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Research article

Assessment of factors affecting the decision of smallholder farmers to use alternative maize storage technologies in Gatsibo District-Rwanda

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ABSTRACT

Storage is an important aspect of food security in developing countries. Therefore, it is crucial for farmers to have access to sustainable storage technologies to cope with storage losses. Maize is an important staple and commercial food in Rwanda, but maize farmers are still being challenged by storage losses because of the lack of proper storage facilities. It is in that regard that advanced maize storage technology, notably hermetic maize storage technology, has been introduced in Rwanda in 2012. However, since its introduction, the adoption rate is low among smallholder maize farmers. Understanding the factors influencing farmers' choice of alternative maize storage technology could provide Rwandan policymakers with important information for designing policies and programs aimed at reducing maize post-harvest losses to enhance household food security. This study used a multivariate probit model on a randomly selected cross-sectional sample of 301 smallholder maize farmers from the Gatsibo District of Rwanda to take part. The results revealed that the common maize storage technologies used among smallholder farmers were polypropylene sacks with and without chemicals, hermetic bags, and silos. Only 41% of respondents used hermetic maize storage technology. The model results showed that membership in a farmer group, access to credit, the quantity of maize produced, access to training, and selling maize soon after it dries, were the major factors influencing the decision of smallholder farmers to use alternative maize storage technologies. The study recommends that the policymakers and other stakeholders in post-harvest loss reduction should support the dissemination of advanced storage technologies to facilitate access. The government should support farmer acquisition of post-harvest maize loss reduction technologies either through subsidization of hermetic bags or provision of cheap credit.

1. Introduction

The measures and actions aimed at reducing food losses are contributing factors to enhancing food security as well as alleviating poverty among smallholder farmers in sub-Saharan Africa (SSA). And, although the global food systems produce sufficient food to feed everyone, still in 2016 about 13.8% of food produced in the world get lost annually either through post-harvest mishandling, infestation by pests and diseases, or just mere waste at the table (Food and Agriculture Organization [FAO], 2019). Over 30% of the food produced in SSA gets lost post-harvest along the food supply chain because of financial, managerial, and technical constraints (The Rockefeller Foundation, 2015; Gustavsson et al., 2011; FAO 2011). Estimates by FAO showed that post-harvest losses (PHL) in SSA reach up to 20% for cereals valued at US$4 billion, which is equivalent to the value of cereals imported annually in SSA (FAO, 2011). Although governments and development partners availed investment to reduce PHL, the 2019 State of Food and Agriculture (SOFA) report by the Food and Agriculture Organization [FAO] reveals that approximately 14% of food produced in SSA still gets lost. It is therefore imperative that those post-harvest methods and requite technologies be accorded similar attention by policymakers as they do to food production (Kaminski and Christiaensen, 2014; Obeng-Ofori et al., 2015).

In the east and southern Africa, maize is the most important food staple and a cash crop for most resource-poor smallholder farmers (Shiferaw et al., 2011; Tefera, 2012; CIMMYT, 2010). Farmers store the maize to bridge seasonal supply shortfalls and attendant price fluctuation (Gitonga et al., 2013). However, between 14 and 36% of maize produced

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in eastern and southern Africa is lost during post-harvest because of poor handling and improper storage. Of this loss, between 4.3 and 11.2% is lost, during storage, due to infestation by rodents, insect pests, and mycotoxins which are associated with the lack of effective storage technology (Giertz et al., 2015; Gitonga et al., 2013).

In Rwanda, about 32% of the total volume was lost because of the lack of capacity in post-harvest handling and storage (Kathiresan, 2011; MINAGRI, 2018a, 2018b). In response to the high post-harvest maize losses, the Government of Rwanda launched the post-harvest handling and storage (PHHS) task force in 2010 with the mandate of minimizing post-harvest losses through training of maize farmers in best practices in post-harvest handling and storage technologies, construction of post-harvest management systems, and distribution of post-harvest equipment including hermetic storage technologies (MINAGRI, 2016). As a result, the post-harvest losses in maize fell from 32% in 2011 to 16.4% in 2019 (African Post Harvest Information System, 2018).

The hermetic storage technologies were introduced in Rwanda in 2012 and comprised hermetic bags and silos among smallholder farmers. The government subsidized both silos and hermetic bags at 75% to encourage adoption (MINAGRI, 2011; WFP, 2017). However, by 2014, One Acre Fund [OAF] reported that only 37% of the smallholder maize farmers adopted the hermetic storage technology. In Rwanda, grain losses are among the major causes of food shortage, food insecurity, high prices, and prohibiting farmers' access and affordability (Umubyeyi and Rukazambuga, 2016). Likewise, maize farmers are facing challenges in producing the required quality and quantity of maize. Due to the damages experienced at storage from rodents, pests, and aflatoxin contamination, their maize is sold at a lower price or rejected by buyers. It results in food insecurity and low income because of losses incurred by farmers (MINAGRI, 2018a, 2018b; De Groote et al., 2013). Although studies (e.g., Nyamulinda et al., 2011; OAF, 2014 and Chigoverah and Mvumi, 2016) have shown unequivocally the effectiveness of the hermetic storage technologies in loss reduction.

This study aligns with the Government of Rwanda's fourth Strategic Plan for Agriculture Transformation (PSTA IV, 2018–2024) that aims to increase agricultural productivity and commercialization, leading to agricultural transformation (MINAGRI, 2018). The study contributes to the United Nations' Sustainable Development Goals (SDGs); goals number one and two that, respectively, aim at eliminating poverty and hunger, and SDG target 12.3 that calls for actions to reducing food waste and food loss along production and supply chains by 2030. Therefore, this study sought to bridge the gap in knowledge by providing information on factors influencing smallholder maize farmers' choice of alternative storage technologies in the Gatsibo District of Rwanda. It will guide policymakers in formulating policies and strategies aimed at promoting the use of hermetic storage technology (HST) among farmers, which will contribute to the reduction of maize storage losses. In addition, the findings will assist maize farmers in gaining knowledge on the effectiveness of different storage technologies to increase the adoption of improved maize storage technologies.

2. Materials and methods

2.1. Theoretical framework

This study is based on the random utility theory. The theory states that a decision-maker chooses from a batch of alternatives, an alternative that maximizes his utility (Greene and Hensher, 2010; Greene, 2012). Each alternative in the decision maker's choice set is associated with a true value (Soufiani et al., 2014). In this theory, a decision-maker has both observable and unobservable characteristics that can influence his choice of a utility-maximizing alternative within a random utility model. The observable characteristics include farmer, farm, and institutional factors, and the unobservable characteristics include intrinsic factors, such as motivation and ability. These unobservable characteristics are often immeasurable and are captured by the error term (Greene and Hensher, 2010). Hence, the random utility model is helpful because it captures the strength of a decision maker's preference owing to his outcome, which corresponds to an order of real numbers. This theory permits choice models such as the binary probit or logit model (Greene and Hensher, 2010). In this study, the multivariate probit model has been employed in analysing maize farmers' choice between the different storage technologies– whether the maize farmers choose to use a specific storage technology or not. The multivariate probit model considers the likelihood of correlation of the error term across the different equations for alternative storage technologies and does not require the assumption that choices are independent across alternatives (Greene, 2003; Gujarati, 2009; Otieno, 2010).

Regarding the random utility theory, a rational smallholder maize farmer will use a storage technology that maximizes their utility. This utility can be derived from the profits got from the use of that specific technology. According to Greene (2012), the utility smallholder maize farmers get from choosing a particular storage technology can be decomposed into the systematic utility (V_{ij}) and the random residual (ε_{ij}) components. According to Cascetta (2009), the systematic utility (V_{ij}) is the mean utility perceived by decision-makers who have the same choice set as decision-maker *i* and the random residual (ε_{ij}) represents the unknown deviation of the perceived utility of decision-maker *i* from this mean value, errors from perception and measurement, instrumental variables, and unobserved attributes and preferences (Payne et al., 1992, 1993).

This random residual captures the combined effects of the different factors that bring uncertainty into choice modelling:

$$U_{ij} = V_{ij} + \varepsilon_{ij} \tag{1}$$

Assume a farmer *i* has two choices *a* and *b* and utilities U_i and U_j, respectively (Greene, 2012).

U_i: Utility delivered from using a specific storage technology.

U_j: Other ways

$$U_i = w\beta_i + Z_i\gamma i + \varepsilon_i \tag{2}$$

$$U_j = w\beta_j + Z_j\gamma j + \varepsilon_j \tag{3}$$

From Eqs. (2) and (3), *w* is the observable characteristics of a farmer, such as social-economic characteristics. The term *Z* represents the attributes of a specific storage technology: *i* or other ways: *j*; and ε represents the utilities that are not observed by the researcher. A farmer will use a specific storage technology:

$Y = 1$ if $U_i > U_j$ and.

$Y = 0$ if $U_i \leq U_j$.

2.2. Analytical method

This study used the chi-square test, t-test, proportional test, and ANOVA to assess the level of usage of advanced storage technologies (hermetic storage technologies) vis-à-vis other storage technologies and the constraints and opportunities for different storage technologies. The Multivariate probit model (MVP) was employed to investigate the factors that affect smallholder maize farmers' choices and decisions on the alternative storage technologies in Rwanda. This study shows that the most-used storage technologies are four, namely polypropylene sacks, polypropylene sacks with a chemical application, and hermetic technologies (silos and hermetic bag). The MVP is a natural extension for the probit model. It can accommodate over one equation, and accounts for the likelihood of correlation of the error term across the different equations for alternative storage technologies (Greene, 2003; Gujarati, 2009).

The probit model is among the statistical probability models that have two categories in the explained variable (Liao, 1994). It generates the marginal effects of the explanatory variables on the probability of adoption (Hosmer& Lemeshow, 2000). According to Aldrich et al., (1984) and Owach et al., (2017), the analysis of the probit model is based on the cumulative normal probability distribution of the error terms, that makes it more preferred for regression analysis. However, MVP does not require the assumption that choices are independent across alternatives (Greene, 2003; Gujarati, 2009; Otieno, 2010).

The multivariate probit model presupposes that the decision by a smallholder maize farmer to adopt any of the alternative storage technologies or not would depend on an unobservable index Y_{ij} determined by explanatory variables, where the higher the index, the greater the probability of smallholder maize farmers to adopt a specific storage technology.

The expression takes the form:

$$Y_{ij}^{*} = \beta_i X_i + \varepsilon_i \tag{4}$$

where Y_{ij}^{*} ($j = 1,..., m$) in Eq. (4) represents an unobservable latent variable of the storage technologies j used by smallholder farmer i (in this case $m = 4$); X: is a (1 x k) vector of observed variables that affect storage technology adoption decision; β: is a (k x 1) vector of unknown parameters to be estimated and ε_i is a vector of the stochastic error terms. A smallholder maize farmer will choose j technology if the utility of choosing it exceeds the gain of not using it. These preferences may be correlated with individual and farm characteristics and institutional factors that are captured in β. Since the latent variable is unobservable, two index functions are defined. Referring to Eq. (4), with using any of the alternative storage technology, this is:

$$Y_{ij} = 1 if Y_{ij}^{*} > 0$$

$$Y_{ij} = 0 if Y_{ij}^{*} \leq 0$$

By considering Y_{ij} as a dummy variable with values 1, if the i^{th} smallholder maize farmer adopts the j^{th} technology, and 0 otherwise; where the value of j ranges from 1 to 4 representing polypropylene sacks only, polypropylene sacks + chemical application, silos, and hermetic bags, respectively.

Therefore, the system of equation is written as follows:

$$\left\{ \begin{array}{l} Y_1^{*} = \beta_1 X_1 + \varepsilon_1 , \; Y_1^{*} > 0; \; Y_1 = 0 \quad otherwise \\ Y_2^{*} = \beta_2 X_2 + \varepsilon_2 , \; Y_2^{*} > 0; \; Y_2 = 0 \quad otherwise \\ Y_3^{*} = \beta_3 X_3 + \varepsilon_3 , \; Y_3^{*} > 0; \; Y_3 = 0 \quad otherwise \\ Y_4^{*} = \beta_4 X_4 + \varepsilon_4 , \; Y_4^{*} > 0; \; Y_4 = 0 \quad otherwise \end{array} \right\} \tag{5}$$

The system of Eq. (5) will be jointly estimated using maximum likelihood. The choice of alternative storage technology will depend on smallholder maize farmer and farm-level characteristics, as well as institutional factors.

2.3. Study area

Gatsibo District is one of the seven districts that make up the Eastern province, the largest, and the highest in terms of percentage of households (NISR, 2018). It was selected for this study because of the high adoption of Hermetic storage technologies. About 40% of maize farmers supported by Rwanda's post-harvest handling and storage task force are from Gatsibo District (MINAGRI, 2016). Therefore, Gatsibo district was selected to better analyze the factors determining the choice of alternative storage technologies and the relationship between adopting HST and income among maize farmers. It borders Nyagatare District in the North, Gicumbi District in the West, Gasabo District in the South-West, Rwamagana District in the South, and Kayonza District in the East (Figure 1). Gatsibo District is divided into 14 sectors, 69 cells, and 603 villages. About 89% of the residents depend on agriculture for their livelihood, with maize representing 49% of the total land area under the Crop Intensification Program, and about 54% of the marketed produce (MINAGRI, 2018a, 2018b).

2.4. Research design and sampling procedure

A multistage sampling technique was used to identify the sampling units. In the first stage, Gatsibo District was selected based, as stated above, on having the highest number of smallholder maize farmers that use drying hangers in Rwanda's Eastern Province. A list of all smallholder maize farmers in Gatsibo District who used drying hangers and were supported by Rwanda post-harvest handling and storage task force (PHHS) was got from Gatsibo District Agricultural Division. The list contained 75,000 farmers. In the second stage, 12 cells were selected based on the location of the drying hungers. Because the population of farmers who were using drying hangers in the district was known, the Yamane (1967) formula for calculating a sample size from a known population was used:

$$n = \frac{N}{1 + N(e)^2} \tag{6}$$

where n is the sample size; N is the number of farmers using drying hangers in the district, and e is the level of precision. Substituting 75000 maize farmers in Eq. (6) and assuming a 95% confidence level and a 5% precision gave 398 households. However, due to invalid response and missing data, the study ended up using only 301 maize farmers in the analysis.

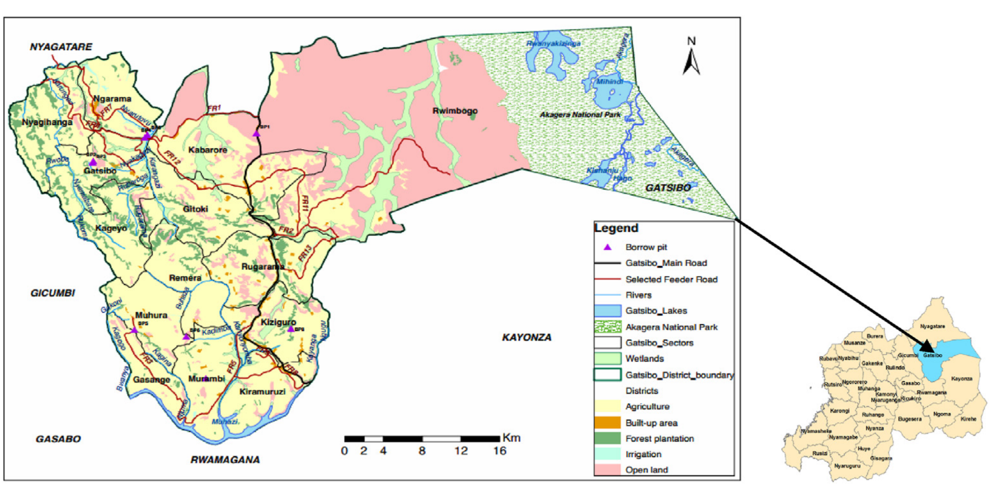

Figure 1. Map of Gatsibo District, Rwanda. Source: Gatsibo district, 2018.

Table 1. Summary statistics of socio-demographic characteristics of hermetic storage technologies adopters and non-adopters in Gatsibo District, Rwanda.

Variables	MEAN			2-tailed t-test	χ2-value
	Adopters n = 122	Non-Adopters n = 179	Overall n = 301		
Household characteristic					
Age of household head	48.2 (11.87)	45.7 (11.96)	46.7 (12.00)	1.79**	
Year of schooling-household head	6.07 (3.52)	5.67 (3.47)	5.83 (3.50)	0.96	
Size of household	5.17 (2.13)	4.45 (2.01)	4.74 (2.10)	2.98***	
Experience- maize production (Years)	11.52 (9.44)	10.15 (8.2)	10.7 (8.70)	1.34*	
Awareness of HST (1 = aware; 0 = not aware)	1 (0.16)	0.36 (0.48)	0.61 (0.50)		116.21***
Sex of household head (1 = male; 0 = female)	0.75 (0.43)	0.76 (0.43)	0.76 (0.40)		0.013
Institutional Characteristics					
Access to extension services (1 = yes; 0 = no)	0.88 (0.33)	0.42 (.49)	0.60 (0.50)		63.68***
Access to training (1 = yes; 0 = no)	0.94 (0.23)	0.43 (0.50)	0.64 (0.50)		82.50***
Group membership (1 = yes; 0 = no)	0.9 (.29)	0.89 (0.30)	0.90 (0.30)		0.004
Access to credit (1 = yes; 0 = no)	0.39 (0.49)	0.26 (0.43)	0.31 (0.46)		6.29**

*, **, *** significant at 10%, 5% and 1% respectively. Standard deviations are in parentheses.
HST stands for Hermetic storage technologies in maize.

2.5. Data collection and analysis

This study used primary data that have been obtained through a household survey using face-to-face interviews and focus group discussions and secondary data that have been sourced from Gatsibo district Agricultural division, Rwanda post-harvest and storage task force, and MINAGRI. Trained enumerators interviewed selected farmers using a pre-tested semi-structured questionnaire. The questionnaire gathered smallholder maize farmers' socio-demographic and economic characteristics, as well as the adoption and utilization of hermetic storage technology in the Gatsibo District among selected smallholder maize farmers. The data were analysed using STATA with the use of econometrics models- Multivariate Probit (MVP).

3. Results and discussion

3.1. Farmers' socio-demographic characteristics

Out of the total of 301 respondents, 41% of the smallholder maize farmers in Gatsibo district have adopted hermetic storage technologies (silos and hermetic bag) while 59% used polypropylene sacks with and without chemicals (Table 1). The majority (76%) of heads of households were male. The pooled average age of the household heads in Gatsibo District was 47 years (range from 25 to 69 years old). The HST adopters were significantly older than non-adopters with more experience in maize production. However, the household heads of the two groups had attained a similar level of formal education of 5.8 years, against the national average of 4.4 (United Nations Development Programme [UNDP], 2020).

The majority (90%) of household heads belonged to maize farmer groups, and 60% had received government extension services twelve months preceding the survey. This is against the 2017 Rwanda agricultural household survey report that 12.5% of agricultural households have at least one member belonging to agricultural cooperatives and 29.6% receiving agricultural extension services or training (NISR, 2018). Of the 301 maize farming households, 64% received training on post-harvest handling and storage. HST adopters had greater access to extension services and training related to post-harvest handling and storage compared to non-adopters. They, therefore, seem to have higher social capital from better access to information and social services.

Access to credit was low, as reported by 31% of respondents. The major sources of credit (42%) were from village saving associations (VSAs) (42%), cooperatives (37%), friends and family (12%), and 8% from banks and other financial institutions. The farmers decried the high

Table 2. Summary statistics of selected farm characteristics among HST adopters and non-adopters in in Gatsibo District, Rwanda.

Variables	Mean			2-tailed t-test	χ2-value
	Adopters n = 122	Non-Adopters n = 179	Overall n = 301		
Farm Characteristics					
Size of maize plot (Ha)	0.54 (39.69)	0.42 (33)	0.47 (36.3)	3.02***	
Quantity of maize produced (Kg)	757.3 (264)	658.3 (291.4)	698.4 (284.4)	3.006***	
Quantity of stored maize (Kg)	232.3 (182)	187.2 (142.21)	205.5 (160.8)	2.41***	
Distance home- input provider (Km)	1.57 (1.35)	1.86 (1.45)	1.73 (1.4)	- 1.67**	
Off farm income in (USD)	58 (150.9)	43.3 (102.7)	49.3 (124.5)	1.002	
Other crops plot number	4 (2.86)	3.2 (2.49)	3.5 (2.7)	2.44***	
Selling maize soon after it dries (1 = Yes)	0.75 (0.43)	0.77 (0.42)	0.76 (0.4)		0.11
Buying maize (1 = yes)	0.06 (0.23)	0.12 (0.32)	0.09 (0.3)		3.09*
Outcome variable					
Maize income (USD)	61.8 (53.12)	49.8 (44.23)	54.67 (49.82)	2.41***	

*, **, *** significant at 10%, 5% and 1% respectively. Standard deviations are in parentheses.
USD stands for United States of America dollar.
HST stands for Hermetic storage technologies in maize.
Source: Author's analysis of household survey data, 2019

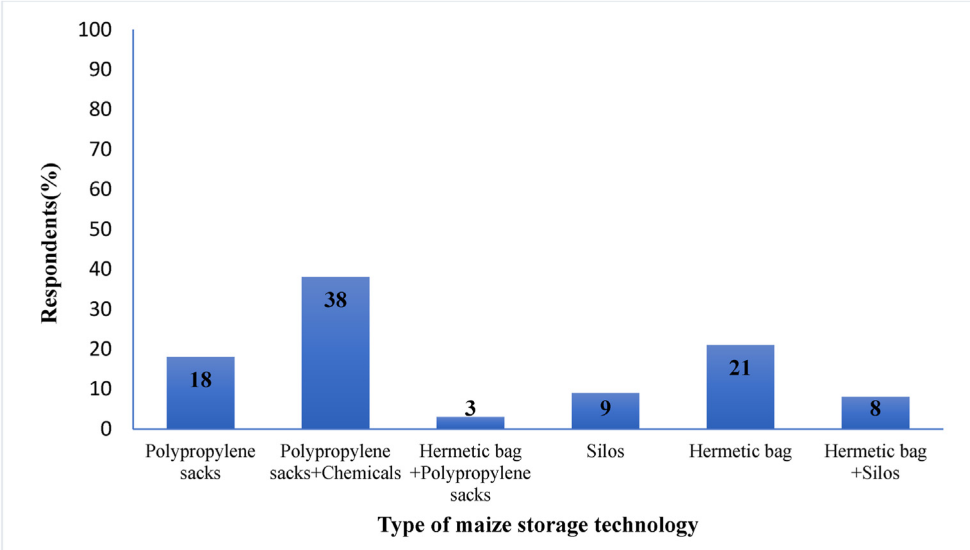

Figure 2. Alternatives maize storage technologies used by smallholder farmers in Gatsibo district in May 2019.

interest rates on bank loans and irregular cash flow from farming because of the seasonal nature of production, making monthly loan payments untenable. It is in line with the 2017 Agricultural Household Survey that revealed that countrywide, only 4.7% of households had at least one household member who requested an agricultural loan.

The average area under maize farm was 0.47 ha. On average, HST adopters had significantly more land under maize than non-adopters (Table 2). However, the average land size under maize was smaller than the national agricultural land average of 0.6 (NISR, 2018). Probably as a result, more (12%) HST non-adopters bought maize within the season than adopters (6%), suggesting the latter was more self-sufficient in maize than the former. Similarly, the average quantities of maize produced and stored were significantly higher among the HST adopters compared to non-adopters. It suggests that in terms of maize production, HST adopters were better off relative to non-adopters.

Figure (2) presents various maize storage technologies commonly reported by maize farmers in Gatsibo District. Polypropylene sacks with chemicals were the most popular, followed by polypropylene sacks without chemicals and hermetic bags. Considering HST, i.e., silos and hermetic bags, 41% of farmers had adopted at the time of the survey against 37% nationally (OAF, 2014), showing that HST is getting attention in Gatsibo District. The fact that 59% of farmers did not use HST suggests the need for much more effort to facilitate the adoption of HST in Gatsibo District, Rwanda.

Table 3. Pairwise correlation coefficients of the error terms of the adoption equations of the four maize storage technologies used in Gatsibo District, Rwanda.

Technology	Polypropylene sacks	Polypropylene sacks and chemicals	Silos	Hermetic bags
Polypropylene sacks	1.00			
Polypropylene sacks and chemicals	-0.43*** (0.00)	1.00		
Silos	-0.22*** (0.00)	-0.4*** (0.00)	1.00	
Hermetic bags	-0.32*** (0.00)	-0.46*** (0.00)	0.14** (0.02)	1.00

Numbers in parenthesis are p-values; *p < 0.1, **p < 0.05, ***p < 0.01.
Source: Author's analysis of household survey data, 2019

3.2. *Potential substitutability between alternative maize storage technologies*

The specific objective of this paper was to assess the factors affecting smallholder farmers' decision to use alternative maize storage technologies. To accommodate the four alternative technologies identified, the multivariate probit model (MVP) was applied. The appropriateness of the model was assessed by considering the pairwise correlation between error terms of the adoption equations first (Table 3). The correlation coefficients were found to be statistically significant, implying that the decision to use one specific maize storage technology affects his likelihood of using the other maize storage technologies.

The correlation between hermetic and non-hermetic maize storage technologies was negative and statistically significant, showing the potential substitutability between the two groups of storage technologies. Thus, the promotion of HST is likely to reduce the use of non-hermetic storage technologies among maize farmers if the right conditions, including pricing, affordability, and availability, are provided. There is also a positive correlation between hermetic bags and silos, implying that they are complementary (i.e., silos and hermetic bags, are perceived by farmers to work well together).

About 8% of farmers who used both silos and hermetic bags noted that hermetic bags are preferred for short-term storage of smaller quantities of maize. Silos are also used for the long-term storage of large quantities of maize (above 100 Kg). This finding is consistent with that of Alemu et al. (2021), who revealed that the selection of a specific hermetic storage technology to use depends on its storage capacity. The preference is rational because it avoids repeated breaking of the hermetically sealed silos, which reduces the risk of fungal growth and aflatoxin contamination, especially in warm and humid storage environments. According to Villers et al. (2008), uncompromised hermetic seals ensure that the moisture levels in the silo remain constant, preventing fungal growth.

3.3. *Factors influencing smallholder farmers' choice of alternative maize storage technologies in Gatsibo District of Rwanda*

The Multivariate probit results are shown in Table 4, got referring to the system of Eq. (5), which revealed that the MVP model fitted the data well (Wald $\chi^2 = 248.12$; $p = 0.0000$). Since the Likelihood Ratio Chi-Square value (χ^2) (6) = 134 was significant at $p < 0.01$, we reject the null hypothesis that the covariances of the error terms in the adoption equations are not correlated. It implies that farmers' decision

Table 4. Maximum likelihood estimates of factors influencing smallholder farmers' choice of alternative maize storage technologies in Gatsibo District, Rwanda.

Variables	Polypropylene sacks alone			Polypropylene sacks & chemicals			Silos			Hermetic bags		
	COEF.	R.SD	MFX	COEF.	R.SE	MFX	COEF.	R.SE	MFX	COEF.	R.SE	MFX
Household characteristics												
Age of household head	0.55	0.37	0.12	-0.32	0.34	-0.1	0.4	0.4	0.07	-0.6	0.37	-0.16
Sex of household head (1 = Male)	-0.07	0.2	-0.016	0.4*	0.2	0.12	-0.7***	0.26	-0.13	-0.2	0.22	-0.05
Family size (number)	0.07	0.2	0.01	-0.33*	0.2	-0.11	0.6**	0.25	0.11	0.3	0.2	0.08
Schooling of household head (Years)	0.4***	0.14	0.09	-0.2*	0.12	-0.06	0.09	0.15	0.02	0.016	0.16	0.004
Off farm Income (USD)	-0.02	0.05	-0.004	-0.012	0.05	-0.004	0.08	0.056	0.01	0.02	0.05	0.06
Buying maize(1 = yes)	0.15	0.3	0.03	0.3	0.33	0.1	0.03	0.44	0.01	-0.2	0.4	-0.05
Institutional characteristics												
Access to training (1 = Yes)	-0.51**	0.21	-0.11	-1.1***	0.19	-0.35	1.8***	0.34	0.32	1.4***	0.24	0.4
Access to credit (1 = Yes)	-0.42*	0.23	-0.1	0.3	0.21	0.1	-0.8***	0.3	-0.15	0.5**	0.21	0.14
Group-membership (1 = Yes)	-0.62**	0.3	-0.14	0.43	0.3	0.14	0.5	0.35	0.1	-0.3	0.3	-0.08
Farm characteristics												
Other crop plot number	-0.11	0.19	-0.02	-0.13	0.7	-0.4	0.33*	0.2	0.06	0.37**	0.18	0.1
Quantity of maize (Kg)	-0.3*	0.16	-0.07	0.02	0.14	0.007	0.15	0.22	0.03	0.22	0.17	0.06
Distance input market (Km)	0.22	0.14	0.05	0.21**	0.1	0.07	-1.36***	0.13	-0.07	-0.13	0.1	-0.036
Selling maize soon after it dries(1 = Yes)	1.32***	0.32	0.3	-0.2	0.2	-0.06	-0.31	0.26	-0.06	-0.34	0.22	-0.09
Constant	-2	1.54	-0.44	2	1.5	0.66	-5.8***	2.1	-1	-1.1	1.7	-0.32
Log likelihood	-454											
Wald Chi2(χ^2)	248.12***											
Likelihood ratio test χ^2 (6)	134***											

***, **, * represent statistical significance at 1%, 5%, 10% respectively. **COEF:** Coefficient; **RSE:** Robust standard Errors, **MFX:** marginal effect; **n** = 301.

to adopt one technology affects the decision to adopt other technologies. It leads to the conclusion that the results of the multivariate regression are more reliable compared to results from separate univariate regressions. In the following discussion of the results, the effect of a variable on the decision to adopt different storage technologies is considered statistically significant if it is at the 10% significance level or lower, as stated in the table.

Among the socio-demographic characteristics, gender of the household head, family size, and years of schooling of the household head had a significant effect on farmers' choice of alternative maize storage technologies in Gatsibo District. Male-headed households were 12% more likely to use polypropylene sacks with chemicals but 13% less likely to use silos, implying that female-headed households were more likely than male-headed ones to use silos. Since silos avail longer-term chemical-free storage for maize, they complement the caregiving role and household food security concerns of women in the area. This finding contradicts that of Gitonga et al. (2015), who found that the sex of the household head had no significant effect on the adoption of grain silos.

The results in Table 4 show that an increase in family size decreased the probability of choosing polypropylene sack with chemicals by 11% but increased the likelihood of choosing silos by the same margin. This is consistent with the higher food and income needs of larger households, as silos can store more maize and ensure its safety for a long time without requiring the use of chemicals (Hodges et al., 2011). It also points to household efforts to avoid the use of chemicals for maize storage, which is not only expensive but also perceived as detrimental to human health (Umubyeyi and Rukazambuga, 2016).

The number of years of formal schooling by the household head decreased the probability of using polypropylene sacks with chemicals by 6% but increased the probability of using polypropylene sacks without chemicals by 9%. This is because more educated farmers can seek, read, and interpret health-related messages more effectively relative to their uneducated counterparts. Therefore, they are more aware of the side effects of different chemicals used in maize storage on health. This result is supported by the fact that 54% and 24% of farmers who used polypropylene sacks with chemicals used malathion dust and phosphine (fumigant tablets) respectively. It is worth noting that 22% of farmers stated that they often used unauthorized chemicals like Dichlorodiphenyltrichloroethane (DDT). It is an example of a chemical, which is no longer recommended for stored-grain pest control, as it is classified as a health hazard (RAB, 2018). Serious markets rejected maize that has been stored using this chemical, deeming it to be of lower quality. This finding is like that of Gitonga et al. (2015), who observed that an increase in the number of years spent at school by the household head increased the likelihood of adopting storage technologies that maintain the quality of stored maize and do not require the use of chemicals.

Among the institutional factors, training on post-harvest handling and storage of grain reduced the probability of choosing polypropylene sacks with and without chemicals. However, it increased the probability of choosing silos and hermetic bags by 32% and 40%, respectively. This can be taken as evidence that training on post-harvest handling and storage of grains increased farmer awareness of the importance of hermetic maize storage technologies in Gatsibo District. These results are consistent with the findings of Kisogo (2018), who revealed that the selection of hermetic bags and silos have been influenced by access to training while reducing the probability of using Sulphate bags. These results support the conclusion of Kassie et al. (2015) that certain knowledge and skills (imparted during post-harvest handling and storage training) are necessary at the initial introduction of the technology as for its continued use.

Access to credit had a positive and significant effect on the probability of a farmer choosing hermetic bags. A shift from credit no-access to access would increase the choice probability by 14%. However, it would reduce the probability of choosing polypropylene sacks without chemicals by 10% and silos by 15%. This could be since farmers who had access to credit get the financial means to purchase hermetic storage technologies to reduce storage losses. The average price of a hermetic bag and a polypropylene sack was 1400 RwFr (1.6 USD) and 300RwFr (0.33USD), respectively, which is affordable by Rwandese standards. During the survey, farmers intimated that at 83,500 RwFr (92.6 USD), a 500 kg silo was too expensive for them to afford, particularly given that the average credit amount received by farmers was RwFr 23,403 (USD 26). The positive role of credit access to technology adoption observed in this study is consistent with Teklewold et al. (2013), who reported that liquidity-constrained households are less likely to adopt sustainable agricultural practices and technologies which require investment beyond their means. This result is also in line with Adegbola et al., 2010, who found that access to credit reduced the probability of adopting improved wooden granary in Benin.

Membership in farmer groups decreased the probability of choosing polypropylene bags without chemicals by 14%. It suggests that membership in a maize farmer group exposed farmers to information about different advanced storage technologies, reducing their inclination to use polypropylene sacks without chemicals and motivating them to use storage technology that reduces storage losses. This finding is consistent with the argument advanced by Teklewold et al. (2013) and Shiferaw et al. (2006) that social network (membership in farmer group or association) enhances the uptake of technological innovations through the mobilization of resources and information sharing.

The number of plots allocated to other crops had a positive and significant effect on the probability of choosing silos and hermetic bags. An additional plot committed to other crops would increase the likelihood of choosing the two technologies by 6% and 10%, respectively. It suggests that farmers with larger farm sizes are assured to have food that will supplement maize, thus increasing the quantity of maize to store. Farmers are, therefore, more likely to experiment with advanced maize storage technologies since they will need a technology that will assure the security of their stored maize. This result tallies with that of Gitonga et al. (2015), who observed that the increase in farm size influenced the adoption of HST in Kenya. Maonga et al. (2013) found that farmers with large farm sizes were likely to adopt advanced storage technologies in Malawi.

Distance to input markets had a positive and significant effect on the use of polypropylene bags with chemicals. A 1 km increase in the distance to the input provider would increase the probability of choosing polypropylene sacks and reduce that for choosing silos by 7%. The farmers complained that, unlike polypropylene sacks and chemicals, silos were not available in the nearest input markets. Therefore, an increase in transaction cost associated with the transport and search for information to acquire silos over longer distances is a plausible explanation for them choosing polypropylene bags with chemicals found in the nearest input markets. These results are consistent with those of Owach et al. (2017), who found that farmers near (42%) the input market were more informed and more likely to use silo and hermetic bags in Northern Uganda.

Selling maize soon after it dries had a positive effect on the use of polypropylene bags without chemicals. A smallholder farmer who sells his/her maize soon after drying is 30% more likely to use polypropylene sacks. Such farmers hardly store their maize for any length of time; therefore, polypropylene bags meet their needs and are easily affordable. This result is consistent with that of Bokusheva et al., (2012), who reported that farmers who sold their maize immediately after harvest were more likely to use polypropylene sacks as they did not have a plan to store them for a long period. Similarly, Gitonga et al. (2015) found that non-adopters of hermetic maize storage technologies sold most of their maize immediately after harvest, with the quantity consumed at home being higher than that sold.

4. Conclusion and recommendations

This study sought to determine factors affecting the adoption of alternative storage technologies by using the multivariate probit model. The results show that polypropylene sacks, chemicals, hermetic bags, and grain silos are the commonest storage technologies used by smallholder maize farmers in Gatsibo District. Despite government and donor support, only 41% of the respondents had adopted hermetic maize storage technologies at the time of this study. Hermetic and non-hermetic maize storage technologies had potential substitutability, suggesting that the promotion of HST is likely to reduce the use of non-hermetic storage technologies among maize farmers if the right conditions, including pricing, affordability, and availability, are provided. Hence, the adopters of hermetic maize storage technologies differed significantly from non-adopters in terms of their socio-economic characteristics.

The model results revealed that the probability of choosing polypropylene sacks with and without chemicals increased with the household head's years of schooling, his/her gender, selling maize before it dries, and the distance to the input provider. while it decreased with access to training in post-harvest handling and storage, access to credit, group membership, and household size. It suggests that policies facilitating farmers' easy access to input markets, credit and training related to post-harvest and storage loss reduction are recommended to help farmers abandon inadequate storage technologies.

Farmers' choice of silos and hermetic bags, both of which are hermetic maize storage technologies, have been positively influenced by household size, training in post-harvest handling, and storage., Thus, it has been negatively affected by the sex of the household head and the distance to the input provider. Therefore, there is a need to facilitate maize farmers' access to information on post-harvest handling and storage by investing in capacity building and technical support to farmer groups. There is the need to enhance easy access to maize storage technologies, such as hermetic bags and silos through smart subsidies (e.g., grants, and discounted charges for vulnerable farmers) to facilitate their wide adoption.

The number of plots allocated to other crops positively influenced the probability of choosing hermetic storage technologies. There is, therefore, the need to promote crop diversification practices to help farmers increase the quantity of maize stored by complementing it with other crops. It will not only contribute to household food security but also income. If this were to happen, it would motivate farmers to use advanced storage technologies to secure their stored maize.

Declarations

Author contribution statement

Gilberthe Uwera Benimana: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Cecilia Ritho; Patrick Irungu: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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