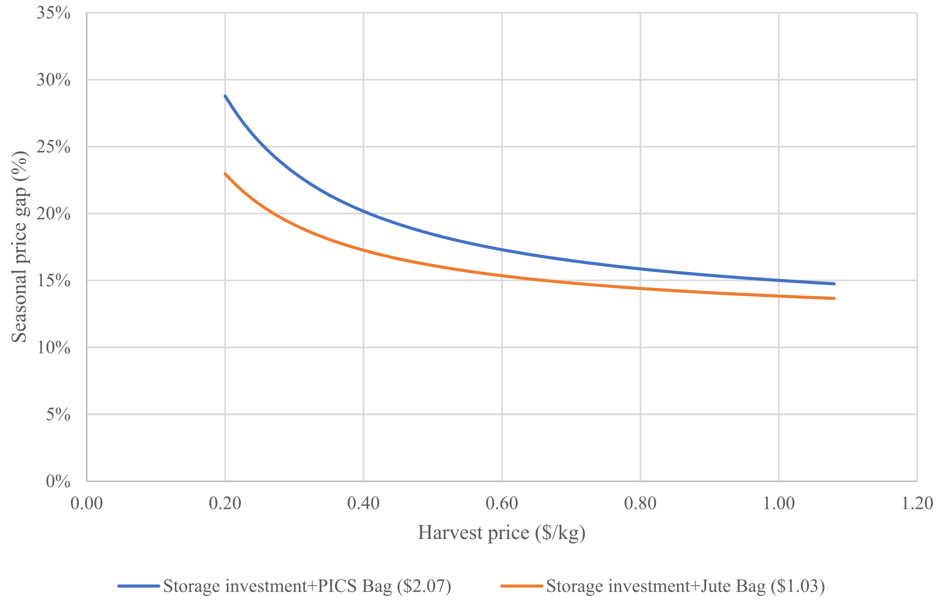

Fig. 5. Financial threshold for storage profit for soybean retailers (Best case scenario).

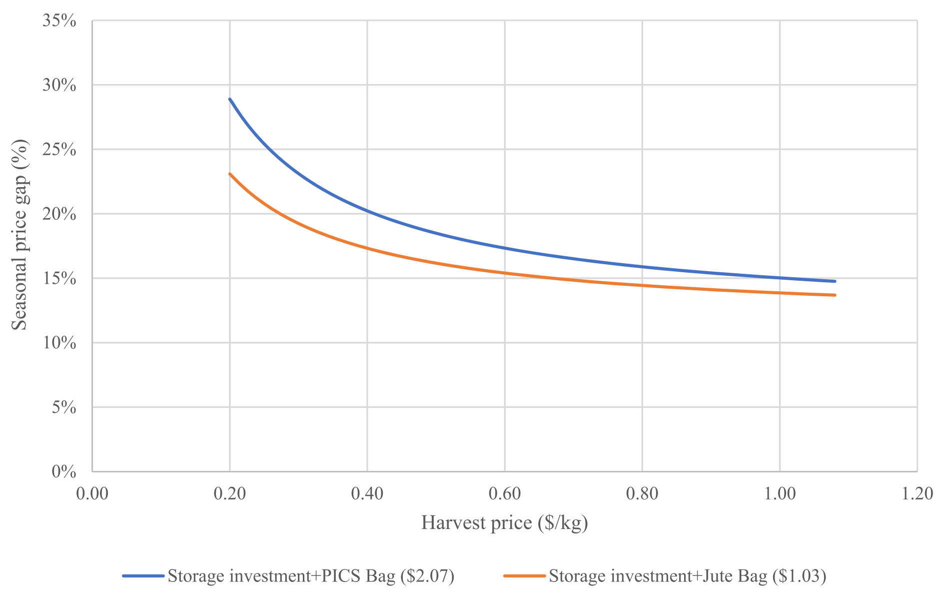

Fig. 6. Financial threshold for storage profit for soybean wholesalers (Best case scenario).

profitability for two storage technologies (PICS bag and poly sacks) of wholesalers and retailers, given the soybean harvest price and expected seasonal price increase assuming zero storage losses ($\varphi = 0$) and no price discounting ($\omega = 0$) for grain damage. The retailers and wholesalers storage period is four and three months, respectively.

Poly bags are a low-cost storage investment of $0.54 with no storage protectants. Many traders use poly bags due to the short duration of soybean storage. However, PICS bags are tripled layer sack and when combined with one phostoxin pellet per 100 kg bag, is used to preserve grains for a minimum of one year [30]. The retail price of the PICS bag is $1.58, which is consistent with the reported value ($2-$4) for West and Central Africa [31]. The curve represents the threshold at which storage becomes profitable for storage technology. Following the argument of [21]; storage is profitable at a given harvest price if the expected seasonal price increase is above the threshold for that technology and vice versa.

Fig. 5 compares the PICS and poly sacks storage technologies at different costs for retailers. The figure shows that the poly bag is the most cost-effective options for traders, given that it has the lowest expected price seasonality for profit maximization at the given harvest price. For example, if the PICS bag has a $1.58 annual cost, soybean with a harvest price of $0.30/kg to $0.44/kg would require at least a 23%–19% expected seasonal price increase for profitable storage, respectively. Similarly, if the poly sack has a $0.54 annual cost, soybean with a harvest price of $0.30/kg to $0.44/kg would require at least a 19%–17% expected seasonal price increase for profitable storage, respectively. Comparatively, retailers will use the poly sacks to store soybean given the seasonal price increase required to generate profit based on the assumption of no storage losses and price discounting.

Fig. 6 compares the PICS and poly sack storage technologies at different costs for the wholesalers. Like Fig. 5, the curve for poly sacks is below the PICS bag at all levels of the harvested price. A similar seasonal harvest price and seasonal price gap was observed for wholesalers which suggests that they will be more likely to use poly bags because of no storage losses and price discounting.

In summary, traders will likely invest in poly bag since profitability is more likely to occur at the minimum expected seasonal price increase provided there are zero losses and price discount. The percent of minimum expected price increase to ensure the profitability of the PICS bag is comparatively higher which may not be achieved despite the price volatility of soybean.

3.3.2. Profitability of storage based on positive losses and price discounting

In this sub-section, we analyze storage profitability for retailers and wholesalers by accounting for storage losses and price discounting for grain damage as well as the total cost of storage based on equation (8). Specifically, we estimated the seasonal price gap required for traders to consider grain storage profitable. Our study assumes that deadweight loss associated with using a PICS bag is zero while using a poly bag is related to positive dead weight loss and a price discounting. Figs. 7 and 8 show a similar trend regarding the seasonal harvest price for retailers and wholesalers. However, after accounting for the losses and price discounting associated with low-quality soybean result in a higher seasonal price gap required to guarantee storage profitability. For example, if the PICS bag has a $1.58 annual cost, soybean with a harvest price of $0.30/kg to $0.44/kg would require at least a 38%–34% expected seasonal price increase for profitable storage, respectively. Similarly, if the poly bag has a $0.54 annual cost, soybean with a harvest price of $0.30/kg to $0.44/kg would require at least a 35%–32% expected seasonal price increase for profitable storage respectively. Based on our previous argument, we conclude that traders will be more likely to use poly bags given that the poly sack recorded the lowest expected seasonality for each harvest price.

4. Conclusion

Storage protection technologies play a crucial role in efforts to address food security challenges and low incomes, especially among the rural poor. However, investment in such technologies requires a clear understanding of the magnitudes of the losses and the economics. This study employed a simple financial methodology to estimate the returns to storage and the profitability of using different storage protection technologies (PICS and Poly bags) and also investigated traders' willingness to invest in storage protection technologies. Using a cross-section of soybean traders who represent the wholesale and retail component of the soybean supply chain in Ghana, returns to storage using poly bags were higher than the profitability associated with using PICS bags across the seasonal harvest prices investigated. The expected seasonal price increase for profitable storage protection using poly sacks was relatively low when price discounting and losses were assumed to be zero but doubled after accounting for price discounting and losses. Traders will likely use poly sacks since the expected price increase to guarantee the profitability of PICS bags is slightly higher which may not be achieved despite the price volatility of soybean. The results suggest that less than 20% of the traders were willing to invest in PICS bags, given that the value of their losses is higher than the value of the investment.

There are a few limitations worth mentioning. First, the study focused on soybean, although both traders use the same existing storage structure for multiple crops. It will be interesting to compare the profitability of storage protection technologies across several crops and also account for the practices employed by traders from purchase to storage. Second, the small sample size limited the scope of the analysis in terms of separate results based on location and storage type. Third, there is lack of data on socioeconomic and other factors that may influence traders' choice of storage technique. Fourthly, the study considered insect pests and theft as the only causes of storage losses which are not exhaustive. Future studies may incorporate different causes of storage losses in the profitability analysis.

Despite the limitations of the study, there are three major implications. First, a policy that focuses on disseminating storage protection technologies must consider both the drivers of the losses and the economics to make an informed investment decision. Second, the policy must focus on improving storage infrastructure to improve the quality of the grains. Lastly, the private sector can benefit from these findings by adopting low-cost storage protection technologies that effectively reduce postharvest losses.

Ethical approval

This study does not involve human subjects.

Funding

The data for this study was obtained from the Soybean Innovation Lab who received support from the USAID (AID-OAA-L-14-00001) (Goldsmith as the Principal Investigator) and the ADMI Institute for the Prevention of Postharvest Loss at the University of Illinois at Urbana

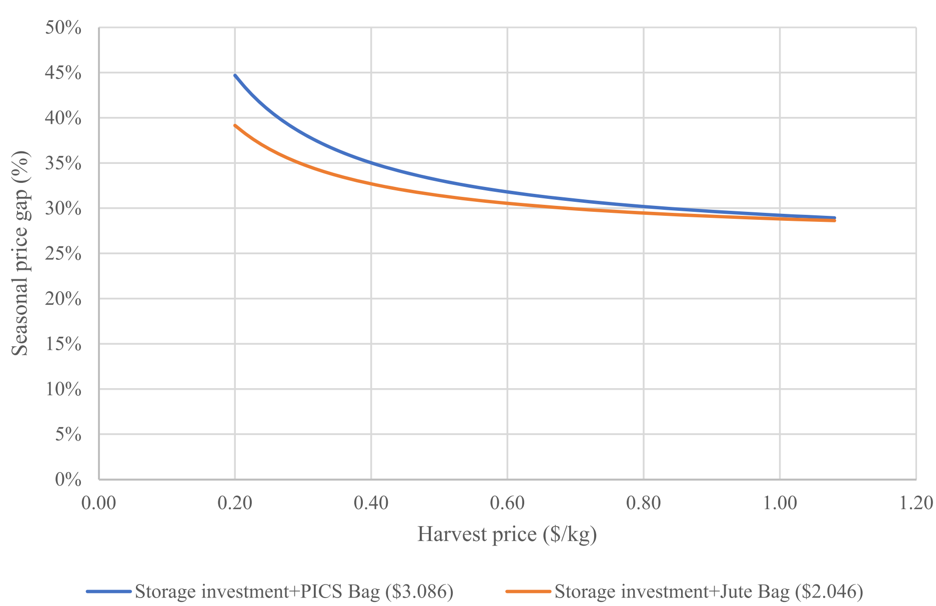

Fig. 7. Financial threshold for storage profit for soybean retailers.

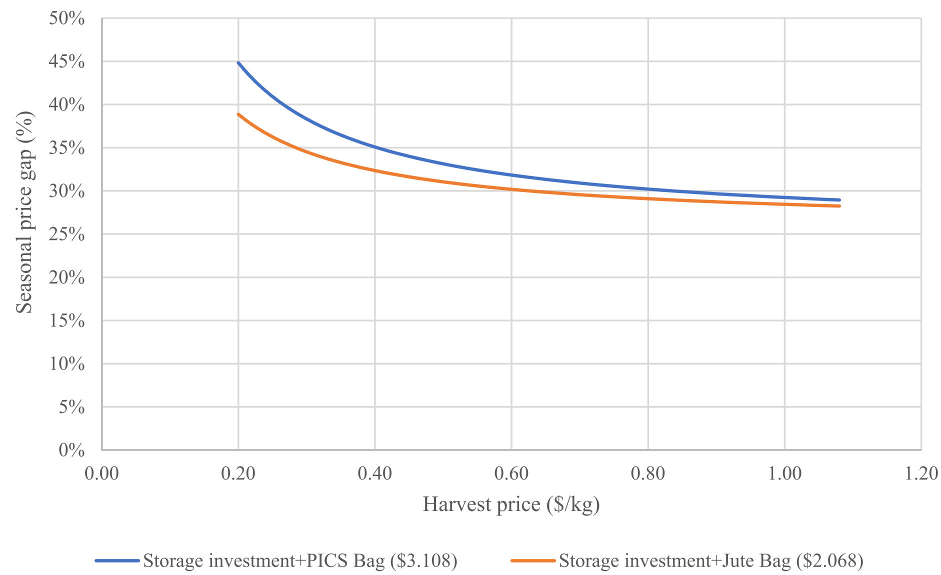

Fig. 8. Financial threshold for storage profit for soybean wholesalers.

Champaign (Edward Martey as the Principal Investigator). The contents are the responsibility of the authors and do not necessarily reflect the views of the USAID or the United States government and the ADMI Institute for the Prevention of Postharvest Loss.

Availability of data and materials

The authors do not have the right to share the data but available upon request.

Declaration of competing interest

The authors declare that they have no competing interests both financial and non-financial.

Data availability

Data will be made available on request.

Appendix A. Derivation of price seasonality based on rate of return

The rate of return (RoR) from storage investment is specified as:

$$RoR = \frac{R-K}{K} \tag{1}$$

Let $R = p_t q_t = (1+s)(1-v)(p_o)(1-w)$ and $K = (1+r)(p_o q_o + c)$, then RoR can be expressed as:

$$RoR = \frac{(1+s)(1-v)(p_o)(1-w)q_o - (1+r)(p_o q_o + c)}{(1+r)(p_o q_o + c)} \tag{2}$$

$$RoR = \frac{(1+s)(1-v)(1-w)p_o q_o - (1+r)(p_o q_o + c)}{(1+r)(p_o q_o + c)} \tag{3}$$

$$RoR = \frac{(1+s)(1-v)(1-w)p_o q_o - [p_o q_o + c + r p_o q_o + rc]}{(1+r)(p_o q_o + c)} \tag{4}$$

From equation (4), we equate RoR to zero if the trader will be indifferent between investing and storing.

$$\frac{[(1+s)(1-v)(1-w) - 1 - r]p_o q_o - c - rc}{(1+r)(p_o q_o + c)} = 0 \tag{5}$$

$$[(1+s)(1-v)(1-w) - 1 - r] = \frac{rc + c}{p_o q_o} \tag{6}$$

$$(1+s)(1-v)(1-w) = \frac{c(r+1)}{p_o q_o} + 1 + r \tag{7}$$

$$(1+s)(1-v)(1-w) = 1 + r + \frac{c(r+1)}{p_o q_o} \tag{8}$$

$$(1+s) = \frac{1}{(1-v)(1-w)}\left[1 + r + \frac{c(r+1)}{p_o q_o}\right] \tag{9}$$

$$s = \frac{1}{(1-v)(1-w)}\left[1 + r + \frac{c(r+1)}{p_o q_o}\right] - 1 \tag{10}$$

Assuming the price discounting (v) and dry weight loss (w) are zero due to the effectiveness of the storage structure, then equation (10) reduces to:

$$s = r + \frac{c(r+1)}{p_o q_o} \tag{11}$$

References

[1] A.A. Chigoverah, B.M. Mvumi, Efficacy of metal silos and hermetic bags against stored-maize insect pests under simulated smallholder farmer conditions, J. Stored Prod. Res. 69 (2016) 179–189.

[2] D. Kumar, P. Kalita, Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries, Foods 6 (1) (2017) 1–22.

[3] P.C. Coradi, R.E. Lima, C.L. Padia, C.Z. Alves, P.E. Teodoro, A. Carina da Silva Cândido, Soybean seed storage: packaging technologies and conditions of storage environments, J. Stored Prod. Res. 89 (2020), 101709, https://doi.org/10.1016/j.jspr.2020.101709.

[4] World Food Programme of the United Nations (WFP), Reducing Food Losses in Sub-saharan Africa (Improving Post-harvest Management and Storage Technologies of Smallholder Farmers): an 'Action Research' Evaluation Trial from Uganda and Burkina Faso, 2015. Retrieved from, http://documents.wfp.org/stellent/groups/public/documents/special_initiatives/WFP265205.pdf.

[5] K.N. Nwaigwe, An overview of cereal grain storage techniques and prospects in Africa, J. Bioiosci. Bioeng 4 (2019) 19–25. http://www.openscienceonline.com/journal/ijbb.

[6] United State Agency for International Development, Staple Crops Storage Handbook, 2011 (Washington).

[7] C.A. Midega, A.W. Murage, J.O. Pittchar, Z.R. Khan, Managing storage pests of maize: farmers' knowledge, perceptions and practices in western Kenya, Crop Protect. 90 (2016) 142–149.

[8] D. Kadjo, J.E. Ricker-Gilbert, C.E. Alexander, A. Tahirou, Effects of storage losses and grain management practices on storage: eEvidence from maize production in Benin, in: 2013 Annual Meeting, August 4-6, 2013, Washington, DC(No. 150522), Agricultural and Applied Economics Association, 2013. https://ideas.repec.org/p/ags/aaea13/150522.html.

[9] I. Sugri, M. Abubakari, R.K. Owusu, J.K. Bidzakin, Postharvest losses and mitigating technologies: eEvidence from Upper East Region of Ghana, Sustainable Futures 3 (2021), 100048.

[10] C. Karthikigan, D. Veerarargavathatham, D. Karpagam, S. Ayisha Firdouse, Traditional storage practices, International Journal of Traditional Knowledge 8 (4) (2009) 564–568.

[11] M. Schmidt, E. Zannini, E.K. Arendt, Screening of post-harvest decontamination methods for cereal grains and their impact on grain quality and technological performance, Eur. Food Res. Technol. 245 (2019) 1061–1074.

[12] H. De Groote, S.C. Kimenju, P. Likhayo, F. Kanampiu, T. Tefera, J. Hellin, Effectiveness of hermetic systems in controlling maize storage pests in Kenya, J. Stored Prod. Res. 53 (2013) 27–36.

[13] M. Zeigler, G. Truitt Nakata, The Next Global Breadbasket: How Latin America Can Feed the World: A Call to Action for Addressing Challenges & Developing Solutions, Inter-American Development Bank, Washington, DC, 2014.

[14] H. Sudini, G.R. Rao, C.L.L. Gowda, R. Chandrika, V. Margam, A. Rathore, L. L. Murdock, Purdue Improved Crop Storage (PICS) bags for safe storage of groundnuts, J. Stored Prod. Res. 64 (2015) 133–138.

[15] M.R. Momanyi, J.M. Nduko, M. Omwamba, Effect of hermetic Purdue Improved Crop Storage (PICS) bag on chemical and anti-nutritional properties of common Bean (Phaseolus vulgaris L.) varieties during storage, Curr. Res. Food Sci. 5 (2022) 107–116.

[16] A. Elgersma, K. Søegaard, Changes in nutritive value and herbage yield during extended growth intervals in grass–legume mixtures: effects of species, maturity at harvest, and relationships between productivity and components of feed quality, Grass Forage Sci. 73 (1) (2018) 78–93.

[17] B.H. Kotu, A.B. Abass, I. Hoeschle-Zeledon, H. Mbwambo, M. Bekunda, Exploring the profitability of improved storage technologies and their potential impacts on food security and income of smallholder farm households in Tanzania, J. Stored Prod. Res. 82 (2019) 98–109.

[18] T. Tubbs, D. Baributsa, C. Woloshuk, Impact of opening hermetic storage bags on grain quality, fungal growth and aflatoxin accumulation, J. Stored Prod. Res. 69 (2016) 276–281.

[19] I.B. Baoua, L. Amadou, B. Ousmane, D. Baributsa, L.L. Murdock, PICS bags for post-harvest storage of maize grain in West Africa, J. Stored Prod. Res. 58 (2014) 20–28.

[20] S.B. Williams, D. Baributsa, C. Woloshuk, Assessing Purdue Improved Crop Storage (PICS) bags to mitigate fungal growth and aflatoxin contamination, J. Stored Prod. Res. 59 (2014) 190–196.

[21] M. Jones, C. Alexander, J. Lowenberg-DeBoer, A simple methodology for measuring profitability of on-farm storage pest management in developing countries, J. Stored Prod. Res. 58 (2014) 67–76.

[22] C.M. Mutungi, H. Affognon, A.W. Njoroge, D. Baributsa, L.L. Murdock, Storage of mung bean (Vigna radiata [L.] Wilczek) and pigeonpea grains (Cajanus cajan [L.] Millsp) in hermetic triple-layer bags stops losses caused by Callosobruchus maculatus (F.)(Coleoptera: bruchidae), J. Stored Prod. Res. 58 (2014) 39–47.

[23] R.J. Hodges, J.C. Buzby, B. Bennett, Postharvest losses and waste in developed and less developed countries: oOpportunities to improve resource use, J. Agric. Sci. 149 (S1) (2011) 37.

[24] C.E. Alexander, P. Kenkel, Economics of Commodity Storage. Stored Product Protection, Kansas State, Manhattan, KS, 2012, pp. 1–11. http://entomology.k-state.edu/doc/finishedchapters/s156-ch-27-economics-of-commodity-storage.pdf.

[25] Ministry of Food and Agriculture (MoFA)- Statistics, Research, and Information Directorate (SRID), Agriculture in Ghana: Facts and Figures 2020. Accra: Statistics, Research, and Information Directorate of the Ministry of Food and Agriculture, 2020.

[26] Ministry of Food and Agriculture (MoFA)-International Food policy Research Institute (IFPRI), Ghana's Soybean Market. Market Brief No. 6, 2020. https://www.ifpri.org/publication/ghanas-soya-bean-market. (Accessed 18 May 2021).

[27] Statistics, Research and Information Directorate of Ministry of Food and Agriculture (SRID), Production Estimates, SRID, Accra, Ghana, 2020.

[28] E. Martey, P. Goldsmith, Heterogeneous demand for soybean quality, Afr. J. Agric. Resour. Econ. 15 (311–2020-1779) (2020) 27–50.

[29] H. Working, The theory of price of storage, Am. Econ. Rev. 39 (6) (1949) 1254–1262.

[30] A.B. Abass, M. Fischler, K. Schneider, S. Daudi, A. Gaspar, J. Rüst, D. Msola, On-farm comparison of different postharvest storage technologies in a maize farming system of Tanzania Central Corridor, J. Stored Prod. Res. 77 (2018) 55–65.

[31] D. Baributsa, J. Lowenberg-DeBoer, L. Murdock, B. Moussa, Profitable chemical-free cowpea storage technology for smallholder farmers in Africa: opportunities and challenges, Gates Open Res 3 (853) (2019) 853.

[32] C.J. Bern, H.M. Hanna, W.F. Wilcke, Harvesting, Storing, and Post-harvest Management of Soybeans. In*Soybeans*, AOCS Press, 2008, pp. 67–92.