Agricultural Sciences, 2022, 13, 989-1011
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Grain Hermetic Storage Adoption in Northern Uganda: Awareness, Use, and the Constraints to Technology Adoption

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How to cite this paper: Okori, F., Cherotich, S., Abaca, A., Baidhe, E., Adibaku, F. and Onyinge, J.D. (2022) Grain Hermetic Storage Adoption in Northern Uganda: Awareness, Use, and the Constraints to Technology Adoption. *Agricultural Sciences*, **13**, 989-1011.
https://doi.org/10.4236/as.2022.139061

Received: May 20, 2022
Accepted: September 12, 2022
Published: September 15, 2022

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Abstract

Post-harvest storage losses (PHLs) remain significant in Sub-Saharan Africa (SSA) due to several factors mainly insect pests and molds. Hermetic storage technologies (HSTs) are being promoted to address these storage losses. In Uganda, HSTs were first introduced in 2012. However, its use among farming households remains low today. Data were collected from 306 smallholder farmers from four districts of Northern Uganda using a pre-tested semi-structured questionnaire to understand their knowledge, use, and constraints to the adoption of hermetic storage. A multivariate Logit regression model was used to find the significance of the factors affecting adoption. Results showed low awareness and use of hermetic storage among smallholder farmers. Only 53.3% of the interviewed farmers were aware of the use of hermetic storage for grain storage. The SuperGrain bag was the most known form of hermetic storage (35.3%), followed by the Purdue Improved Crop Storage (PICS) bag (34.9%), metallic silo (15.5%), and plastic silo (14.4%). Hermetic storage use was even lower as only 17.6% of the surveyed farmers were using one or more forms of hermetic storage to store their grains. Insect pest management without chemical insecticides was the main reason (83.1%) for hermetic storage use. About 75.5% of those aware of hermetic storage had received training in the technology. Hermetic storage use in farming households led to improved food availability, household income, and nutrition. Lack of local availability (50.2%), high costs (37.8%), and inadequate knowledge (6.9%) were the main constraints hindering the adoption of hermetic storage in Northern Uganda. The logit regression models showed that only training in hermetic storage significantly ($p = 0.002$) affected farmers' decision to adopt hermetic storage. Understanding the factors that constrain the adoption of HSTs could provide policymakers with important information to initiate and design policies and programs aimed at reducing crop storage losses.

Keywords

Grain Crops, Post-Harvest Storage Losses, Hermetic Storage, Smallholder Farmers, Food Security

1. Introduction

The goal of feeding the global population by 2050 has drawn the interest of world leaders, philanthropists, and development partners alike. According to projections, global food output will need to increase by up to 70% from current levels by 2050 to guarantee future food demands [1] [2] [3]. This projection is a concern because 957 million people currently do not have enough food to eat, with 239 million out of these requiring life-saving humanitarian assistance [4]. While the population of developed countries will remain stable or even decline, developing countries will have a high population growth rate causing a substantial increase in food demand [2] [5] [6]. This predicament is exacerbated by the fact that previous international agricultural development efforts tended to concentrate on addressing concerns related to boosting crop production and productivity [7], with issues to do with post-harvest management receiving little to no attention [5]. Crop post-harvest management only started gaining attention recently due to the high magnitude of reported PHLs and the realization of its immense contributions to food security, health, and farming household incomes.

Grain PHLs in SSA are mainly caused by insect pests and mycotoxin contamination [8] [9] [10]. These pose a substantial food security threat as they cause significant quantitative and qualitative losses of otherwise edible grains [11] [12] [13]. Globally, approximately one-third of the food produced for human consumption is lost or wasted annually post-harvest [14]. This quantity of food loss equates to the annual worth of cereal imports to SSA and exceeds the value of food aid supplied to SSA in a decade [15] [16]. Food that is lost or squandered on its way to consumption signifies a waste of resources in terms of land, labor, water, and other resources used to produce the food in vain [17] [18]. Because of the criticality of post-harvest food loss reduction, the 2030 Sustainable Development Goals (SDGs) emphasize raising global awareness of the issue. Target 12.3 of the SDGs calls for halving the global per capita food waste by 2030 and reducing food losses in the production and supply chains [19].

Grain PHLs during storage are estimated to be high, with dry weight losses reaching up to 30% [20] [21], but can be higher when considered together with quality losses [22] [23]. Insects, rodents, and molds are the leading causes of grain storage losses [23] [24]. One of the factors contributing to high grain storage losses is the vulnerability of existing traditional storage methods. High costs, lack of information and knowledge on use, and limited access to credit hinder smallholder farmers' access to effective storage technologies [25] [26]. Many smallholder farmers often opt to sell their produce to grain traders shortly after harvest due to a lack of confidence in the ability of their storage technologies to protect their stored grains [12] [22]. Regrettably, this is the time when grain prices are at their lowest. This is made worse by the fact that farmers have to buy grains from the traders during lean seasons at often relatively higher prices than sold to meet their household food needs. Among other factors, this has caused many smallholder farmers to live in a vicious cycle of poverty. When grains are not sold immediately after harvest, smallholder farmers employ synthetic insecticides to control insect pests in stored grains [27] [28]. Synthetic pesticides, however, have several drawbacks including high costs and associated dangers to consumer health and the environment [29] [30]. Besides, the protective action of synthetic pesticides is known to wear over time, allowing pest re-infestation to occur [31]. Due to these, alternative safe, cost-effective, and sustainable grain storage systems are required.

In Uganda, grain storage contributes significantly to smallholder farmers' food security and household income as farming is the main economic activity yet the gap between one harvest and another can extend for longer than six to nine months. The woven polypropylene (PP) bag is the most common form of grain storage in Uganda used by more than 73% of farming households [22], yet it is ineffective in protecting grains from storage losses. Farmers need storage technologies that are sustainable, cost-effective, and easy to use to be successful [32]. In the quest for better grain storage, HSTs have proven effective in matching most of these requirements. Hermetic storage bags and metallic and plastic silos of various forms and sizes are among the HSTs extensively promoted and marketed in East Africa. There is a wealth of literature on the protective efficacy of different HSTs for grain storage [30] [31] [33] [34] [35] [36] [37].

The United Nations World Food Programme (WFP) implemented a Special Operation Project in Uganda between 2013 and 2015 to improve smallholder on-farm post-harvest management [7] [38]. Some of the activities of this project included the promotion/dissemination of modern household grain handling and storage technologies in 28 districts of Northern and Eastern Uganda. Through this intervention, hermetic storage bags, plastic silos, and metallic silos were distributed at subsidized rates to 16,600 families in the project areas. In participating households, grain storage losses were reduced by at least 98% and household incomes doubled due to this intervention [38]. Since then, several other development partners in Uganda started the promotion of improved storage technologies as part of their national and local agricultural programs. Currently, several HSTs are used for grain storage in Uganda's farming communities. Despite the initiative to promote hermetic storage use in Northern Uganda, little is known today about the awareness and use of these storage technologies in the region. The objective of this study was thus to understand smallholder farmer awareness, use, and constraints to the adoption of HSTs in Northern Uganda.

2. Materials and Methods

2.1. Study Area and Timing

This study was conducted in Northern Uganda in the districts of Adjumani, Amuru, Apac, and Dokolo during October and November 2020 (**Figure 1**).

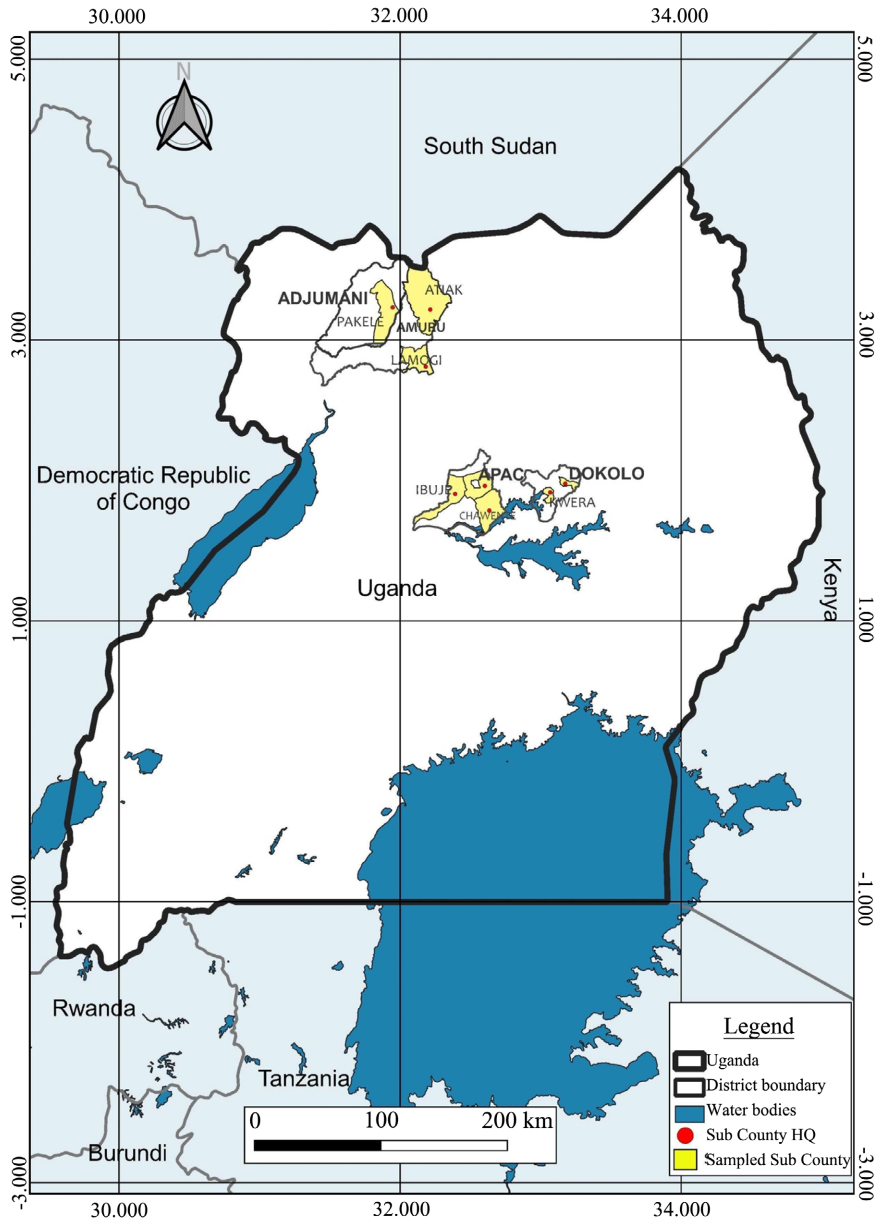

Figure 1. Map of Uganda showing the location of the study sites (in yellow) in Northern Uganda.

Northern Uganda was chosen since the promotion and dissemination of HSTs were previously carried out in the region by several projects since 2012. Villages for the survey were selected with the help of district and Sub-County agricultural extension officers in the study area. The geographical coverage was limited to the selected districts due to financial and logistical constraints.

2.2. Sampling, Data Collection, and Data Analysis

Three hundred and six (306) smallholder farmers were purposively selected and interviewed from 43 villages across the four districts of Northern Uganda. In each village, seven (7) respondents (each representing a household) who are active farmers were randomly selected to participate in the survey. The selection of villages was based on active engagement in agricultural production. A pre-tested semi-structured questionnaire with open and closed-ended questions was designed and used to elicit information from respondents.

Data were collected on household demographic and socioeconomic characteristics, access to agricultural information, crop production details, grain storage practices, hermetic storage awareness, use and constraints to adoption, and grain prices at harvest and during the lean seasons. Key informant interviews were used to validate some of the information obtained from the survey. Quantitative and qualitative data collected were coded, entered, and analyzed using the Statistical Packages for the Social Sciences (IBM SPSS Statistics 20; New York, United States). Descriptive statistics and frequencies were used to present the findings of the study.

2.3. Econometric Analysis

The use of probability models to identify the key factors affecting the decision to adopt a new technology is commonly used [26]. Logit, Probit, and Tobit models are commonly used statistical models. To understand the adoption of hermetic storage in the study area, the binary logit model was used as is commonly used in new technology adoption studies. The binary logit model was used to determine the effect of socioeconomic variables influencing the adoption of HSTs. In this kind of model, the dependent variable "hermetic storage adoption" is a dichotomous variable and takes the value of 1 if the respondent adopts the use of hermetic storage and 0 otherwise. Socioeconomic variables such as age, gender, marital status, education, membership of an association, etc. were used in the logit model. The variables used in the regression analysis to develop adoption models are shown in **Table 1**. These variables were selected based on adoption literature and the experience of grain storage adoption factors [26] [39].

Multiple logit regressions were developed in which the dependent variable (hermetic storage adoption) was expressed as (Rabé *et al.*, 2021):

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_4 D + \cdots + \beta_i N + e_i \quad (1)$$

where

Table 1. Description of the variables applied in the logit regression model.

Variables	Description	Form of variable
Adoption	1 if a respondent adopted hermetic storage otherwise 0	Dependent variable
Gender	1 if a respondent is male and zero for female	Independent variable
Age	Continuous variable indicating the age of the respondent	Independent variable
Marital status	1 if a respondent is married and zero otherwise	Independent variable
Education	1 if a respondent is literate (know how to read and write) and zero otherwise	Independent variable
Household head	1 if a respondent is a household head and zero otherwise	Independent variable
Farmer group member	1 if a respondent is a member of a farmer group association or else zero	Independent variable
Owns a radio	1 if a respondent owns a radio and 0 otherwise	Independent variable
Received training on HSTs	1 if a respondent receives training on hermetic storage and 0 otherwise.	Independent variable
Access to extension services	1 if a respondent had access to extension services and 0 otherwise.	Independent variable

Y is the adoption of hermetic storage;

β_0 is the constant term in the logit model;

β_i are the coefficients of the adoption factors to be estimated;

$A, B, C, \cdots, N$ are the independent variables whose effects on the adoption of hermetic storage were investigated; and

e_i is the model error term.

3. Results

3.1. Demographic, Socioeconomic, and Farming Characteristics of the Farmers

Northern Uganda is a kind of shrubby Grassland Savannah vegetation that receives a bimodal rainfall pattern from March to May and August to November annually. Rainfall patterns have, however, been unpredictable in the past few decades. The demographic and socioeconomic characteristics of the respondents are shown in Table 2. Among the respondents, 55.9% were male while 81.0% were married. Forty-nine percent of the respondents were aged 18 - 35 years, and 59.5% had only completed primary school education. A large number of the respondents (41.8%) were smallholder farmers who owned 3 - 6 acres of land. Seventy percent of the respondents had more than 50% of total cultivated land under grain production. About 32% of the respondents earned between UGX 500,000 - 1,000,000 (USD 136 - 272) as their annual household income. About 37.6% of respondents cultivate family-owned land while 29.4% use both family land and rented land (Table 2).

At least 12-grain crops are cultivated by smallholder farmers in the survey area (*Data not shown*). These crops include legumes (common beans, pigeon peas, mung beans, groundnuts, and cowpeas), cereals (maize, finger millet, rice, and sorghum), and oil crops (soybean, sesame, and sunflower). Maize, common

Table 2. Demographic characteristics and socio-economic attributes of the respondents in Northern Uganda.

Parameter	% of respondents (n = 306)
Gender	
Male	55.9
Female	44.1
Marital status	
Single	5.9
Married	81.0
Widowed	5.6
Divorced/separated	3.3
Living together/cohabiting	4.2
Age	
18 - 35 years	48.7
36 - 53 years	36.6
Above 53 years	14.7
Education	
None	10.1
Primary	59.5
Secondary	18.3
Tertiary (Post-secondary education)	12.1
Household size	
1 - 3 members	7.5
4 - 6 members	43.5
Above 6 members	49.0
Annual household income	
Less than UGX 500,000	30.4
UGX 500,001 - 1,000,000	32.0
UGX 1,000,001 - 1,500,000	16.3
UGX 1,500,001 - 2,000,000	4.9
Above 2,000,000	16.3
Land ownership	
Personal land	10.8
Family land	37.6
Personal land and family land	2.9
Rented or hired land	5.6
Personal land and rented land	6.2

Continued

Family land and rented land	29.4
Personal land, family land, and rented land	7.5
Total land under cultivation	
Less than 1 acre	1.0
1 - 3 acres	34.0
3 - 6 acres	41.8
Above 6 acres	23.2
Proportion of land under grain production	
Less than 25%	1.6
25% - 50%	28.4
Above 50%	69.9

n is the number of respondents. *1USD = 3674UGX at the time of the survey study.

beans, soybeans, and groundnuts are the dominant crop commodities cultivated by 85.3%, 42.5%, 32.0%, and 28.4% of the respondents respectively. The least cultivated crops were cowpea, green gram, and pigeon pea cultivated by 1.0%, 5.2%, and 5.6% of the respondents respectively.

3.2. The Main Source of Livelihood for the Farmers

Figure 2 shows the main source of livelihood of the respondents in the surveyed region. Overall, crop production is the main source of livelihood practiced by 99.7% of the respondents, followed by livestock rearing (86.9%) and self-employment (23.5%). Crops are grown primarily for food security and household financial requirements such as school fees for the children. Besides crop production, farmers kept chicken, cows, goats, sheep, and pigs for income, diversification of their diets, and to fulfill other socio-cultural purposes. Other sources of livelihood for the farmers included casual labor, brick or charcoal burning, and formal employment.

3.3. Quantity of Grains Harvested, Stored, and Quantity Remaining after Three Months

Maize was the commodity harvested in the largest quantity while green gram was the least harvested among the traditional grain crops in the study area (Figure 3). The most stored commodities following harvest were pigeon pea (95.3%), sorghum (80.6%), green gram (80.3%), common beans (75.7%), and finger millet (74.2%). The least stored commodities were sunflower (5.0%) and soybean (39.6%). Three months after harvest, most grain stocks in smallholder farming households were reduced to between 18.8% to 52.9% of the harvested quantity except for pigeon pea which still had an average of 59.3% remaining

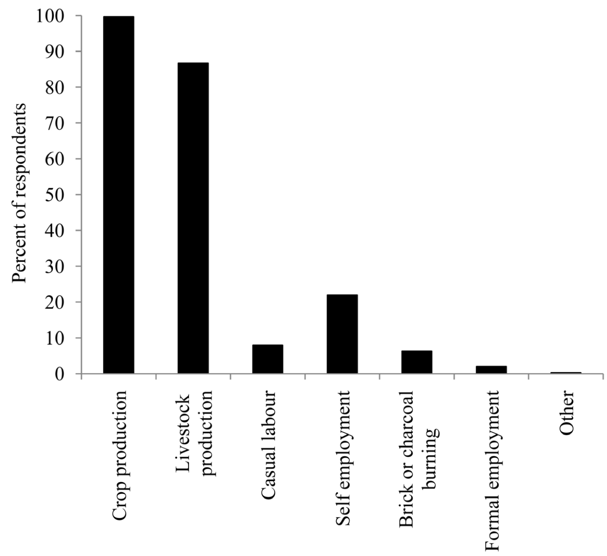

Figure 2. The main source of livelihood of the respondents in Northern Uganda.

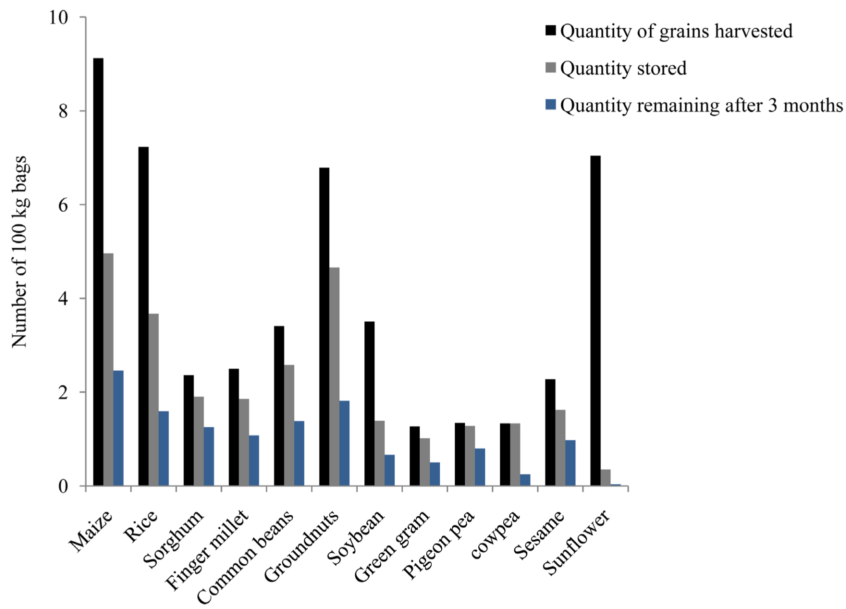

Figure 3. Grain harvested, stored, and stock balance after three months in the study area (Quantity is reported in 100 kg bag capacity).

after three months. Sunflower remaining after three months was less than 1% of the initial harvest.

3.4. Variations in Grain Price between the Harvest Season and Lean Periods

Figure 4 shows the variations in the market prices of grain commodities between the peak (harvest) seasons and lean periods in Northern Uganda. Variations in grain prices were significant ($p < 0.05$) for all grain commodities but were insignificant ($p > 0.05$) for rice, pigeon pea, and cowpea. The differences in

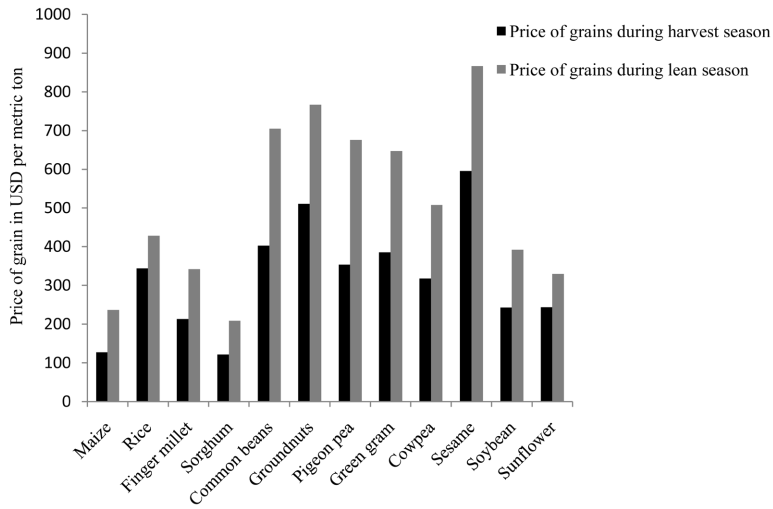

Figure 4. Prices of grain crops during harvest seasons and lean seasons in Northern Uganda.

prices between the lean season and harvest season amounted to USD 322, 302, 271, and 262 per metric ton for pigeon pea, common beans, sesame, and green gram.

3.5. Provision of Agricultural Extension Services, Information, and Training on Hermetic Storage Technologies

Table 3 shows how grain farmers in Northern Uganda access general agricultural extension services, information, and training specifically on HSTs. About 66.3% of the respondents mentioned having had contact with agricultural extension services provided in their area of operation. Of those who received extension services, 50.7% had access to extension services from Non-Governmental Organizations (NGOs) while 40.4% accessed government extension or research services (**Table 3**). Concerning HSTs, a large number of respondents received information on HSTs from NGOs (50.0%), radio (20.8%), and farmer group extension agents (15.7%) (**Table 3**). A paltry 4.7% of the respondents received information on HSTs from government extension agents. This deviation emphasizes the little effort put by the government to promote and disseminate improved grain storage technologies to Ugandan smallholder farmers in Northern Uganda. Other farmers were also important for the dissemination of improved grain storage technologies as 5.9% of the respondents obtained HST information from fellow farmers. About 75.5% of the total respondents had received training on HSTs. Training on HSTs was provided mainly by extension officers/village demonstrations (77.8%) and other farmers/neighbors (8.9%).

3.6. Farmers' Knowledge/Awareness, Use, and Handling of HSTs in Northern Uganda

Awareness of new agricultural technology is a key to promoting farmer acceptance and adoption. Fifty-three percent of the respondents were aware of some

Table 3. Access to agricultural extension, information, and training on hermetic storage technologies in Northern Uganda.

Description	Parameter	% of respondents
Access to agricultural extension (n = 306)	Yes	66.3
	No	33.7
Source of agricultural extension (n = 203)	Government research and extension	40.4
	NGOs extension	50.7
	Farmer group extension	8.0
	Private entity	0.9
Source of information on HSTs (n = 163)	Radio	20.8
	Government extension agents	4.7
	Agrodealers	2.1
	NGOs	50.0
	Other farmers	5.9
	Roadshow	0.4
	Leaflet or brochure	0.4
	Farmer group extension	15.7
Received training on HSTs (n = 163)	Yes	75.5
	No	24.5
Source of HST training (n = 123)	Extension officers/village demonstrations	77.8
	Farmers/Neighbors	8.9
	Training posters	0.7
	Others	12.6

form of grain HSTs whereas 46.7% were unaware and had no prior knowledge of any form of HSTs (Table 4). The SuperGrain bag (35.3%) was the most commonly known form of hermetic storage in Northern Uganda followed by the PICS bag (34.9%), metallic silo (15.5%), and plastic silo (14.4%) (Figure 5). The respondents were unaware of any other hermetic storage brands marketed in Uganda outside those indicated. Of those aware of HSTs (163), only 33.1% had ever used or were currently using one or more of the HSTs. Of these, 34.5%, 51.7%, 1.7%, and 12.1% had ever used or were using PICS bag, SuperGrain bag, metallic silo, and plastic silo respectively. 96.3% of the HST users do not apply chemical insecticides to grains before and during storage.

Farmers use HSTs to store grains for several reasons. Insect pest control (83.1%), mold management (4.6%), rodent management (7.7%), and others (4.6%) were the main reasons cited by respondents for choosing HSTs over traditional storage methods (Table 4). For those who were aware of HSTs but are not using them, the main reasons for not using HSTs for grain storage were

Table 4. Awareness, use, and handling of hermetic storage technologies by farmers of Northern Uganda.

Variable	Parameter	% of respondents
Hermetic storage awareness (n = 306)	Aware of HST	53.3
	Not aware of HST	46.7
Hermetic storage use (n = 306)	Have used HST	17.6
	Have not used HST	82.4%
Reason for using HSTs (n = 54)	Insect control	83.1
	Mould management	4.6
	Rodent management	7.7
	Others	4.6
Reason for not using HSTs (n = 109)	Lack of availability	50.2
	High cost	37.8
	Lack of knowledge	6.9
	Low grain production	1.4
	Periodical purchase	0.9
	Cultural preference for local storage methods	1.4
	Others	1.4
HST reuse (n = 54)	No reuse	9.3
	Reuse for 1 season	5.6
	Reuse for 2 seasons	33.3
	Reuse for at least 3 seasons	51.9
Acquisition of hermetic storage (n = 54)	Buy (or bought)	44.4
	Receive(d) for free	55.6
HST reopening frequency (n = 54)	Monthly	44.4
	After 2 months	9.3
	After 3 months	25.9
	More frequently	20.4
Re-opening HSTs for (n = 54)	Consumption	22.2
	Sale	13.0
	Both sale and consumption	64.8
Most suitable approach way to make HST available (n = 163)	Farmer based organizations	41.4
	Markets	16.7
	Retail shops	34.0
	Extension workers	5.6
	Grain traders	1.9
	Others	0.6

n is the number of respondents.

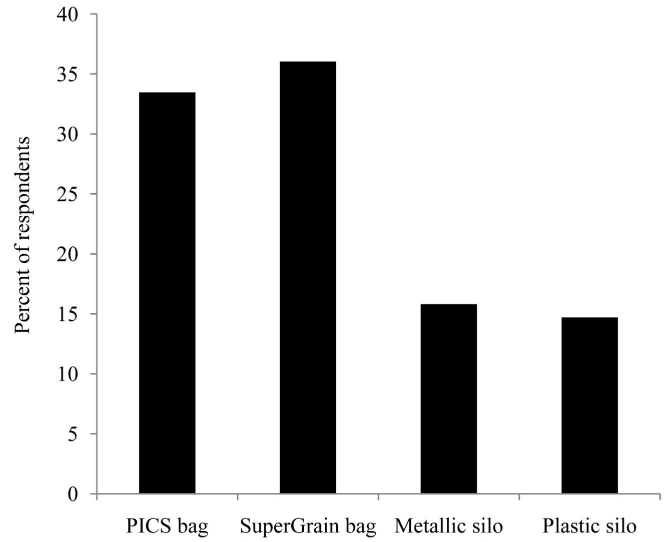

Figure 5. Awareness of different grain hermetic storage technologies (n = 163) in Northern Uganda.

lack of availability (50.2%), high cost (37.8%), and lack of knowledge on how to use (6.9%) among others (**Table 4**). About 55.6% of HST users had received their HSTs for free while the rest acquired them through purchasing.

Among the HST users, 51.9% of the respondents said they would like to reuse their HSTs for at least three seasons. About 44.4% of the respondents opened their hermetic storage containers every month while 25.9% opened after every three months (**Table 4**). Most of the respondents (64.8%) gave the reason for HSTs opening as to obtain grains for sale and consumption. To improve HSTs availability and use, most farmers think the use of farmer-based organizations (41.4%) and retail shops in their villages (34.0%) would be the most suitable approaches.

3.7. Contributions of Hermetic Storage to Food Security and Household Income

When asked about the benefits of using HSTs, the respondents described several benefits that originate from the adoption of improved grain storage technologies. Among the HST users in our study, the benefits of using hermetic storage over conventional storage technologies included improved food availability in the farming households, household income, improved grain quality, and nutrition reported by 98.1%, 90.7%, 100%, and 90.7% of the respondents respectively (*Data not shown*).

3.8. Econometric Analysis Results

The binary logit regression analysis was used to identify the important factors affecting the decision to adopt the use of hermetic storage in Northern Uganda. The determinants of adoption of HSTs are shown in the Logit model estimation results shown in **Table 5**. The logit model incorporates both quantitative and

Table 5. Factors affecting the adoption of hermetic storage by smallholder farmers in Dokolo, Apac, Amuru, and Adjumani districts in Northern Uganda.

Variables	Coefficient	Wald	p-value
Gender	0.233	0.207	0.649
Marital status	0.793	3.745	0.053
Age	0.096	0.772	0.680
Farmer group association member	0.947	0.516	0.066
Household head	−0.416	0.623	0.430
Education	−0.332	1.647	0.199
Access to radio	−0.257	0.446	0.581
Received training on HSTs	2.032	9.34	0.002
Access to agricultural extension	1.092	2.552	0.110
Constant	−4.22	4.692	0.030

qualitative variables to determine the significance of the adoption factors. Of all the independent variables, only one variable significantly affected the adoption of hermetic storage by users. This variable was training in the use of hermetic storage ($p = 0.002$). Respondents who received training on HSTs were significantly more likely to adopt the use of hermetic storage technology.

4. Discussions

4.1. Demographic and Socioeconomic Characteristics of the Farmers

In Uganda, agriculture is the mainstay of the population upon which people directly or indirectly derive their livelihoods. Subsistence agriculture in the country contributes significantly to the food and income requirements of about 85% - 90% of households in Uganda [40]. In our study, young people between 18 - 35 years made up nearly half (48.7%) of the surveyed population. The population of Uganda is one of the youngest in the world [41]. Young farmers are considered more energetic and productive in agricultural work as most fieldwork activities in smallholder farmer settings of SSA require physical effort characteristic of young people. Besides, young people are more likely to adopt new agricultural technologies faster than their aged counterparts [42]. The majority of Ugandan farmers are smallholder farmers who produce food chiefly to meet their food and income requirements. At least 76% of the surveyed population owned between 1 - 6 acres of agricultural land, with grain production accounting for much of the total land under cultivation. Grain production is a key social and economic activity in Uganda, contributing to food security and smallholder farmers' household income requirements [43] [44]. This indicates that priority is given to grain crops when it comes to land allocation compared to traditional root and tuber crops in the study area. The majority of the respondents are low resource farmers (63.7%), earning up to a maximum of UGX 1,000,000 (USD 286) as their annual household income. Such low resource farmers may find it difficult to invest their little resources in improved grain storage technologies.

4.2. Quantity of Grains Harvested, Stored, and Quantity Remaining at Farming Households after Three Months

Northern Uganda receives two rainy seasons from March to May and August to November each year, and there are at least six to eight months of grain storage before the next harvest season. This duration of food storage may affect the food security and household income of smallholder farmers especially if they lack better storage technologies. While food production is a seasonal activity, food consumption is an ongoing activity that must be met regularly and adequately [45]. Farmers should thus be able to store enough food to meet their household food and income needs during the lean periods. From our study, most smallholder farmers remained with only a limited quantity of grains in their food stores just three months following harvest. This indicates the vulnerability of many smallholder farmers during the lean periods and the struggle they go through to meet their household food needs between one harvest season and the other. In a study carried out in Tanzania, crop stocks were less by 63% - 94% of the harvest amount after just one month of storage [8].

Shortly after harvest, many smallholder farmers opt to sell most of their crops for several reasons. These include raising money for school fees, household requirements, and the perception of grain surplus above storability [8]. Besides, the onset of the crop harvest season coincides with financial pressures that farming households have been subject to during the lean periods, with the immediate option being the sale of some or all of the crop harvests. Other farmers also sell their surplus crop harvests for fear of losing them to the agents of deterioration during storage [22] [46]. When sold immediately after harvest, households will be forced, in a few months, to buy grains at relatively higher prices than sold to meet their food needs [12] [47] [48]. Among other factors, this has kept many smallholder farmers of SSA in perpetual poverty.

For all the grain commodities produced by farmers, prices during the lean seasons were significantly higher than during the harvest seasons, amounting to gains of US $322, 302, 271, and 262 per metric ton of pigeon pea, common beans, sesame, and green gram sold in the lean periods. This benefit of fetching higher prices when grains are sold during the lean periods is an opportunity for smallholder farmers to invest in and use effective and sustainable storage solutions such as hermetic storage that retain higher crop quality for longer in storage. The ability to be able to store crops from harvest time until when local market prices are favorable could improve smallholder farmers' incomes that would eventually break the perpetual cycle of poverty resulting from farmers' poor grain storage habits [8]. Besides fetching higher market prices, storing grains in superior storage technologies that avoid storage losses can guarantee farmers' food security in farming households [48].

4.3. Provision of Agricultural Extension Services, Information, and Training on Hermetic Storage Technologies

Agricultural extension services are important to enhance farmer knowledge and awareness of the availability of new and improved farming technologies [49]. A large proportion of the respondents in the study area had access to general agricultural extension services. Northern Uganda has several extension service providers including NGOs, governmental agencies, and other private entities. Those with access to extension services in the study area relied on NGOs, Government research and extension services, and farmer-group extension service providers. NGOs accounted for the largest source of extension services followed by Government research and extension services. The overreliance of smallholder farmers on NGOs to offer extension services is worrying since the withdrawal of the services of such an entity at any time would drastically affect smallholder farmers. The lack of access to agricultural extension services by about 33.7% of the population could be attributed to limited government support to provide extension services to these farmers. About 8.0% of the respondents received extension services from farmer group extension workers. Sebaggala and Matovu [50] argued that formal extension workers are not the only source of agricultural extension information for farmers as other informal sources have emerged. It has become common to see established farmer groups in Uganda employ skilled and trained personnel to provide agricultural extension services to their farmer group members in agricultural communities.

The vast majority of respondents who were aware of hermetic storage had received some form of training on its use, primarily from agricultural extension workers in their area. The efforts of development partners mainly the WFP to promote sustainable post-harvest solutions that reduce grain handling and storage losses brought to the knowledge and use of HSTs in Northern Uganda. Despite these and other stakeholders' efforts, our study indicated that awareness and use of HSTs remain low in Northern Uganda. Hermetic storage bags, plastic silos, and metallic silos were among the first HSTs promoted in Uganda between 2012 to 2016 by WFP and other partners [7] [38]. Since then, several other organizations including the private sector have picked interest in activities such as technology dissemination, research, and manufacturing to meet the needs of smallholder farmers to improve grain storage in the region.

4.4. Awareness, Use, and Constraints to the Adoption of Hermetic Storage

Our study indicated that awareness and use of HSTs in Northern Uganda are low among the surveyed farmers, and the same could be true for the whole country. Despite the promotion and dissemination of HSTs in Uganda by development partners including WFP from 2012 to 2016 and the inclusion of promotion and dissemination of HSTs into the activities of many development partners, a large proportion of the population in the surveyed area are still unaware of improved forms of grain storage. Among those who are aware, the use of HSTs to store grains was even much lower as only 18% of total respondents were using one or more forms of hermetic storage. Compared to the study of Moussa, Lowenberg-DeBoer [51] where there was a 70% adoption level of HSTs in Burkina Faso and Niger for the storage of cowpeas, there is still a low adoption rate of hermetic storage in Uganda. The main reason for farmers to use HSTs was the management of insect pests during storage. Insect pests are the greatest challenge to stored grains, causing significant quantity and quality loss of up to 40% in some commodities [52]. By using HSTs, insect pests cannot thrive due to the creation of interstitial modified atmospheres of low oxygen and high carbon dioxide [48] [53] [54]. Due to inadequate oxygen supply, cessation of insect feeding, growth, development, reproduction, and eventual death occurs for insect pest species and their life stages [55]. Besides, the lack of oxygen blocks the supply of vital metabolic water leading to the desiccation of insect pests and their life stages [55].

The main constraints to hermetic storage technology adoption in Northern Uganda were lack of availability and high cost compared to conventional grain storage methods. In West and Central Africa, lack of availability of HSTs and lack of information were noted as the top most important constraints hindering farmers from using hermetic grain storage [26]. In a related adoption study in West Africa, lack of availability and high price were the top reasons for the low adoption of PICS bags for grain storage [26]. The users of hermetic storage have to strike a balance between technology cost, availability, and durability [32]. The initial acquisition cost of HSTs is a major constraint to smallholder farmers in Uganda. Metallic silos cost about USD 35 for a 100 kg silo and USD 2 - 4 for a 100 kg hermetic bag compared to the popularly used woven PP bag which cost at most USD 0.4 for a 100 kg bag. From this, it is clear that the cost of HSTs is highly substantial for smallholder farmers given the limited financial capacity of smallholder farmers of SSA [12].

Among the HST users, most farmers received them for free or paid a small fraction of the total costs as promotion incentives offered by the promoters of the technology. To ensure rapid awareness and adoption of HSTs, development partners and other promoters of new storage technologies initially offer them to participating households at a small fraction of the total technology fee or completely free [22]. This is usually done so that the beneficiary farmers and other farmers would learn about the benefits of the technology and later take personal interest to buy them for improved food security and incomes in their households. Most of the surveyed farmers opened their HSTs periodically after sealing to obtain grains either to be used as food or to sell for income to meet their household needs. While the opening of hermetic storage interrupts the hermeticity principle, sealing the container shortly after has been shown not to significantly impact grain quality [56].

The logit regression model results showed that training on HSTs was the main predictor of the adoption of storage technology in Northern Uganda. While other factors such as age, education, gender, and marital status among others are known to affect the adoption of storage technology [26] [39] [57], these were not the main factors in our study. It has been demonstrated that awareness-building exercises increase the adoption and use of new improved storage technologies [58]. Training and dissemination of knowledge and information about new technologies thus play a key role in raising awareness and subsequent diffusion of technologies among targeted users. Unlike in other hermetic storage adoption studies, education, membership in a farmer association, household headship, access to radio, and access to extension services did not significantly affect the adoption of hermetic storage in our study [26] [39]. This could be explained by the fact that the factors that affect hermetic storage adoption are area-specific and could have been different for Northern Uganda where our study was conducted.

5. Conclusions and Recommendations

The users of hermetic storage rely on this improved storage technology to control insect infestations without the need to use chemical insecticides. Despite the known effectiveness and superiority over conventional storage technologies, our study has shown that awareness and use of hermetic storage in Northern Uganda are low compared to other regions of SSA. Although numerous efforts have been put in by development partners, the awareness and use of hermetic storage remain low in Uganda. The most important constraints to the adoption of HSTs in Uganda are lack of availability and high costs as indicated by 50.2% and 37.8% respectively of the respondents in the study area. If the adoption and use of hermetic storage technology are to improve, these constraints should be addressed by all interested stakeholders. Innovative awareness creation activities such as public demonstrations and radio programs among others could be useful to improve farmers' knowledge and adoption of the technology.

Acknowledgements

We are grateful to the Government of Uganda through the Makerere University Research Innovations Fund (RIF) [Grant No. RIF1/CAES/022] for funding this study. In addition, we are indebted to the 306 smallholder farmers for their willingness to participate in the survey. Finally, we wish to thank George Akwec, Ambrose Ogwal, Deus Basiime, and all the data enumerators for facilitating the process of data collection and data entry.

Ethics Approval and Consent to Participate

The smallholder farmers used as respondents and informants were informed of the purpose of the study and the rights to withdraw their participation at any stage of the interview. The collection and handling of the data have been done following the general data protection guidelines to ensure confidentiality and privacy.

Conflicts of Interest

The authors declare no known conflicts of interest, financial or non-financial. The funding organization had no role and interest in the study design, data collection, and analysis.

Funding

This work was funded by the Government of Uganda through the Makerere University Research Innovations Fund (Mak-RIF) [Grant No. RIF1/CAES/022].

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List of Abbreviations

HSTs: Hermetic Storage Technologies;
PHLs: Post-Harvest Losses;
NGOs: Non-Governmental Organizations;
PICS bag: Purdue Improved Crop Storage bag;
PP bag: Woven polypropylene bag;
SDGs: Sustainable Development Goals;
SSA: Sub-Saharan Africa;
WFP: United Nations World Food Programme.