Hindawi
Advances in Agriculture
Volume 2022, Article ID 8953918, 19 pages
https://doi.org/10.1155/2022/8953918

Research Article

Economics of Bulk Storage Techniques: Maize and Cowpea Storage in Ghana

John K. Bidzakin[1,2] **Osei Yeboah,**[3] **Issah Sugri**[2] **Anil Graves**[1] **and Dadson Awunyo-Vitor**[4]

[1]*Cranfield University, School of Water, Energy and Environment, Building 53 (Bullock Building) F03, Cranfield MK43 0AL, Bedfordshire, UK*
[2]*Savanna Agricultural Research Institute (SARI)-Nyankpala, Council for Scientific and Industrial Research (CSIR), P.O. Box TL 52, Tamale, Ghana*
[3]*Department of Agribusiness, Applied Economics and Agriscience Education, North Carolina A&T State University, 1601 East Market Street, Greensboro 27411, NC, USA*
[4]*Department of Agricultural Economics, Agribusiness & Extension, Kwame Nkrumah University of Science & Technology, PMB, Kumasi, Ghana*

Correspondence should be addressed to John K. Bidzakin; bidzakin2@gmail.com

Received 5 April 2022; Revised 2 June 2022; Accepted 20 June 2022; Published 16 July 2022

Academic Editor: Xinqing Xiao

High postharvest loss is one of the major challenges faced by farmers in many African countries in their efforts to achieve food and nutrition security. Several postharvest techniques have been developed and introduced to farmers aimed at reducing food losses. This study evaluated the economic viability of four such grain storage techniques using capital budgeting techniques. Two grain protectants were applied at recommended rates in three treatment combinations to jute sacks, PICS sacks, polytanks, and poly sacks at different treatment levels and at different discount rates. Under maize storage, the net present value of all treatments yielded positive net returns. The polytank technique proved to be the most economically viable storage technique, followed by PICS and then jute sacks. Under cowpea storage, polytank proved to be the most viable, followed by PICS. This is consistent under replacement chain method and equivalent annual annuity under the three different discount rates used. Cowpea is best stored in polytanks and PICS sacks. Polytank is recommended as the most economically viable storage technique for both maize and cowpea storage. PICS is also recommend for both maize and cowpea storage. However, jute sacks and poly sacks are not suitable for cowpea storage even under chemical treatment, especially under long-term storage (over 6 months). The choice of storage technique should consider the commodity under consideration.

1. Introduction

1.1. Postharvest Losses and Food Security. Food losses and waste are the results of the ineffective functioning of food systems. Postharvest losses (PHL) in the food system refer to the quantitative and qualitative loss of food in various postharvest operations. “Food loss” is defined too as food available for human consumption but not consumed. Minimizing PHL is a priority development and policy issue across agencies such as the FAO and world development banks [1–3]. About a third of the food produced in the world per year for human consumption is lost or wasted [4, 5]. Food losses and waste total approximately $680 billion in industrialized countries and around $310 billion in developing countries.

At a time when the demand for food of a growing population is a major global problem, more than a third of food is lost or wasted in postharvest agricultural operations. Therefore, reducing waste after harvest, especially in developing countries, can be a sustainable solution to increase food availability, reduce pressure on natural resources, eliminate hunger, and improve farmers' living conditions. Cereal crops are the basis of food in most developing countries around the world. The maximum losses after harvest are estimated on the basis of calories among all agricultural products. As much as 50–60% of cereal yields can be lost at the storage stage due to the lack of technical capacities for their proper harvesting and storage. The use of scientific storage methods can reduce storage losses by up to 1–2% [6, 7]. Depending on the volume or area in which these losses occur, they generate economic, social, environmental, and health effects.

One of the challenges faced by African countries in achieving food security is high postharvest losses. It has been estimated that the value of postharvest losses in sub-Saharan Africa is about US$48 billion a year. A report by the World Bank [8] revealed that, each year, significant volumes of food are lost after harvest in sub-Saharan Africa (SSA), the value of which is estimated at USD 4 billion for grains alone. Storage of grains is critical for food supply and seed availability for small-scale farmers [9].

Storage is a process by which agricultural produce or products are preserved for future use [10]. Poor storage infrastructure creates vulnerability for rural businesses. Insect pests are the major challenge to grain storage in sub-Saharan Africa [11]. Farmers are compelled to sell grain during the harvest period, usually when prices are at their lowest levels [12, 13]. Grain storage is very strategic for the agricultural business [14, 15]. Grain spoilage and food waste can be minimized through the use of improved storage technologies [16].

Many farmers are mostly compelled to sell their produce immediately after harvest to avoid storage losses due to pest attack and therefore forfeit potential profits [17, 18]. Reducing the postharvest losses, especially in developing countries, could be a sustainable solution to increase food availability, reduce pressure on natural resources, eliminate hunger, and improve farmers' livelihoods [19]. In Ghana, for example, postharvest losses for maize, cassava, and yam are estimated to be 35%, 35%, and 24%, respectively [20]. According to the World Bank [8], important volumes of cereals are lost after harvest in developing countries which worsens the hunger situation. In addition to the loss in volumes, quality of grain is compromised, resulting in lower market opportunities and nutritional value. In fact, in 1975, the United Nations brought postharvest storage losses into international focus when it declared that "further reduction of postharvest food losses in developing countries should be undertaken as a matter of priority" [21]. Based on these reasons, experts now agree that investing in postharvest losses (PHLs) reduction is a quick impact intervention for enhancing food security [22].

1.2. Maize and Cowpea Postharvest Status. Maize and cowpea are important staple food crops in all parts of Ghana. Currently, maize-based cropping systems have become dominant in drier northern savanna areas of Ghana, where sorghum and millet were the traditional food security crops. According to SRID [23], maize is the most cultivated in Ghana, occupying up to 1,023,000 ha on arable land compared to rice (197,000 ha), millet (179,000 ha), sorghum (243,000 ha), cassava (889,013 ha), yam (204,000 ha), and plantain (336,000) [23]. Currently, Ghana is a net importer of maize and rice, even though it has great potential to be a self-sufficient and net exporter. Per capita consumption of maize is estimated at 44 kg/person/year [24].

Over the last few decades, a myriad of maize, rice, cowpea, and soybean varieties and hybrids have been released. These genotypes possess traits such as early maturing, drought resistance, diseases, and pest resistance, *Striga* resistance, as well as additional nutritional values. Grains of these genotypes possess diverse textural, physical, and compositional characteristics which relate differently to light, moisture, and temperature as well as susceptibility to insect pests and disease pathogens, particularly during prolonged storage. This requires commensurate postharvest techniques and strategies to contain harvested surpluses. Also, due to intensification and productivity increase, the need for bulk and prolonged storage has become critical. The crop productivity increase can be attributed to government- and donor-assisted projects such as providing subsidies on agricultural inputs and capacity building on good agronomic practices. Nonetheless, current storage methods are suited for small-holder farmers requiring storage of less than one ton. Interventions to introduce large storage units such as community warehousing, community grain banks, or metal silos, which can contain several tons of grain, are still constrained by national agricultural policies as well as low adoption from farmers.

Generally, stored maize and cowpea can be damaged by insect pests if they are not properly conditioned and protected [25]. This challenge may be exacerbated due to cropping intensification, introduction of hybrid cultivars, late harvesting after the cessation of the rainy season, and prolonged storage beyond 8 months after harvest. Grains are often stored in traditional grain silos or in jute and polypropylene sacks with or without chemical protection. However, pest infestation is a perennial constraint; the conditions favorable for grain storage are as well suitable for insect pest reproduction.

Additional challenges including on-farm infestation of notorious storage pests such as larger grain borer (*Prostephanus truncatus*), lesser grain borer (*Rhyzopertha dominica*), weevil (*Sitophilus zeamais*), and granary weevil (*S. granarius*) as well as mycotoxins accumulation are a threat in grain storage. Indiscriminate use of common grain protectants such as actellic (pirimiphos-methyl), bioresmethrin (pyrethroid), phostoxin, and Gastox (aluminum phosphate) is widespread among small-holder farmers [26]. Most farmers acquire agrochemicals from nonaccredited input dealers without any training on appropriate use. There is a need to integrate production and postharvest practices to achieve quality food for consumers. Integration of good agronomic operations, pest management, and appropriate storage techniques to minimize pest damage is therefore very essential.

1.3. Cowpea Grain Storage Practices. Cowpea contributes greatly to the household income and food security in Ghana. However, high postharvest losses remain a perennial constraint in cowpea storage compared to other dry cereals. The introduction of several improved varieties and climate change may exacerbate such high losses in most parts of sub-Saharan Africa. In many communities, farmers utilize traditional storage methods which are unable to protect stored grain from biological, physical, and environmental hazards, leading to unbearable economic losses. During storage, grain cowpea is vulnerable to the cowpea weevil (*Callosobruchus maculatus;* Coleoptera: Bruchidae). Damage caused by this weevil approaches 20 to 50% within the first 3 months of storage if the grain is not protected.

A review of postharvest losses in Ghana showed losses between 8 and 28% in cowpea [27]. Farmers' declared losses in the northern savanna zone are pegged at 22%, but a lower estimate (13.5%) was obtained using standard measurements in farm stores [28]. Apart from the economic losses, insect contamination of grains via dead insects, pupae, larval cocoons, and integument has recently been reported to contain carcinogenic compounds such as ethyl, methyl, and methoxy quinines which cannot be denatured by boiling or baking [29]. Quite recently, PICS bags have been promoted as a potential insecticide-free, long-term storage of cowpea and are now promoted for maize and cereals except paddy rice [28]. Despite its potential, cost and access to the PICS bags are still a limitation requiring the attention of policymakers.

Several studies suggest the integrated use of improved storage methods such as PICS bags and safe grain protectants [28, 30]. For instance, treatment combination involving jute bags recorded higher losses (68.3 to 71.8%) compared to grain stored in PICS bags (6.4 to 7.1%) and plastic drums (6.7 to 11.1%) [28]. The application of either grain protectant significantly reduced losses compared to the control, but no significant differences existed between the two grain protectants. For all treatment combinations involving jute bags (control or treated), the ideal storage duration for the grain was below 4 months, when losses hovered at 18.1 to 24.2%. Grain with a high level of damage will attract low market prices, particularly in urban markets where consumers are sensitive to physical appearance. Ordinarily, farmers do not store cowpea beyond 2 months in farm stores, except for extremely small quantities for household consumption.

1.4. Maize Grain Storage Practices. Reference [31] reported that weevils account for 36% of the total loss for maize, while the large grain borers (LGB) account for more than half of the losses recorded for maize in Tanzania. In a similar study, Dick [32] reported that the LGB alone could increase losses of stored maize and dried cassava to 30%. A similar observation was made in Sudan, where 8.34% of sorghum inside nonairtight sweibas (cylindrical mud bins) for 8 months was lost. But, the loss was reduced to 2.23% when the sweibas were hermetically sealed and raised above the ground [33]. A study on maize storage revealed that losses of 2.2 to 5.8% were incurred in grain stored in PICS bags and plastic drums as compared to 7.2 to 21.7% losses when stored in jute and polypropylene bags during 12 months of storage [34]. Due to differences in varieties, harvest timing, and drying operations among farmers, the use of grain protectants should be considered where prolonged storage of 8 to 12 months is anticipated, particularly if jute and polypropylene bags are to be used. Treating grain with chemicals may not be necessary when using PICS bags or plastic drums during 1 year of storage.

As part of the activities of a project titled "containing productivity increases of maize in Northern Ghana through large-scale storage methods" [35], four major grain storage technologies were evaluated by farmers to assess their effectiveness. These technologies were able to reduce the postharvest losses of maize from 36.7% to 3.1% and cowpea from 77.8% to 6.4% during 12 months of storage [28]; however, there is very little work done on their financial and economic viability and also they do not control for the difference in lifespans; hence the need for this study. The economic and financial viability of these techniques will be very necessary to serve as a decision support tool to guide the public and policymakers [36–38].

2. Materials and Methods

2.1. Study Area. Situated on the coast of the Gulf of Guinea in western Africa, Ghana is bordered to the northwest and north by Burkina Faso, to the east by Togo, to the south by the Atlantic Ocean, and to the west by Côte d'Ivoire. Relief throughout Ghana is generally low, with elevations not exceeding 3,000 feet (900 meters). Apart from providing the bulk of national income, agriculture, forestry, and fishing employ more than half of the population. The value of food produced for local consumption is considerable. The soil and climate favor the production of a wide range of food crops. Yam, cassava, and cereals such as maize, rice, cowpea, soybean, groundnut, sorghum, and millet are produced primarily in the northern savanna zone. Successive governments have strongly supported diversification of food production to reduce reliance on a few crops and to cut down on food imports, but these measures have often been contradictory because of the emphasis on exports capable of earning foreign exchange.

This study was specifically conducted in the Upper East region of Ghana (UER). The region lies between longitude 1015′W to 005′E and stretches from latitude 10030′N to 1108′N. The region lies in the Sudan savanna agroecology, which forms the semiarid part of Ghana. The area is part of what is sometimes referred to as interior savanna and is characterized by level to gently undulating topography. Important crops include millet, sorghum, maize, rice, sweet potato, groundnut, cowpea, soybean, cotton onion, and tomato. The shea nut tree grows wild, and it is an important cash crop. It has alternating wet and dry seasons, with the wet season occurring between May and October, during which about 95% of rainfall occurs. Maximum rainfall occurs in August-September, and severe dry conditions exist between November and April each year. Annual rainfall ranges from 800 to 1200 mm. There is wide fluctuation in relative humidity, with as low values as 30% in the dry season and above 75% in the wet season (https://www.ghanadistricts.com).

2.2. Description of Experiment. Maize and cowpea grain were bulked by farmers during the harvesting season of 2019 and 2020. For each commodity, 100 kg each was stored in polypropylene sacks (PS), jute sacks (JS), Perdue Improved Crop Storage sacks (PICS) (a PICS sack consists of two layers of polyethylene liners and a third layer made from woven polypropylene and it is hermetic), and polytanks (PT) (it is a rubber cylindrical tank with a lid that when closed makes it airtight (hermetic)) (see Figure 1) with and without grain protectants. Two grain protectants, Actellic Super 5EC and phostoxin, were applied at recommended rates. Actellic Super 5EC is a food-grade chemical containing 80 g Pirimiphos-methyl and 15 g Permethrin/L. Phostoxin (aluminum phosphate) is a food-grade fumigant. Jute sacks are made of natural fiber, and polypropylene is an artificial fiber. The PICS has 2 inner plastic layers, which provides hermitic conditions for the content stored. The polytanks are ordinary plastic drums commonly used in household water storage. They have airtight seals which provide hermitic conditions for grain storage. The grain was dried to the recommended moisture content of 13%–14% for maize and 12%–13% for cowpea, and they were all stored under the same room condition. Each technology had three treatments, and each treatment was applied to 100 kg each of grain maize and cowpea. The treatments were storage technique without any chemical; storage technique with Actellic Super 5EC; and storage technique with phostoxin. These were replicated in four locations, namely, Manga, Tansia, Azum-Sapielga, and Tes-Natinga, all in the UER, located in Guinea Sudan Agroecology.

Data was collected on the initial weight and final weight at 12 months of storage. Average market prices of maize and cowpea at the time of storage and after storage, when the majority of farmers bring out their stored produce to sell due to price increases and need for income, were surveyed. Grain prices at the time of storage were collected as an average of prices in September, October, and November when prices are low due to high grain supply to the market. The market price at the time of sale was also collected as an average of prices in April, May, and June when the demand for these commodities is very high.

2.3. Economic Viability Evaluation Techniques. We adopted the methodology of economic evaluation as outlined by [39] using capital budgeting techniques. In capital budgeting (capital budgeting is defined as the process by which a business determines which fixed asset purchases or project investments are acceptable and which are not), many different criteria are used for evaluating a project, measuring economic efficiency, and deciding among alternatives. Net present value (NPV) is considered the most theoretically reliable tool [40–42]. Approaches for carrying out economic evaluations are currently very diverse [43]. Although the existing methods largely differ in implementation strategy, they all share a common principle, which is the capital budgeting approach which is used in calculating the economic return of projects using discounted cash flows [44, 45].

2.3.1. Net Present Value Concept. The NPV approach consists of discounting all future cash flows (both in- and outflow) resulting from the innovation/project with a given discount rate (DR) and then summing them together. The merit of innovation is measured considering its contribution to the creation of economic value out of the investment needed. This technique offers many variations [45]. Considering our interest in assessing the economic viability of these storage techniques and identifying the most economically viable option for recommendation, the NPV approach was adopted. This is because the study involved investment in technologies with a future stream of costs and benefits, which must be discounted to find their present worth.

Net present value method is a popular capital budgeting technique that takes into account the time value of money [39, 46]. It uses the net present value of the investment project as the basis to accept or reject a proposed investment. Net present value is the difference between the present value of all cash inflows and the present value of all cash outflows that occur as a result of undertaking an investment project. It may be positive, zero, or negative. When the present value of cash inflows is greater than the present value of the cash outflows, the net present value is said to be positive, and the investment proposal is considered to be economically viable. If the present value of cash inflow is equal to the present value of cash outflow, the net present value is said to be zero, and the investment proposal is considered to be acceptable. When the present value of cash inflow is less than the present value of cash outflow, the net present value is said to be negative, and the investment proposal is rejected because it is not economically viable [39, 46]. The higher the NPV, the higher its viability, and for mutually exclusive investment proposals that all yield positive NPV, the one with the highest NPV should be selected. The NPV method is employed to assess the four storage techniques (poly sacks, jute sacks, PICS sacks, and polytank) with different chemical treatments.

2.3.2. Economic Evaluation of Projects with Unequal Duration. The duration of a project is important when comparing alternative projects. The rule is that you cannot compare the NPVs of projects with unequal durations. You must make some adjustments for the duration to make them comparable. Hence, the replacement chain method (RCM) and equivalent annual annuity (EAA) techniques were used to adjust for the difference in project duration or the lifespan of the different storage techniques [47, 48].

2.3.3. Replacement Chain Method (RCM). The replacement chain method is a capital budgeting tool used to compare two or more mutually exclusive capital projects with unequal lifespan. The replacement chain method takes into consideration the different life spans of alternative projects as well as their expected cash flows. That makes it easier to compare the projects. In the replacement chain method, the cash flow projections for the projects under consideration are repeated up to the least common useful life. Replacement

Poly sack | Jute sack | PICS sack | Poly tank

Figure 1: Pictures of the four storage techniques.

chain analysis is also called the common life approach. It is simple when applying it to two projects but gets cumbersome when the projects exceed two.

2.3.4. Equivalent Annual Annuity (EAA). Equivalent annual annuity (EAA) is a method for evaluating projects with different life durations. Equivalent annual annuity is also an approach used in capital budgeting to choose between mutually exclusive projects with unequal lifespans. It assumes that the projects are annuities, calculates the net present value for each project, and then finds annual cash flows that, when discounted at the relevant discount rate for the life of the relevant project, would equal the net present value for that project. Equivalent annual annuity approach (also called the annual net present value method) ranks projects based on their net present value per year, which is calculated by dividing the net present value by the present value of the annuity factor corresponding to the discount rate (hurdle rate) and life of the project. The project with a higher equivalent annual annuity is preferred.

2.3.5. Net Present Value (NPV) Estimation. The net present value (NPV) measure is the principal investment evaluation indicator. The cash flows consist of a mixture of costs and benefits occurring over time. Net present value is the arithmetic difference between discounted benefits and discounted costs as they occur over time. The formula for NPV is specified as follows:

$$\mathrm{TB} = \frac{B_0}{(1+i)^0} + \frac{B_1}{(1+i)^1} + \cdots + \frac{B_t}{(1+i)^t}, \tag{1}$$

$$\mathrm{TC} = \frac{C_0}{(1+i)^0} + \frac{C_1}{(1+i)^1} + \cdots + \frac{C_t}{(1+i)^t}. \tag{2}$$

Equation (3) (NPV) is obtained by subtracting equation (2) from equation (1)

$$\mathrm{NPV} = TB - TC, \tag{3}$$

$$\mathrm{NPV} = \frac{B_0 - C_0}{(1+i)^0} + \frac{B_1 - C_1}{(1+i)^1} + \cdots + \frac{B_t - C_t}{(1+i)^t}, \tag{4}$$

where NPV is the net present value, t is the time in years, B is the benefits, C is the cost, i is the discount rate, TB is the total benefits, and TC is the total cost.

This technique, however, does not take account of the difference in project life spans, such as in our case, where the storage techniques have different lifespans. Hence, it will not be sufficient to decide on the most viable technique using this approach, which requires the introduction of the replacement chain method and the equivalent annual annuity approaches.

2.3.6. Estimating NPV Using the Replacement Chain Method (NPV-RCM). The replacement chain method (RCM) takes into account the different life spans of alternative projects as well as their expected cash flows. That makes it easier to compare the projects. It is simple when applying it to two projects but gets cumbersome when the projects exceed two. The formula for estimating the replacement chain approach NPV is specified as follows:

$$\mathrm{NPV} = \mathrm{NPV}_{(1)}\left[\frac{(1+i)^t}{(1+i)^t - 1}\right], \tag{5}$$

where $\mathrm{NPV}_{(1)}$ is the net present value of a project at the initial replication, i is the cost of capital (discount rate), and t is the lifespan of the project in years.

In the replacement chain method, the cash flow projections for the storage techniques under consideration are repeated up to the least common useful life. The polytank storage technique has a 10-year lifespan, jute sacks have a life span of 3 years, poly sacks have 2 years life span, and PICS has a 2-year life span giving us a total of 30 years as the least common life. Polytank is repeated twice, jute sacks are repeated 10 times, and poly sacks and PICS are repeated 15 times each. The net present value for that common useful life is compared, and the project with a higher NPV is selected.

2.3.7. Estimating Equivalent Annual Annuity (EAA). Equivalent annual annuity (EAA) approach ranks projects based on their net present value per year, which is calculated by dividing the net present value by the annuity factor corresponding to the discount rate and life of the project.

The project with a higher equivalent annual annuity is preferred. This is specified as follows:

$$\text{EAA} = \frac{i\,(\text{NPV})}{1-(1+i)^{-t}}. \tag{6}$$

Substituting equation (4) into equation (6) will give us equation (7) which is used to estimate the equivalent annual annuity to help in ranking the projects to decide on the most preferred project among the alternatives.

$$\text{EAA} = \frac{i\left(\left[\, B_0 - C_0/(1+i)^0 + B_1 - C_1/(1+i)^1 + \cdots + B_T - C_T/(1+i)^T \,\right]\right)}{1-(1+i)^{-t}}. \tag{7}$$

The EAA of all the techniques under maize and cowpea at different discount rates was estimated using equation (7).

2.4. Sensitivity Analysis. Sensitivity analysis allows analyzing changes in the values obtained from the different storage techniques when there are changes in exogenous variables like the discount rate. Sensitivity analysis measures the extent to which a predetermined change in one or more input variables can influence the value of output variables [49, 50]. By analyzing sensitivity to exogenous variables, the uncertainties and risks of a given project can be minimized [51, 52]. The discount rate sensitivity analysis was chosen due to the unstable nature of lending and inflation rates in Ghana. We used three discount rates of 13%, 15%, and 17% to reflect the most likely increasing trend of interest rates in Ghana.

2.5. Estimating NPV, NPV-RCM, and EAA of Different Storage Technologies. In this study, we discount the incremental benefits and costs of the storage technologies over a period of the project life in years. We used a discount rate (it is the rate of return that the investors expect or the cost of borrowing money) of 15%, which was determined based on the prevailing interest rate used by the banks, which is the cost of capital for the period. We further adjusted it upward to 17% and also downward to 13% to see how sensitive the storage techniques are to the discount rate. This is so perceived because interest rates in Ghana and most parts of Africa are highly unstable and could change at any time, especially upwardly. The technologies evaluated are Hessian jute sacks, polypropylene sacks, hermitic PICS sacks, and hermitic polytanks. These technologies have different life spans and were all adjusted to 30 years as the least common life. Therefore, we have a total of four storage options, with three treatments each giving us a total of twelve treatments replicated in four locations. The initial average price of maize at harvest was $17.2/100 kg, and after storage, the average sale price of maize was $28.0/100 kg. Cowpea average price at harvest was $42.1/100 kg, and after storage, the average price was $84.2/100 kg.

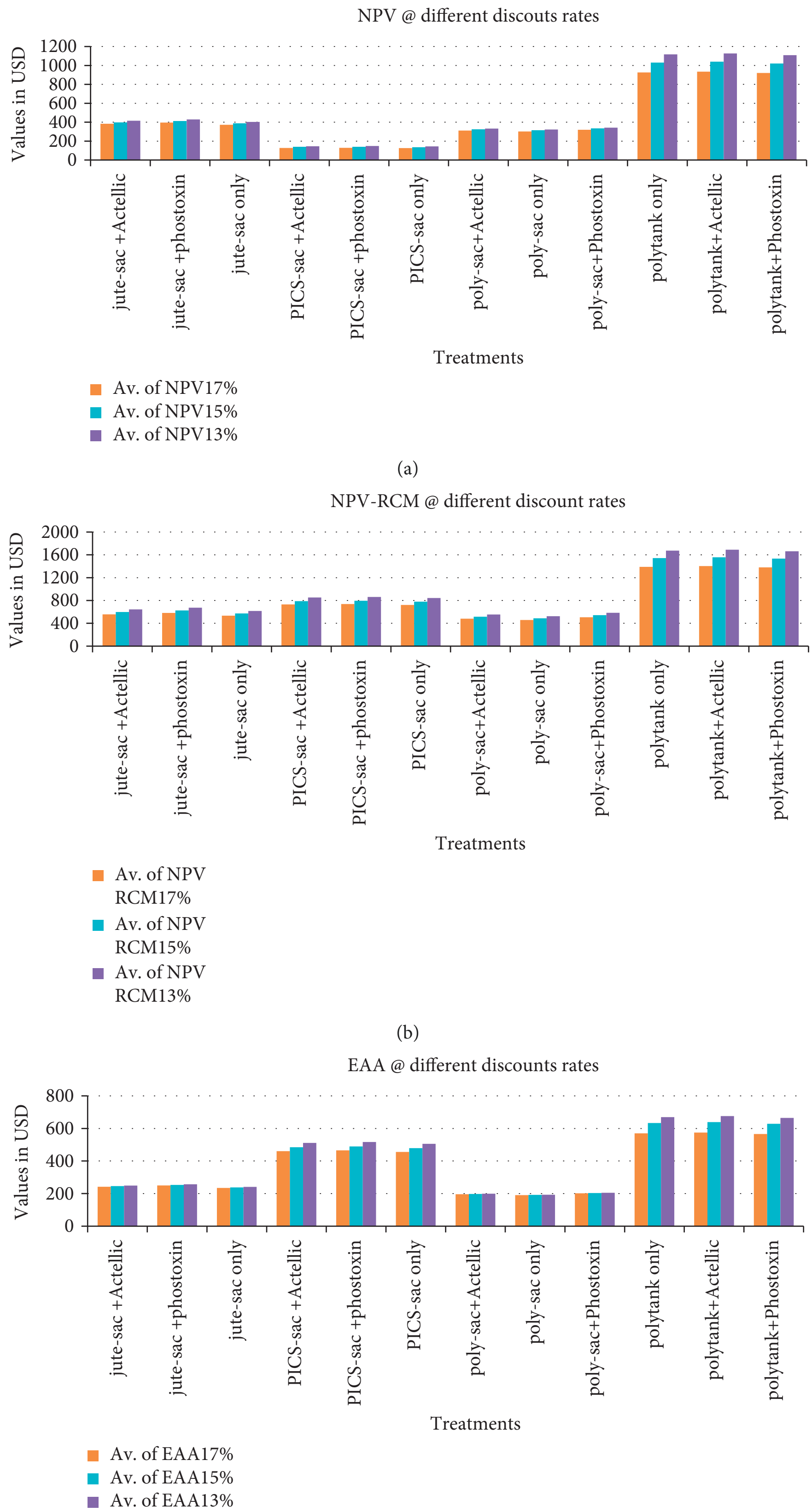
3. Results and Discussion

The study compares the results from the three evaluation approaches, the net present values where project lifespan is not controlled (NPV), and net present value where project lifespan is controlled using the replacement chain method (RCM) and equivalent annual annuities (EAA), which also controls for the difference in project lifespan. This evaluation is done under maize and cowpea storage.

3.1. Maize Storage

3.1.1. Estimated Discounted Net Benefits under the Three Approaches. The results (Figure 2) show that all the technologies returned a positive stream of discounted net benefits irrespective of the approach (NPV, NPV-RCM, and EAA) and discount rate used, which agrees with the work of [28, 53], who also found these techniques in maize storage to be profitable. For a new technology to be deemed attractive and viable for farmers to invest in, it must have a positive NPV, and the greater the NPV, the better it is (Figure 2(a)–2(c)) [39, 46]. Results in Figure 2(a) show that polytank is the most economically viable technique, followed by jute sacks and then poly sacks; the PICS sack is the least viable. However, under NPV-RCM results in Figure 2(b) and EAA results in Figure 2(c), both ranked polytanks as the most viable technique, followed by PICS sacks, and jute sacks ranked third, and poly sacks ranked the least economically viable technique. The results of PICS being economically viable agree with the work of [54–57]. Phostoxin and actellic treatment really did not have a significant effect on the economic viability of PICS and polytank storage techniques which is consistent with the work of [31, 58].

The results indicate that net present values from techniques that do not account for the lifespan of the investment do not deliver consistent estimates. This is evident in this study as the values from the NPV approach are different from the two approaches that accounted for differences in investment lifespans. The results also indicate that chemical protectants do not have any significant effect on the economic and financial viability of PICs and polytank storage techniques under maize storage. This, however, is true when maize is stored within 12 months of storage but may differ when stored beyond this period because our data did not go beyond 1 year of storage. This will be good for future work to



(c)

Figure 2: NPV, NPV-RCM, and EAA of Maize storage at different discount rates.

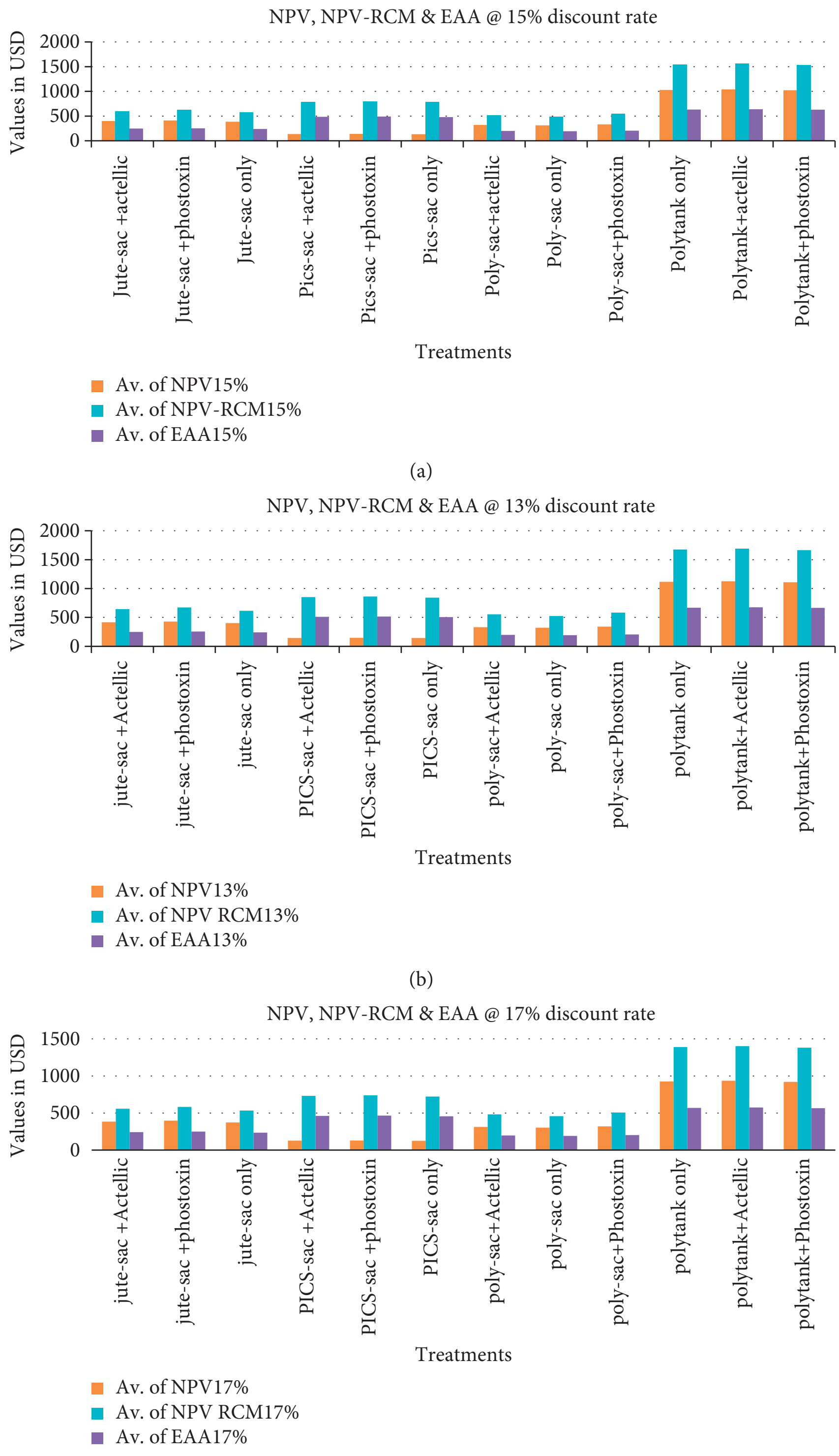


Figure 3: NPV, NPV-RCM, and EAA at a discount rate of 15%, 13%, and 17%.

increase the storage period to examine its impact on their economic viability.

3.1.2. Comparing the Three Evaluation Approaches at Different Discount Rates. The storage techniques are compared under the three treatments at different discount rates to assess the consistency of the results and also check the sensitivity of the storage techniques to discount rates. Using a discount rate of 15%, all treatments yielded positive discounted net benefits under the three evaluation approaches used to measure the discounted net present value (NPV,

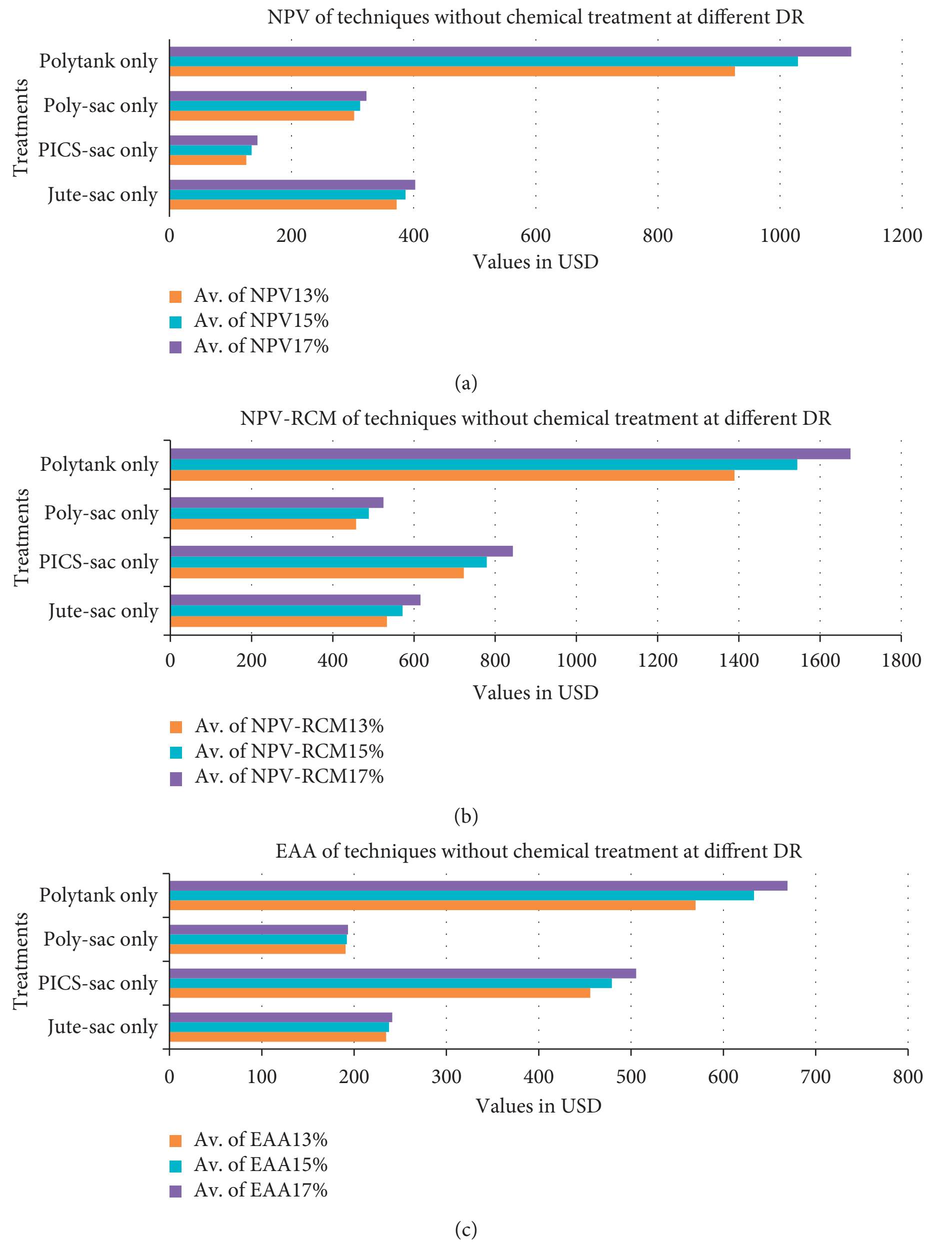


FIGURE 4: Techniques without treatment NPV, NPV-RCM, and EAA at different DR.

NPV-RCM, and EAA), as shown in Figure 3(a). Polytank technique is the most viable, followed by PICS sacks, and then jute sacks and poly sacks have been the least. Using a discount rate of 13%, all treatments yielded positive discounted net benefits under the three evaluation approaches (NPV, NPV-RCM, and EAA). The results show that the polytank technique was the most viable, followed by PICS, and then jute sacks and poly sacks recorded the least, as shown in Figure 3(b). Using a discount rate of 17%, the results trend is the same as in Figures 3(a) and 3(b). All treatments yielded positive discounted net benefits under the three approaches (NPV, NPV-RCM, and EAA). Polytank technique is the most viable, followed by PICS, as shown in Figure 3(c). The economic viability of PICS under maize storage is supported by the work of [56, 57].

The results show that the higher the discount rate, the lower the discounted net benefit, consistent with the work of [59, 60]. The results are consistent, and it shows that the techniques are economically viable even when the cost of capital is going up. Even at a high discount rate of 17%, investment in PICS and polytank technologies is still economically viable and hence will be attractive to investors.

3.1.3. Evaluation of Storage Techniques without Chemical Treatment. The storage techniques without chemical treatment are compared at different discount rates. The discounted net benefits of the storage techniques without treatment at different discount rates (13%, 15%, and 17) indicate that polytank storage is the most viable, followed by

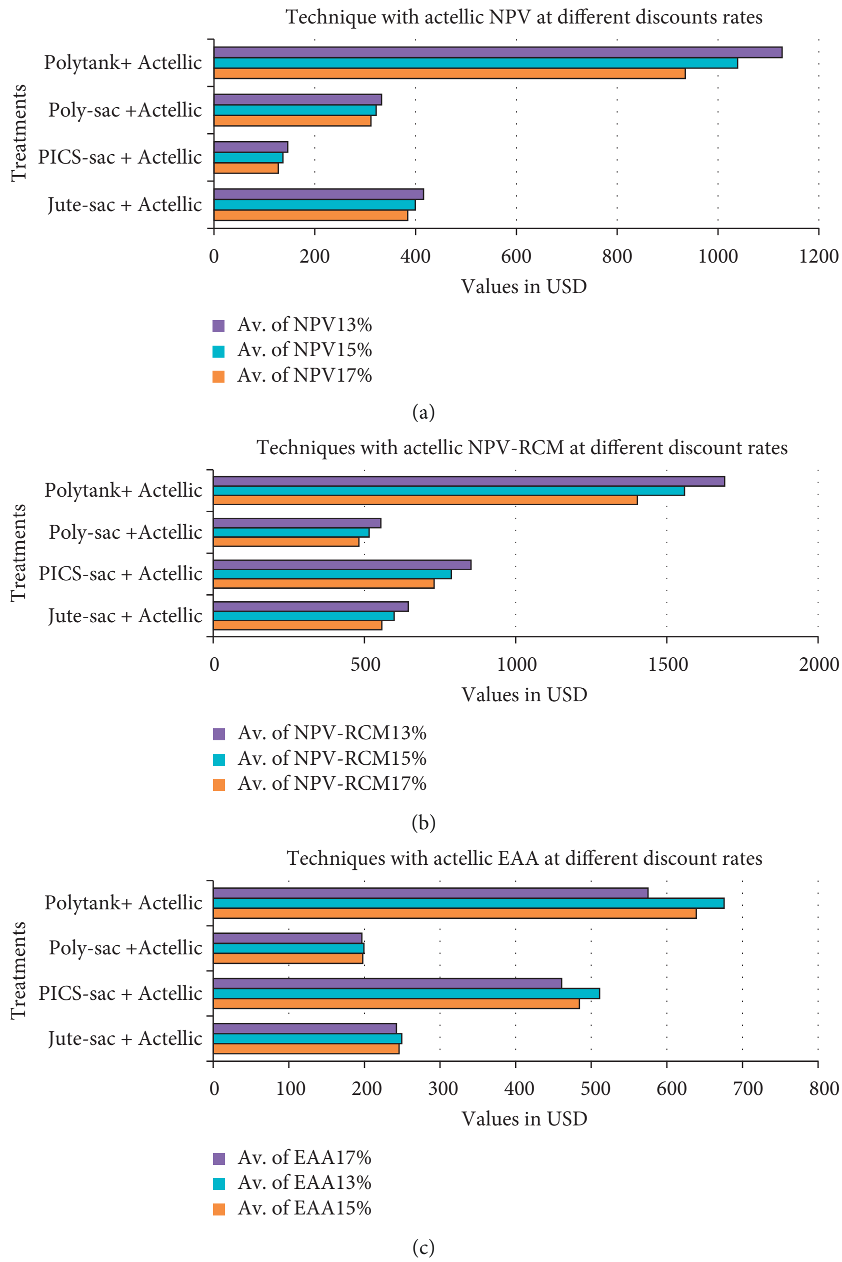


Figure 5: Performance of storage techniques treated with Actellic Supper in maize storage.

jute sacks when investment lifespan is not controlled, and PICS sack is the least viable technique under maize storage; see Figure 4(a). This trend was, however, different when the lifespan of the investment was controlled (NPV-RCM and EAA). Polytank was the most viable, followed by PICS sacks, and then jute sacks came third, with poly sacks recording the least discounted values (Figures 4(b) and 4(c)). This implies that polytank and PICS sacks even without chemical treatment and at a high discount rate are still economically viable and found to be appropriate storage techniques for maize, consistent with the works of [28, 56, 57, 61].

This implies that chemical protectants can be avoided when using PICS and polytank for maize storage. This is very important as it can help reduce the health and environmental risk associated with using chemicals in grain storage [55, 62, 63]. Chemical protectants should only be used by trained persons, and product use instructions should be meticulously adhered to in order to prevent the health and environmental risk it could pose. This should be completely avoided as much as possible.

3.1.4. Evaluation of Storage Techniques Treated with Actellic Supper and Phostoxin in Maize Storage. The storage techniques were compared when treated with actellic to assess the effect of actellic on the economic viability of the storage techniques and how they are affected under different discount rates. The storage techniques treated with actellic

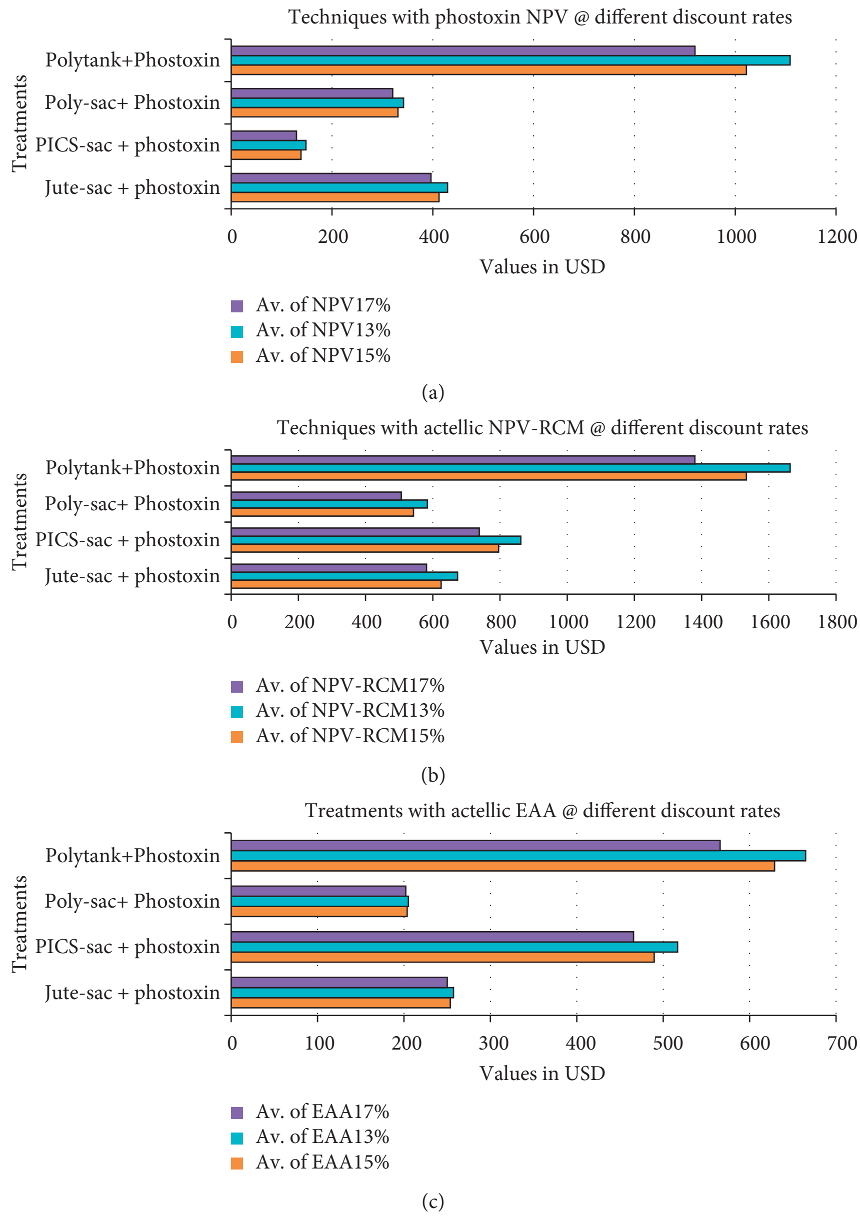


Figure 6: Performance of storage techniques treated with Phostoxin in maize storage.

under the NPV approach using 13, 15, and 17% discount rates indicate that polytank storage was the most viable, followed by jute sacks, and PICS sacks recorded the least discounted net benefit. This trend is, however, different under NPV-RCM and EAA approaches, where polytank storage was most economically viable, followed by PICS sacks, then jute sacks with poly sacks recording the least discounted net value. Polytank and PICS with actellic treatment all performed better than jute and poly sacks under maize storage; for more details, refer to Figure 5. This result is similar when treated with phostoxin, as shown in Figure 6. This result is not significantly different from when there was no chemical treatment. It is therefore advised that chemical treatment can be avoided without compromising the economic viability of PICS and polytank storage techniques in maize storage. Chemical treatments possess health and environmental risk, especially when not properly handled [55, 62, 63], showing that chemicals have regularly been misused by farmers and merchants.

From the maize storage evaluation, the discounted net present value of jute sacks, PICS sacks, polytanks, and poly sacks at different treatment levels and different discount rates all yielded positive NPVs. However, the trend of ranking from the NPV approach was different from NPV-RCM and EAA approaches which accounts for the differences in technique lifespan. The NPV-RCM and EAA approaches rank polytank technique as the most viable, followed by PICS, then jute sacks, and lastly poly sacks. This implies that polytank will yield higher returns on investment than PICS sacks. However, PICS sacks will also yield higher returns than jute sacks. The first storage option should be polytank when available based on our data when storing maize in bulk.

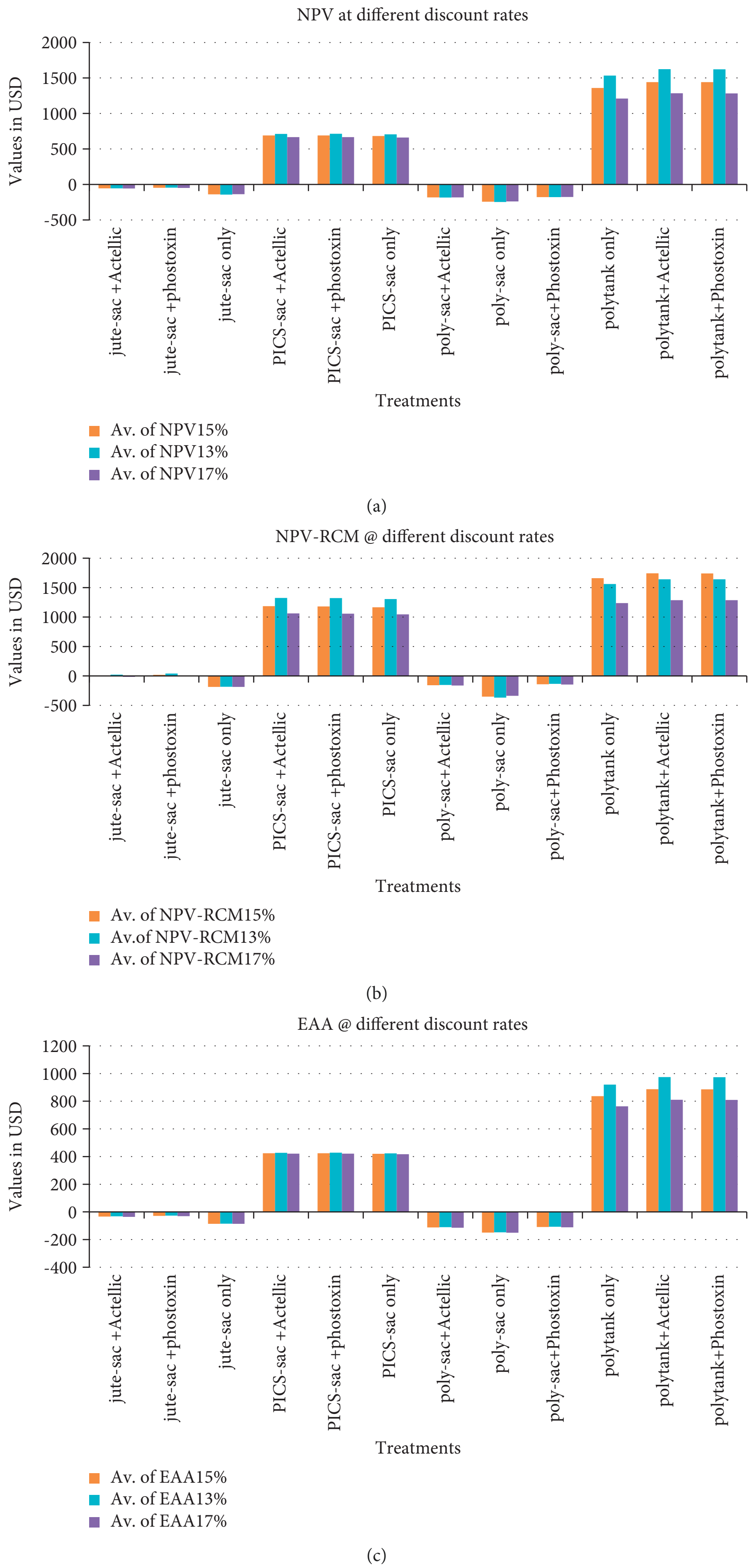
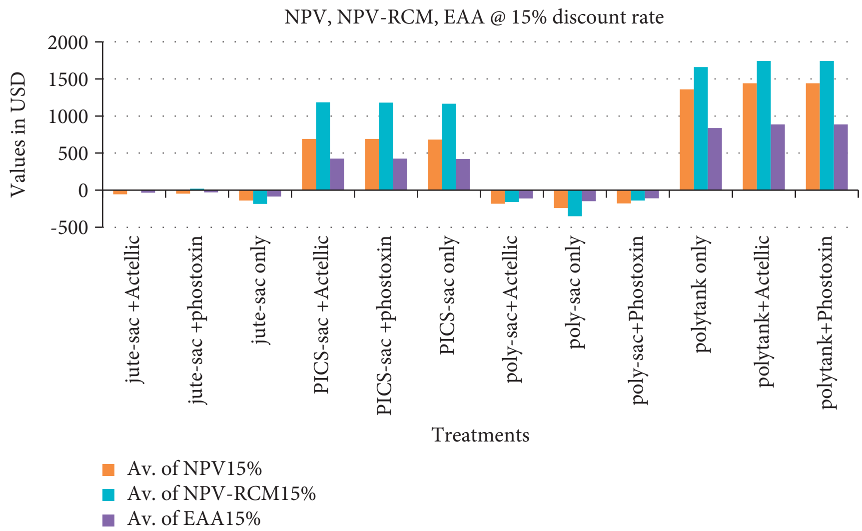
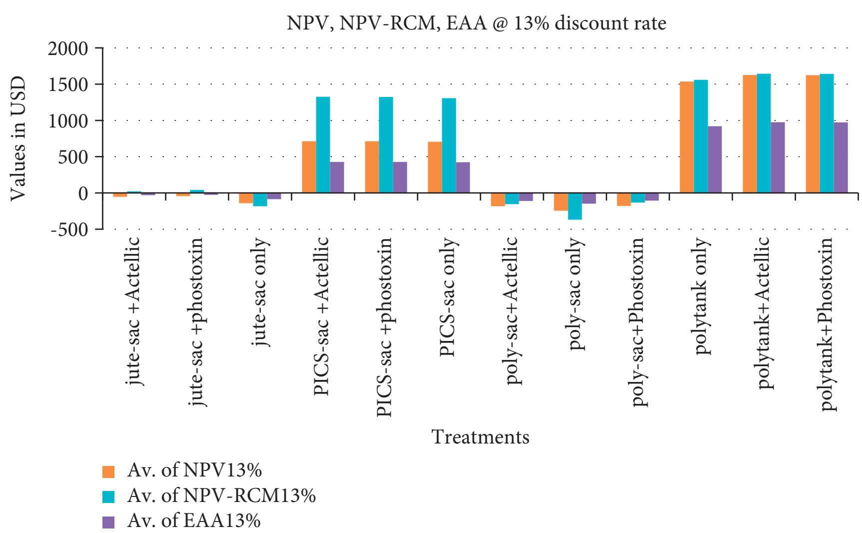


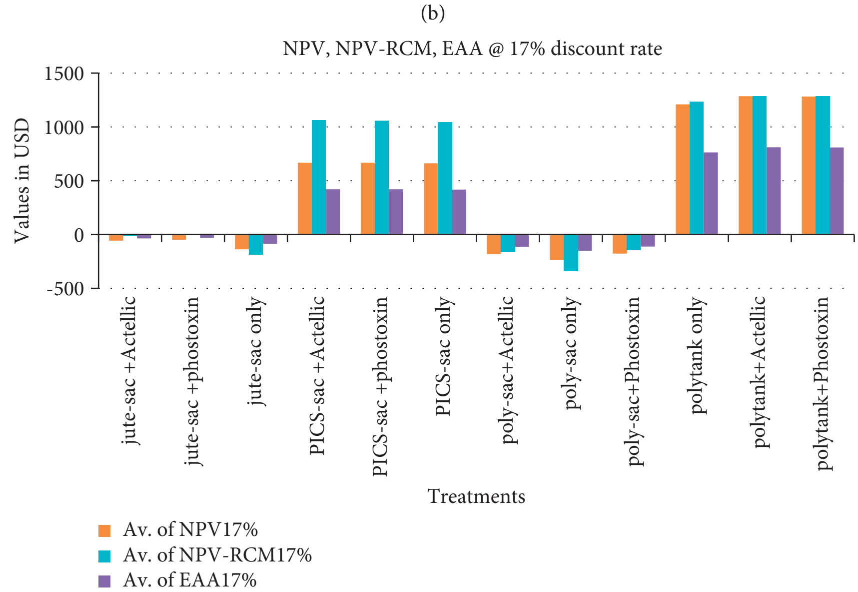
Figure 7: NPV, NPV-RCM, and EAA of cowpea storage at different discount rates.



(a)



(b)



(c)

Figure 8: NPV, NPV-RCM, and EAA at a discount rate of 15%, 13%, and 17%.

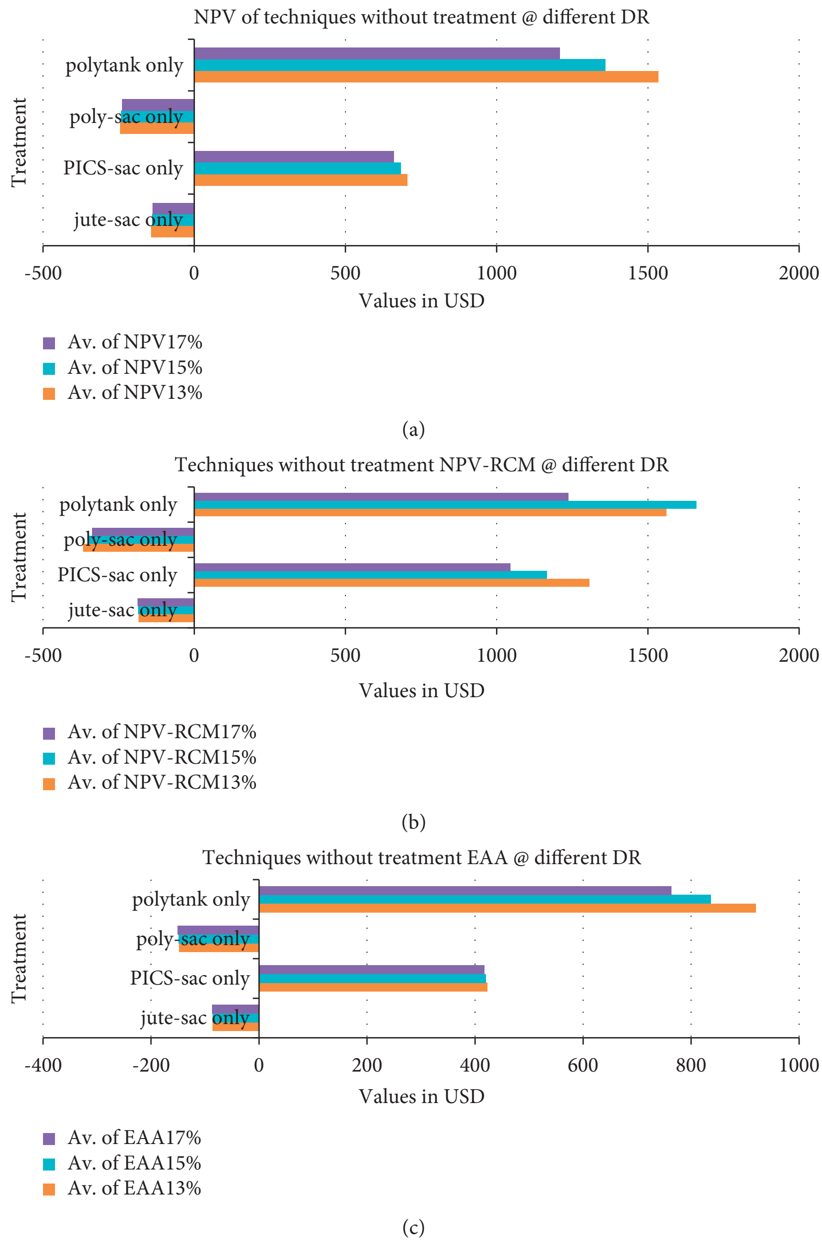


Figure 9: Techniques without treatment NPV, NPV-RCM, and EAA at different DR.

3.2. Cowpea Storage

3.2.1. Estimated Discounted Net Benefits under the Three Approaches. Considering the evaluation under cowpea storage, the storage techniques that returned a positive stream of discounted net present values under the three evaluation methods (NPV, NPV-RCM, and EAA) are polytank and PICS sacks; this is supported by the findings of [64–66] on cowpea storage using PICS sack. Jute sacks and poly sacks all returned negative NPVs, as shown in Figure 7. The positive NPVs of PICS and polytank storage techniques mean that they will be profitable when used to store cowpea in bulk. However, polytank is more profitable than PICS, similar to the maize storage results in this study. The negative NPVs of poly sacks and jute sacks mean that they will not be profitable when used to store cowpea for a long period of time (about 1 year). The best storage options for cowpea storage are polytank and PICS sacks.

3.2.2. Comparing the Three Evaluation Approaches in Cowpea Storage. Storage in polytank and PICS sacks yielded positive NPVs under the three different approaches used to evaluate the technologies (NPV, NPV-RCM, and EAA) across the three discount rates, similar to findings by [65, 66]. Contrary to this, poly sacks and jute sacks technique recorded negative NPVs under the three different approaches used to measure NPV across the different discounts (Figure 8(a)–8(c)), implying that they are not suitable for long-term (1 year and above) storage of cowpea [67, 68].

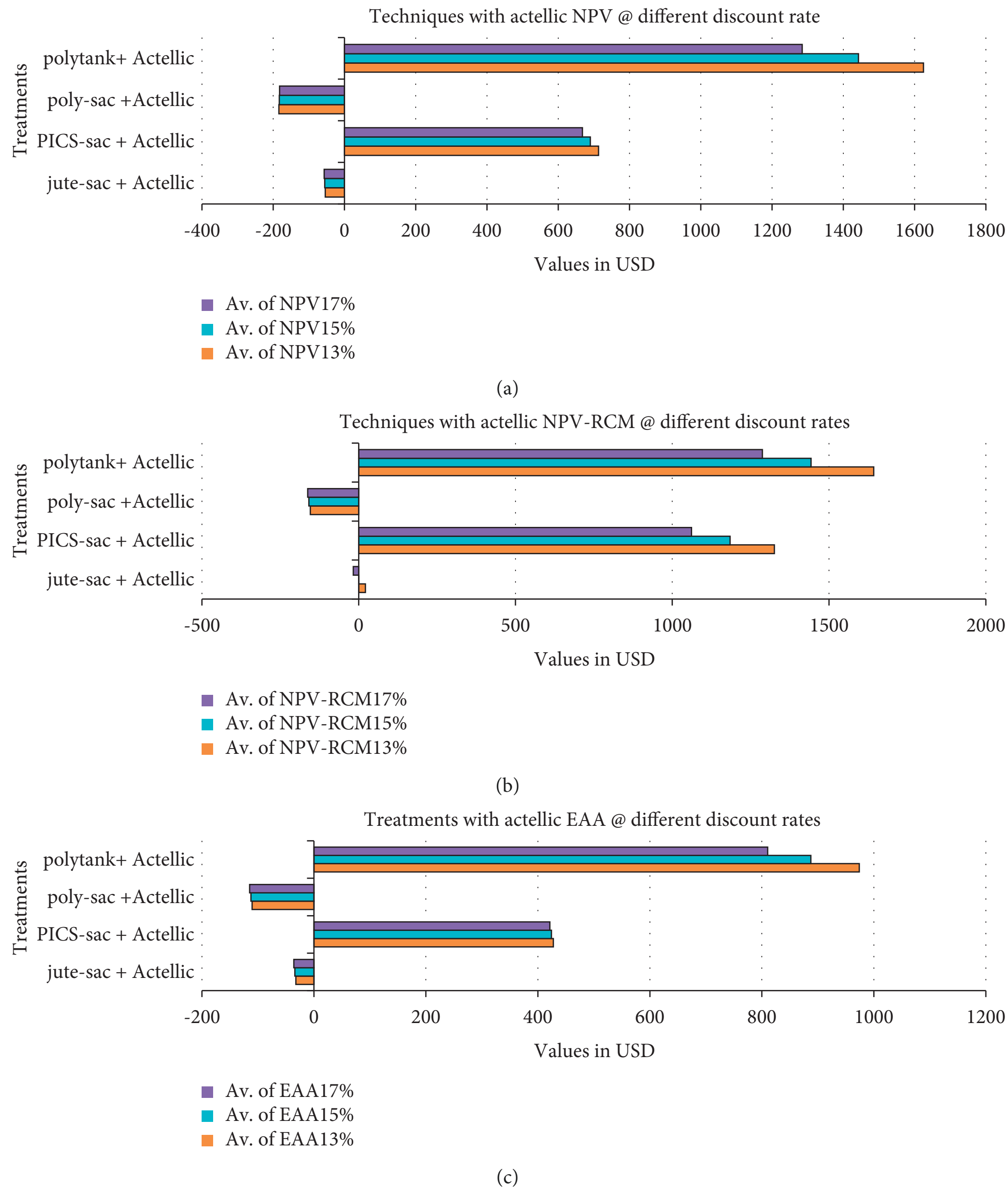
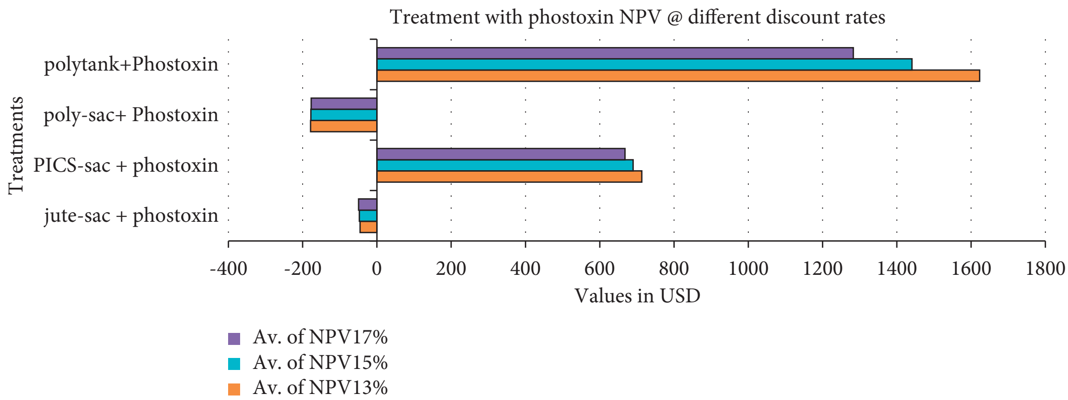


Figure 10: Performance of storage techniques treated with Actellic Supper in cowpea.

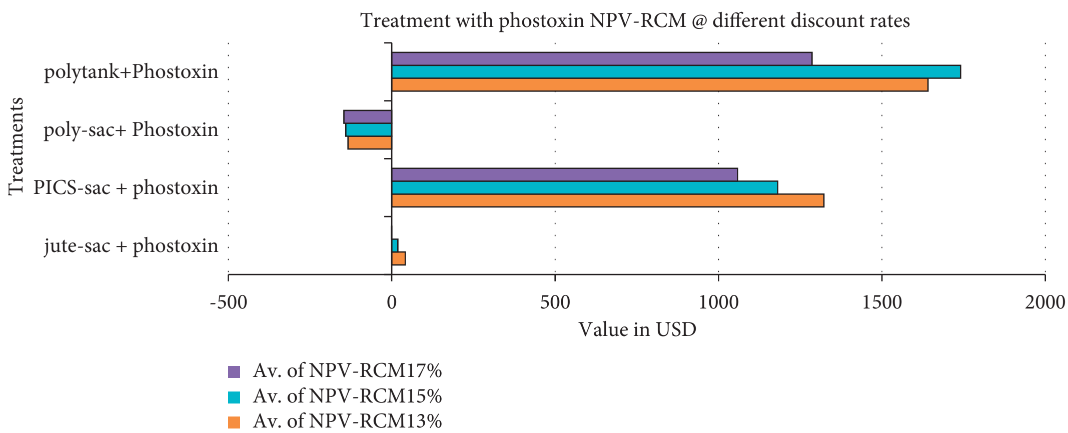
The main effect of storage techniques without chemical treatment under the NPV estimated without controlling differences in lifespans at 13, 15, and 17% discount rates indicates that the polytank technique was the most viable, followed by PICS sacks. Jute sacks and poly sacks both recorded negative NPV (Figure 9(a)). This trend was similar under NPV-RCM and EAA estimates (Figures 9(b) and 9(c)), respectively. This clearly demonstrates that cowpea is better stored in polytanks followed by PICS sacks and aligns with the findings of [65, 66].

3.2.3. Evaluation of Storage Techniques Treated with Actellic and Phostoxin in Cowpea Storage. This is aimed at assessing the effect of actellic and phostoxin chemical treatment on the economic viability of the storage techniques in cowpea storage. Storage techniques treated with Actellic Supper under the NPV estimation approach at 13, 15, and 17% discount rates indicated that the polytank technique was the most viable, followed by PICS sacks [28, 69]. Jute sacks and poly sacks both recorded negative NPV. This result is similar under NPV-RCM and EAA estimates. This indicates that, even under actellic treatment, polytank is still the most economically viable storage technique, followed by PICS (see Figure 10 for more details). The trend is similar under phostoxin treatment, and details can be seen in Figure 11.

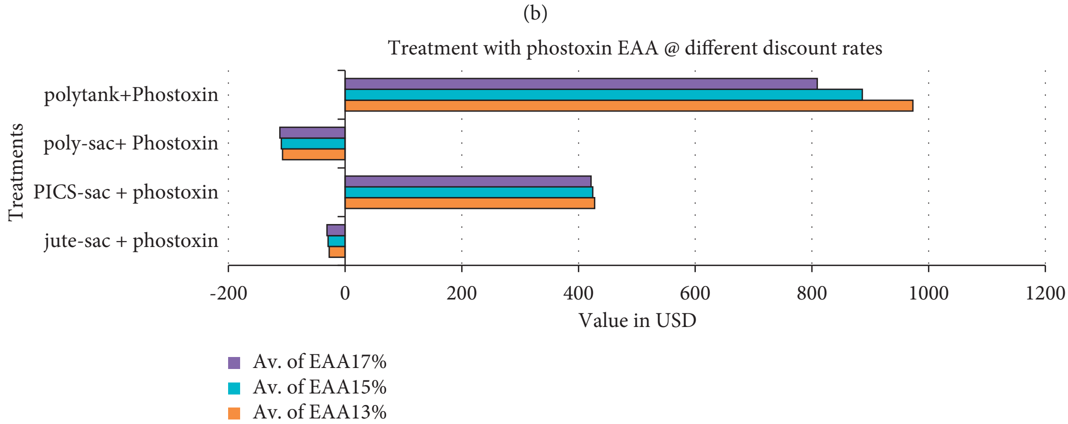
Cowpea storage evaluation clearly demonstrates that discounted net present value of PICS sacks and polytanks



(a)



(b)



(c)

Figure 11: Performance of storage techniques treated with Phostoxin in cowpea.

at different treatment levels and different discount rates all yielded positive discounted net benefits implying that they are profitable. However, jute sacks and poly sacks techniques both yielded negative discounted net benefits similar to the work of [70]. The NPV-RCM and EAA approaches rank polytank technique as the most viable followed by PICS. This clearly demonstrates that jute sacks and poly sacks are not suitable for cowpea storage, especially under long-term storage, even under chemical treatment.

4. Conclusion and Recommendations

Under maize storage, the net present value of jute sacks, PICS sacks, polytanks, and poly sacks at different treatment combinations and different discount rates recorded positive NPVs. However, the trend of ranking of NPV estimates where investment life is not controlled was different from that of the NPV-RCM and EAA, which accounts for the differences in investment lifespan. Both approaches (NPV-RCM and EAA) ranked the polytank technique as the most viable, followed by PICS and lastly jute sacks, irrespective of whether there is chemical treatment or not. Evaluation under cowpea storage revealed that polytank was the most viable storage, which is followed by the PICS storage technique. This trend was consistent across the NPV-RCM and EAA approaches at 13%, 15%, and 17% discount rates. Therefore, where farmers have the capacity to use polytanks for storage, it should be the most preferred storage technique as it was the most economically viable during the 12 months of storage under both maize and cowpea storage. A similar recommendation applies to PICS sacks for both maize and cowpea storage under 12 months storage which is supported by findings from Africa [56, 71, 72]. Polytank will yield the highest profit compared to PICS though they are both profitable and recommended for both maize and cowpea bulk storage, as supported by this study results. Jute and poly sacks are the only recommendations for short-duration storage of cowpea (period less than four months after harvest, and 6–8 months after harvest for maize storage). There is no significant effect of the chemical application on the economic viability of the technologies; hence, the chemical application should be avoided as much as possible.

Data Availability

The experimental data used to support the findings of this study are available from the corresponding author (JKB) upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors wish to acknowledge the financial support of the United States Department of Agriculture (USDA) Scientific Cooperation Research Program. They want to extend their gratitude to North Carolina, A&T State University, for their collaboration in carrying out this work.

References

[1] FAO, *Grain Storage Techniques: Evolution and Trends in Developing Countries*, FAO Agricultural Services Bulletin 109, Rome, Italy, 1994.

[2] R. J. Hodges, "Post-harvest weight losses of cereal grains in sub-Saharan Africa Available from," 2012, http://www.erails.net/FARA/aphlis/aphlis/weightlosses-review/.

[3] B. Sawicka, "Postharvest losses of agricultural produce," 2019, https://www.sciencedirect.com/science/article/pii/S2666188821000071.

[4] N. Mhlanga, E. Seidler, D. Njie et al., "FAO/World Bank workshop on reducing post-harvest losses in grain supply chains in Africa," *Lessons Learned and Practical Guidelines*, pp. 18-19, FAO Headquarters, Rome, Italy, 2010.

[5] D. Prusky, "Reduction of the incidence of postharvest quality losses, and future prospects," *Food Security*, vol. 3, no. 4, pp. 463–474, 2011.

[6] M. De Lucia and D. Assennato, *Agricultural engineering in development: post-harvest operations and management of foodgrains*, FAO, Rome, Italy, 2006.

[7] A. Obiedzińska, "Wpływ strat i marnotrawstwa żywności na bezpieczeństwo żywnościowe," *Zeszyty Naukowe SGGW W Warszawie - Problemy Rolnictwa Światowego*, vol. 17, no. 32, pp. 125–141, 2017.

[8] W. Bank Report, "Responding to Global Food Price Volatility and its Impact on Food Security," 2011, https://documents.worldbank.org/en/publication/documents-reports/documentdetail/426561468336325684/responding-to-global-food-price-volatility-and-its-impact-on-food-security-chairmans-summing-up.

[9] M. O. Adetunji, "Determinants of the use of maize storage techniques by farmers in Kwara State, Nigeria," *Journal of New Seeds*, vol. 10, no. 1, pp. 31–40, 2009.

[10] J. M. Thamaga-Chitja, S. L. Hendriks, G. F. Ortmann, and M. Green, "Impact of maize storage on rural household food security in Northern Kwazulu-Natal," *Journal of Consumer Sciences*, vol. 32, 2004.

[11] T. Abdoulaye, J. H. Ainembabazi, C. Alexander et al., "Postharvest loss of maize and grain legumes in sub-Saharan Africa: insights from household survey data in seven countries," in *Purdue Extension Agricultural Economics EC-807-W*Purdue University, West Lafayette, IN, USA, 2016.

[12] G. B. S. Maia, A. D R. Pinto, C. Y. T. Marques, D. D. Lyra, and F. B. Roitman, "Overview of the storage of agricultural products in Brazil," *Rev. of BNDES*, vol. 40, pp. 161–194, 2013.

[13] O. A. de Oliveira, C. Grzebieluckas, A. R. da C. Nascimento, and T. V. Maldonado, "Soybean storage costs: what is the best strategy, selling in the crop or armazenar," *Custos e @gronegócio line*, vol. 12, pp. 265–281, 2016.

[14] S. Frederico, "The modern agricultural frontier and logistics : the importance of the soybean and grain storage system in Brazil," *Terrae*, vol. 8, pp. 26–34, 2011.

[15] M. T. O. Patino, M. F. Machado, G. T. do Nascimento, and M. R. de Alcantara, "Analysis and forecast of the storage needs of soybeans in Brazil," *Engenharia Agrícola*, vol. 33, no. 4, pp. 834–843, 2013.

[16] R. Strahan and J. Page, "Economics of on-farm grains storage and drying," 2003, https://www.abare.gov.au/publications_html/crops/crops_06/GM_grains.pdf.

[17] C. B. Barrett, M. R. Carter, and C. P. Timmer, "A century-long perspective on agricultural development," *American Journal of Agricultural Economics*, vol. 92, no. 2, pp. 447–468, 2010.

[18] E. C. Stephens and C. B. Barrett, "Incomplete credit markets and commodity marketing behaviour," *Journal of Agricultural Economics*, vol. 62, no. 1, pp. 1–24, 2010.

[19] D. Kumar and P. Kalita, "Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries," *Foods*, vol. 6, no. 1, p. 8, 2017.

[20] Cta, *Analysis of the Postharvest Knowledge System in Ghana Case Study of Cassava*, https://knowledge.cta.int/, 2014.

[21] FAO, *Food Loss Prevention in Perishable Crops*, FAO Agricultural Services Bulletin, Rome, Italy, 1981.

[22] GIZ – Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, "Reducing postharvest losses conserves natural resources and saves money," *Report of GFFA Expert Panel Discussion Held*, 2013.

[23] SRID, "Statistic Research and Information Department of the Ministry of Food and Agriculture," 2011, https://www.sesric.org/sesric-department-statistics.php.

[24] FAO, *Food Agriculture Organization Statistics*, FAO, Rome, Italy, 2013.

[25] D. Obeng-Ofori, “Major stored product arthropod pests,” in *Post-Harvest Science and Technology*, E. W. Cornelius and D. Obeng-Ofori, Eds., pp. 67–91, Smartline Publishing Limited, Accra, 2008.
[26] I. Sugri, “Review of crop storage practices and estimate of postharvest losses in Upper East Region of Ghana,” in *Annual Report of CSIR-Savanna*Agriculture Research Institute, Tamale, Ghana, 2010.
[27] Alliance for a Green Revolution in Africa Report, *Establishing the Status of Post-harvest Losses and Storage for Major Staple Crops in Eleven African Countries (Phase I)*, AGRA, Nairobi, Kenya, 2013.
[28] I. Sugri, M. Abubakari, R. K. Owusu, and J. K. Bidzakin, “Postharvest losses and mitigating technologies: evidence from Upper East Region of Ghana,” *Sustainable Futures*, vol. 3, Article ID 100048, 2021.
[29] K. D. Ileke and O. F. Olotuah, “Bioactivity of anacardium occidentale (L) and allium sativum (L) powders and oils extracts against cowpea bruchid, callosobruchus maculatus (fab.) [Coleoptera: chrysomelidae],” *International Journal of Biology*, vol. 4, no. 1, p. 96, 2011.
[30] I. B. Baoua, V. Margam, L. Amadou, and L. L. Murdock, “Performance of triple bagging hermetic technology for postharvest storage of cowpea grain in Niger,” *Journal of Stored Products Research*, vol. 51, pp. 81–85, 2012.
[31] A. B. Abass, M. Fischler, K. Schneider et al., “On-farm comparison of different postharvest storage technologies in a maize farming system of Tanzania Central Corridor,” *Journal of Stored Products Research*, vol. 77, pp. 55–65, 2018.
[32] K. Dick, *A Review of Insect Infestation of Maize in Farm Storage in Africa with Special Reference to the Ecology and Control of Prostephanus Truncatus*, Overseas Development Natural Resources Institute, Chatham, UK, 1988.
[33] M. E. H. Shazali and M. A. Ahmed, “Assessment and reduction of losses in sorghum stored in traditional mud bins in Sudan,” *Tropical Science*, vol. 38, Article ID 155e160, 1998.
[34] I. Melo, M. Costa, J. K. Braz, and O. Guerra, “Integrated postharvest practices to reduce losses in maize storage for smallholders,” in *Advances and Trends in Agricultural Sciences*vol. 2, pp. 54–62, (2019).
[35] Y. Osei-Agyeman, S. K. Nutsugah, J. M. Komkiok, I. Sugri, J. K. Bidzakin, and C. Naanwaab, *Containing Productivity Increases of Maize in Ghana through Large-Scale Storage Methods*, pp. 1–23, Annual Report of the USDA/North Carolina A&T State Univ., and CSIR-Savanna Agricultural Research Institute, Ghana and USDA- SCRP Project, 2014.
[36] J. M. Argilés, “Accounting information and the prediction of farm non-viability,” *European Accounting Review*, vol. 10, no. 1, pp. 73–105, 2001.
[37] J. P. Aubin, A. M. Bayen, and P. Saint-Pierre, *Viability Theory*, Springer Berlin Heidelberg, Berlin, Germany, 2 edition, 2011.
[38] R. P. King, M. Boehlje, M. L. Cook, and S. T. Sonka, “Agribusiness economics and management,” *American Journal of Agricultural Economics*, vol. 92, no. 2, pp. 554–570, 2010.
[39] J. P. Gittinger, *Economic Analysis of Agricultural Projects*, The World Bank, Washington, DC, USA, 1982.
[40] R. A. Brealey and S. C. Myers, *Principles of Corporate Finance*, McGraw-Hill, New York, NY, USA, 2000.
[41] Department of Treasury and Finance, *Economic Evaluation for Business Cases Technical Guidelines, Department of Treasury and Finance*, McGraw-Hill/Irwin, New York, NY, USA, 2013.
[42] S. A. Ross, R. W. Westerfield, and B. D. Jordan, *Essentials of Corporate Finance*, 7th edition, 2011.
[43] P. A. Ryan and G. P. Ryan, “Capital budgeting practise of the fortune 1000: how have things changed,” *Journal of Business*, 2002.
[44] V. Chiesa and F. Fratini, “Evaluation and Performance Measurement of Research and Development: Techniques and Perspectives for,” 2009, https://www.researchgate.net/publication/239769367_Evaluation_and_Performance_Measurement_of_Research_and_Development_Techniques_and_Perspectives_for_MultiLevel_Analysis_By_Vittorio_Chiesa_and_Federico_Frattini.
[45] T. Copeland, T. Koller, and J. Murrin, *Valuation: Measuring and Managing the Value of Companies*, John Wiley, Hoboken, NJ, USA, 2010.
[46] P. A. Harou, “Economic principles to appraise agro-forestry projects,” *Agricultural Administration*, vol. 12, no. 3, pp. 127–139, 1983.
[47] A. Boardman, D. Greenberg, A. Vining, and D. Weimer, *Cost-benefit Analysis*, Pearson New International Edition PDF eBook. Pearson Higher, London, UK, 2013.
[48] Commonwealth of Australia, “Handbook of cost-benefit analysis,” *Financial Management Reference Material No. 6*, Department of Finance and Administration, Canberra, Australia, 2006.
[49] D. L. Talavera, E. Munoz-Ceron, J. de la Casa, M. J. Ortega, and G. Almonacid, “Energy and economic analysis for large-scale integration of small photovoltaic systems in buildings: the case of a public location in Southern Spain,” *Renewable and Sustainable Energy Reviews*, vol. 15, no. 9, pp. 4310–4319, 2011.
[50] D. L. Talavera, G. Nofuentes, J. De La Casa, and J. Aguilera, “Sensitivity analysis on some profitability indices for photovoltaic grid–connected systems on buildings: the case of two top photovoltaic European areas,” *Journal of Solar Energy Engineering*, vol. 135, no. 1, 2013.
[51] N. Casarotto Filho and B. H. Kopittke, *Investment Analysis: Financial Mathematics, Economic Engineering, Decision Making, Business Strategy*, Atlas, Sao Paulo, Brazil, 11th edition, 2010.
[52] L. J. Gitman, *Principles of Financial Administration*, 7th edition, 2002.
[53] I. Sugri, O.-A. Yeboah, J. K. Bidzakin, C. Naanwaab, S. K. Nutsugah, and J. M. Kombiok, *Participatory On-Farm Evaluation of Some Storage*, 2014.
[54] G. T. Alemu, Z. Nigussie, N. Haregeweyn et al., “Cost-benefit analysis of on-farm grain storage hermetic bags among small-scale maize growers in northwestern Ethiopia,” *Crop Protection (Guildford, Surrey)*, vol. 143, Article ID 105478, 2021.
[55] D. Baributsa, J. Lowenberg-DeBoer, L. Murdock, and B. Moussa, “Profitable chemical-free cowpea storage technology for smallholder farmers in Africa: opportunities and challenges,” *Gates Open Research*, vol. 3, no. 853, 2019.
[56] M. K. Ndegwa, H. De Groote, Z. M. Gitonga, and A. Y. Bruce, “Effectiveness and economics of hermetic bags for maize storage: results of a randomized controlled trial in Kenya,” *Crop Protection*, vol. 90, pp. 17–26, 2016.
[57] P. Ngwenyama, B. M. Mvumi, T. E. Stathers, L. K. Nyanga, and S. Siziba, “How different hermetic bag brands and maize varieties affect grain damage and loss during smallholder farmer storage,” *Crop Protection*, vol. 153, Article ID 105861, 2022.
[58] I. B. Baoua, L. Amadou, and L. L. Murdock, “Triple bagging for cowpea storage in rural Niger: questions farmers ask,” *Journal of Stored Products Research*, vol. 52, pp. 86–92, 2013.

[59] R. Anderson, "Systematic reviews of economic evaluations: utility or futility," *Health Economics*, vol. 19, no. 3, pp. 350–364, 2010.

[60] J. M. Chen, "Beta's cash flow and discount rate components," *Econophysics and Capital Asset Pricing*, pp. 175–187, 2017.

[61] I. Sugri, O. A. Yeboah, J. K. Bidzakin, C. Naanwaab, S. K. Nutsugah, and J. M. Kombiok, "Participatory on-farm evaluation of some storage methods and grain protectants on quality characteristics of maize (Zea mays L.)," *American Journal of Experimental Agriculture*, vol. 4, no. 11, pp. 1268–1279, 2014.

[62] J. T. Snelson, "Safety considerations in insecticide usage in grain storage," *Pesticides and Humid Tropical Grain Storage Systems ACIAR Proceedings*, no. 14, pp. 87–100, 1985.

[63] N. D. White and J. G. Leesch, "Chemical control," in *Integrated Management of Insects in Stored Products*, pp. 287–330, CRC Press, Boca Raton, FL, USA, 2018.

[64] F. Ademang Korletey, "Assessment of the Polytank for Fumigation and Storage of Cowpea," 2009, http://docplayer.net/14544218-Assessment-of-the-polytank-for-fumigation-and-storage-of-cowpea.html.

[65] T. Mesele, K. Dibaba, C. A. Garbaba, and E. Mendesil, "Effectiveness of different storage structures for the management of Mexican bean weevil, Zabrotes subfasciatus (Boheman) (Coleoptera: bruchidae) on stored common bean, Phaseolus vulgaris L. (Fabaceae)," *Journal of Stored Products Research*, vol. 96, Article ID 101928, 2022.

[66] M. I. Vales, G. Ranga Rao, H. Sudini, S. B. Patil, and L. L. Murdock, "Effective and economic storage of pigeonpea seed in triple layer plastic bags," *Journal of Stored Products Research*, vol. 58, pp. 29–38, 2014.

[67] S. R. Babu, S. V. S. Raju, R. Dhanapal, and K. R. Sharma, "Storage of chickpea grains *Cicer arietinum* (L.) in triple layer bags prevent losses caused by *Callosobruchus maculatus* (F.) (Coleoptera: chrysomelidae) under laboratory conditions," *Journal of Stored Products Research*, vol. 88, Article ID 101685, 2020.

[68] G. T. Odamtten and E. H. Kampelmacher, "Influence of packaging material on moisture sorption and the multiplication of some toxigenic and non-toxigenic Aspergillus spp. infecting stored cereal grains, cowpea and groundnut," *International Journal of Food Microbiology*, vol. 3, no. 2, pp. 57–70, 1986.

[69] C. Mutungi, H. D. Affognon, A. W. Njoroge, J. Manono, D. Baributsa, and L. L. Murdock, "Triple-layer plastic bags protect dry common beans (Phaseolus vulgaris) against damage byAcanthoscelides obtectus (Coleoptera: chrysomelidae) during storage," *Journal of Economic Entomology*, vol. 108, no. 5, pp. 2479–2488, 2015.

[70] F. Falayi, "Comparative study of cowpea stored in different household storage materials," *Current Trends in Technology and Science*, vol. 6, pp. 779–783, 2017.

[71] D. Baributsa, T. Abdoulaye, J. Lowenberg-DeBoer et al., "Market building for post-harvest technology through large-scale extension efforts," *Journal of Stored Products Research*, vol. 58, pp. 59–66, 2014.

[72] W. I. F. A. D. Fao, *Food Loss Analysis: Causes and Solutions-Case Study on the Maize Value Chain in the Federal Democratic Republic of Ethiopia*, Food and Agriculture Organization of the United Nations, Rome, Italy, 2018.