Motivational Determinants of Adoption of Tarpaulins and Hermetic Bags for Maize Drying and Storage in Rukwa and Katavi Regions, Tanzania

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ABSTRACT

This paper investigated the adoption of two key improved postharvest technologies—tarpaulins for drying and hermetic bags for storage—among smallholder maize farmers in Rukwa and Katavi regions, Tanzania - using the comprehensive Diffusion and Adoption Model. These two technologies were disseminated in the study area, yet adoption rate remained low. The objectives were to: assess the extent of adoption; analyse the motivational factors influencing adoption; and evaluate how these factors affect the likelihood of adoption. A total of 365 farmers were selected through proportionate stratified sampling during the 2021/2022 agricultural season. Data collection involved structured questionnaires for quantitative data and focus group discussions and key informant interviews for qualitative insights. The analysis utilised thematic content analysis and bivariate probit regression using STATA 17. Findings revealed that male farmers were significantly more likely to adopt tarpaulins (Coef = 1.132; p < 0.01), but less likely to adopt hermetic bags (Coef = -2.668; p < 0.01). Older farmers were less likely to adopt hermetic bags (Coef = -0.146; p < 0.01), whereas greater farming experience increased adoption (Coef = 0.112; p < 0.05). Higher income decreased tarpaulin use (Coef = -0.351; p < 0.05) but increased hermetic bag adoption (Coef = 0.774; p < 0.01). Membership in farmer groups (Coef = 0.932; p < 0.01) and access to extension services (Coef = 0.391; p < 0.05) positively influenced hermetic bag adoption. Farmers facing credit limitations were more likely to use tarpaulins (Coef = 0.601; p < 0.01). Negative attitudes and limited awareness reduced adoption rates. The paper highlighted the influence of gender, age, income, experience, social connections, and extension access on technology adoption. It recommends gender-inclusive training, financial support, strengthened extension services, and market incentives to promote adoption. These interventions can reduce postharvest losses, increase incomes, and enhancing food security among smallholder farmers.

Keywords: Bivariate Probit Regression, Hermetic Bags, Motivation, Postharvest Losses, Technology Adoption, Tarpaulins

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I. INTRODUCTION

Postharvest losses (PHLs) pose a significant challenge to global food security, particularly in sub-Saharan Africa, where smallholder farmers rely heavily on staple crops including maize. The adoption of tarpaulins (TPs) for drying maize and hermetic bags (HBs) for storing maize has been recognized as an effective strategy to reduce food waste, preserve grain quality, and improve farmers' incomes. These technologies align with global efforts to achieve food security and sustainable agricultural practices, particularly under the targets set by The Malabo Declaration (African Union Commission, 2014), which set the target to reduce postharvest losses in Africa by 50% by 2025. The Sustainable Development Goal (SDG) 12.3 aims to halve global food waste and reduce food losses along production chains by 2030. United Republic of Tanzania's Postharvest Management Strategic Plan (2019-2029) (URT, 2019) aligns with these goals, emphasizing improved storage solutions (United Republic of Tanzania-URT, 2019). Despite these efforts, widespread adoption of tarpaulins and hermetic bags remain limited due to lack of awareness and training among smallholder farmers, high initial costs making these technologies inaccessible to many farmers, and limited policy enforcement and investment in postharvest management systems.

The Food and Agriculture Organization (FAO, 2019) defines postharvest losses as quantifiable decrease in quantity or quality of food from harvest to, but excluding, the retail level, encompassing losses during storage, transportation, and processing. These losses waste valuable resources such as labour, water, and fertilizers while also reducing food availability (Mutungi *et al.*, 2020). PHLs continue to pose a threat due to inefficiencies in food use and preservation. Global data suggest that one-third of food produced annually is lost or wasted, with economic losses amounting to US$ 680 billion in industrialized countries and US$ 310 billion in developing countries (Jeremic *et al.*, 2024). Both industrialized and developing countries waste comparable amounts of food, approximately 670 million and 630 million tons, respectively (Sawicka, 2020). Reducing postharvest losses has, therefore, been recognised as a critical pathway to global food security. However, knowledge about improved postharvest drying and storage technologies, such as TPs and HBs, remains limited among smallholder farmers (Strecker *et al*., 2022).

Drying is a crucial postharvest stage that determines the storability and safety of grains. Traditional drying methods, such as spreading maize directly on bare ground, lead to increased moisture retention, promoting mould growth and aflatoxin contamination. Also, traditional drying methods cause pest infestation, contamination from soil contact, and higher drying losses, reaching 32% in some cases (Abass *et al*., 2018). Using tarpaulins for drying significantly improves maize preservation. Tarpaulins reduce drying losses to about 1.56% (Wuiya *et al*., 2022), prevent contamination by keeping grains off the ground, ensure uniform drying, and reduce postharvest fungal infestation. However, proper training and access to tarpaulins remain key challenges, preventing many farmers from realising these benefits.

Once maize is dried to the optimal moisture content, safe storage is necessary to prevent deterioration. Traditional storage methods, such as woven polypropylene bags allow pest infestation, leading to significant weight losses, mould growth, increasing aflatoxin contamination, nutritional degradation, and reducing the quality of stored maize. Hermetic storage solutions, such as hermetic storage bags, have emerged as a superior alternative to conventional grain storage. Hermetic bags create an oxygen-free environment which inhibits pest survival and prevent reinfestation, reduce mould growth and aflatoxin contamination, and preserve grain quality for several months without pesticide use. Studies have confirmed that hermetic bags outperform traditional storage methods, ensuring safer and longer-lasting grain storage (Akumu *et al*., 2020).

Encouraging farmers to adopt improved postharvest technologies requires a combination of intrinsic and extrinsic motivational factors. Intrinsic motivation involves personal satisfaction and attaining long-term benefits. Farmers who understand the benefits of tarpaulins and hermetic bags are more likely to adopt and sustain their use. Thus, long-term food security and increased income act as intrinsic motivators. Extrinsic motivation involves external incentives and financial support whereby subsidies, financial incentives, and government programmes can encourage farmers to invest in these technologies. Also, training programmes and farmer demonstrations can increase adoption rates. However, over-reliance on external incentives may undermine long-term engagement, highlighting the need for balanced strategies (Bandhu *et al*., 2024; Nazarli, 2024).

The selected improved postharvest loss reduction technologies (uses of tarpaulins and hermetic bags) were validated by 'Helvetas' Tanzania (2020), as part of a network of independent development organisations. Moreover, the effectiveness of tarpaulins and hermetic bags has been validated through practical projects such as the Grain Postharvest Loss Prevention (GPLP) project, implemented by Helvetas Tanzania under the Save Safe Food (SSF) program (2019-2022) in Rukwa and Katavi Regions. The project outcomes were to benefit over 100,000 smallholder farmers, create at least 200 jobs for local entrepreneurs, and reduce grain losses by more than 85% (Abass *et al*., 2018). Despite these successes, adoption rates remain below expectations, with the Tanzanian government aiming to attain at least 50% adoption (African Union-Malabo Declaration, 2014; URT, 2019). However, Ngowi and Selejio (2019) reported an adoption rate of just 19%, indicating that further interventions are needed.

1.1 Statement of the Problem

The low adoption of improved grain postharvest handling technologies, such as uses of tarpaulins and hermetic bags among smallholder maize farmers in rural Tanzania presents a significant challenge to food security and economic growth. Despite the availability of tarpaulins and hermetic bags, their adoption is influenced by economic constraints, including household income, credit access, and technology costs (Onuwa *et al*., 2023), as well as social networks and community support (Akpan-Etuk, 2024). Cultural norms, gender roles, and farmers' perceptions also shape the uptake of the technologies (Straver *et al*., 2023; Swart *et al*., 2023). Additionally, education levels and access to information play a critical role; well-trained farmers are more likely to adopt modern grain postharvest handling technologies (Ahmed & Ahmed, 2023). Institutional support, such as agricultural extension services and training programmes, further affect adoption rates (Ahmed & Ahmed, 2023). While economic incentives are often emphasized, socio-psychological factors significantly influence farmers' decisions (Swart *et al*., 2023). Without addressing these underlying barriers, efforts to promote improved postharvest storage technologies might remain ineffective. A deeper understanding of these factors is crucial for designing targeted policies that align with farmers' needs and motivations, ultimately enhancing postharvest handling and reducing postharvest losses among smallholder maize farmers in Tanzania.

1.2 Research Objectives

Therefore, the specific objectives of this paper were to

i. Assess the extent of adoption of tarpaulins and hermetic bags among smallholder maize farmers,
ii. Analyse motivational factors for adoption of tarpaulins and hermetic bags, and
iii. Examine the influence of these motivational factors on adoption likelihood.

II. LITERATURE REVIEW

2.1 Theoretical Review

Two models and two theories underpinned the paper to analyse the decision-making processes of smallholder maize farmers regarding technology adoption. The models and theories are the Economic Constraints Model that was introduced by Eliyahu M. Goldratt in 1984, the Technology Acceptance Model (TAM) that was pioneered by Fred Davis in 1989, the Theory of Planned Behaviour (TPB) that was pioneered by Icek Ajzen in 1985, and the Diffusion of Innovation (DOI) Theory that was pioneered by Everett M. Rogers in 1983. The models and theories were applied to this paper complementarily.

2.1.1 The Economic Constraints Model

The Economic Constraints model highlights the role of financial limitations, income fluctuations, and credit access in shaping technology adoption decisions. Farmers assess the financial implications of adopting new technologies, weighing potential benefits against costs and opportunity costs (Ogunleye *et al*., 2024; Aleke, 2024). Limited credit access can hinder investment in innovations, while income variability may lead farmers to prioritise immediate needs over long-term benefits (Vijitwrannont *et al*., 2023; Wisdom *et al*., 2014).

2.1.2 The Technology Acceptance Model (TAM)

TAM focuses on perceived ease of use and perceived usefulness, both of which are influenced by economic conditions (Spencer, 2021). Farmers are more likely to adopt technologies they find easy to use and beneficial for their productivity.

2.1.3 The Theory of Planned Behaviour (TPB)

TPB extends TAM by incorporating attitudes, subjective norms, and perceived behavioural control. Farmers' attitudes toward adoption are shaped by economic constraints, while subjective norms reflect community influence. Perceived behavioural control is affected by external factors such as access to training and extension services (Borges *et al*., 2015).

2.1.4 The Diffusion of Innovation (DOI) Theory

The theory examines how innovations spread within communities. Social networks, peer recommendations, and economic incentives play key roles in adoption. Technologies that provide visible benefits to early adopters can influence wider adoption within farming communities (Kaur & Kaur, 2010).

While these models and theories provide a robust framework, adoption outcomes vary due to individual circumstances, farm size, crop type, and socio-economic contexts. Thus, tailored approaches are necessary to effectively promote technology adoption.

2.2 Empirical Review

This section reviews empirical studies relevant to the adoption of agricultural technologies, particularly tarpaulins and hermetic bags, by smallholder maize farmers. The review is organized to reflect the study's three specific objectives: assessing the extent of adoption, analysing motivational factors, and examining how these factors influence adoption likelihood.

2.2.1 Adoption Extent of Agricultural Technologies

Several studies have investigated the level of adoption of agricultural innovations among smallholder farmers in Sub-Saharan Africa. Bontsa *et al*. (2023) reported low adoption levels of digital agricultural tools among maize farmers in South Africa, largely due to financial constraints. Similarly, Tanko (2021) found moderate adoption rates of hybrid rice varieties and irrigation technologies in Ghana, influenced by farmers' income levels and access to financial services. These findings underline the need to assess not only the availability but also the actual uptake of technologies such as tarpaulins and hermetic bags among smallholder maize farmers.

2.2.2 Motivational Factors Influencing Adoption

A number of motivational drivers have been identified across different theoretical models. The Economic Constraints Model emphasizes financial capacity as a core motivator. Bontsa *et al*. (2023) found that access to agricultural credit and subsidies significantly motivated farmers to invest in modern tools. Similarly, Zakaria (2018) emphasized that higher income levels increased the willingness to adopt improved maize technologies. Under the Technology Acceptance Model (TAM), Jin *et al*. (2022) found that farmers who had access to extension services and higher literacy levels were more likely to perceive new technologies as useful and easy to use. Asante *et al*. (2024) highlighted the role of extension officers in boosting acceptance through tailored support and training—key motivational factors for farmers considering postharvest technologies. The Theory of Planned Behaviour (TPB) points to psychological and social motivators. Waiswa *et al*. (2025) identified peer influence and perceived behavioural control such as availability of extension services—as strong motivational factors in adopting push-pull technology. Emmanuel *et al*. (2022) further emphasized the importance of subjective norms, noting that farmer-to-farmer recommendations strongly motivated adoption, sometimes more than economic incentives.

2.2.3 Influence of Motivational Factors on Adoption Likelihood

The role of motivational factors in determining adoption likelihood has also been empirically validated. Karbo *et al*. (2024), drawing on Diffusion of Innovation (DOI) Theory, observed that early adopters played a significant role in influencing broader adoption through demonstration plots and peer learning. This suggests that behavioural and social factors, such as learning from others and observing successful use, can substantially increase adoption probabilities. Similarly, Kergna et al. (2017) demonstrated how ICT-based information sharing enhanced technology diffusion among younger farmers in Mali, showing that access to timely, user-friendly information can significantly raise adoption likelihood.

III. METHODOLOGY

3.1 Research Area, Population, sampling, and Sample Size

The study was conducted in Rukwa and Katavi Regions, which are among the major maize-producing regions in Tanzania. The two regions are characterized by bi-modal rainfall patterns, with a single maize cropping season running from December to April and the harvesting season being between May and July. The total land under maize production in the two regions is 340,593 ha, and the annual production in the 2018/19 season was 853 626 MT. Rukwa and Katavi regions jointly contribute an estimated 14.4% of Tanzania's total maize output, which stood at 5.9 million tons in the 2021/22 season (Ministry of Agriculture & National Bureau of Statistics, 2022). The main farming systems comprise other crops, predominantly sunflower (*Helianthus annus*), bean (*Phaseolus vulgaris*), groundnuts (*Arachis hypogaea*) and paddy (*Oryza sativa*). Other commercial crops grown in Katavi Region include cotton and tobacco.

Purposive sampling technique was used to select four districts, namely Sumbawanga and Nkasi in Rukwa Region and Mpimbwe and Tanganyika in Katavi Region. The districts were purposively selected because they contribute a substantial proportion of maize output in the regions, based on their functioning and long time they had been involved in maize postharvest handling and management practices. The surveyed households in each study village involved 25 households which were randomly selected from households which had received a postharvest management (PHM) intervention from a project funded by the Alliance for a Green Revolution in Africa (AGRA). AGRA (2021) created awareness and dissemination of postharvest handling and management practices, and HELVETAS (2020) facilitated distribution channels to manufacturers, agro-dealers and vendors of tarpaulins and hermetic bags.

The study employed a cross-sectional research design. The sample size was 400 households. The sample size was estimated using Yamane's formula (Yamane, 1967), which is:

$$n = \frac{N}{1+[N(e^2)]} \quad \ldots\ldots (1)$$

Where:

n = Sample size,

N = Population size, i.e., 136,748 maize growing households in Rukwa and Katavi Regions, and

e = Level of precision (sampling error) = 5% or 0.05

Therefore = 136,748/1 + [(136,748*0.05*0.05)] = 136,748/1+341.87 = 136,748/342.87 = 398.8334 ≈ 400 households. However, 365 households well filled out questionnaire copies; they are the ones which were included in the analysis.

Proportionate stratified sampling was used to select farmers from sixteen villages. The selected villages had a good history of maize production, experienced high postharvest losses, had postharvest management interventions, and reflected the overall socio-economic and demographic characteristics of the regions (e.g., diversity in household size, income levels, and gender composition of households' heads). The last stage for selection of farmers was simple random sampling method using the lottery technique. The selection of farmers was done from lists of smallholder farmers obtained from village registers. Then questionnaire copies were used to interview the 400 selected respondents, but only 365 of them were filed out. This was due to some respondents providing incomplete, incorrect, and unreliable information, making their data unusable. Thus, these cases were excluded from the final analysis and hence lowered the sample size. The study employed the mixed methods approach in data collection whereby quantitative and qualitative data were collected concurrently to triangulate data collection methods. Primary data were collected using a structured questionnaire, key informant interviews (KIIs), and focus group discussions (FGDs). The participants in KIIs and FGDs were obtained through purposive sampling. The KIIs and the FGDs were guided by a checklist and an FGD guide, respectively. A total of ten (10) key informants were interviewed, including four (4) agricultural extension officers, one (1) in each district; four (4) agro dealers/vendors, one (1) in each district; and two (2) representatives of local agricultural equipment manufacturers, one (1) in each region. Moreover, eight (8) FGDs, each involving 8 to 12 participants—males and females—were conducted, i.e. 2 FGDs in each district. The measurement of variables for this paper is described below, and the data collection and analysis methods are summarised in Table 1.

3.2 Model Specification

The model specification for analysing the adoption of tarpaulins and hermetic bags could be structured using a Bivariate Probit Regression Model. This model is appropriate when examining two related binary variables, as in this case where the adoption of tarpaulins and hermetic bags are both binary (used/not used). The bivariate probit model accounts for joint decision-making, allowing for understanding how the adoption of one technology might influence the other technology (Greene, 2012; Genius *et al*., 2014). The key aspects of this model are that it relies on joint normality of errors, instruments exogeneity, and relevance conditions, which are important for valid inference (Acerenza *et al*., 2023).

The bivariate probit model for technology adoption was specified as follows:

γ_1^* = The latent (unobserved) propensity to adopt tarpaulins (TPs).

γ_2^* =The latent propensity to adopt hermetic bags (HBs).

The observed binary variables γ_1 and γ_2 are defined as:

$$\gamma_1 = \begin{cases} 1 \; if\ the\ farmer\ adopts\ tarpaulins \\ 0 \; otherwise \end{cases}$$

$$\gamma_2 = \begin{cases} 1 \; if\ the\ farmer\ adopts\ hermetic\ bags \\ 0 \; otherwise \end{cases} \quad \ldots\ldots (2)$$

The latent variables γ_1^* and γ_2^* are modelled as functions of the independent variables:

$$\gamma_1^* = \beta_1 x_1 + \beta_2 x_2 + \ldots \beta_k x_k + \varepsilon_1$$

$$\gamma_2^* = \gamma_1 x_1 + \gamma_2\, x_2 + \ldots \gamma_k\, x_k + \varepsilon_2 \quad \ldots\ldots (3)$$

Where:

$x_1, x_2, \ldots, x_k$ are the independent variables (e.g., age, household size, trialability, cost of technology, etc.)

$\beta_1, \beta_2, \ldots, \beta_k$ and $\gamma_1\, \gamma_2, \ldots, \gamma_k$ are parameters to be estimated.

ε_1 and ε_2 are error terms assumed to follow a bivariate normal distribution with zero means, unit variance and correlation p.

The correlation between the error terms (p) was important to the bivariate probit model, as it captured the potential interdependence in the adoption decisions for the two technologies.

Joint Probability Function:

The joint probability of observing specific values for γ_1 and γ_2 can be expressed as

$$\rho(\gamma_1 = 1, \gamma_2 = 1) = \rho(\gamma_1^* > 0,\ \gamma_2^* > 0) \quad \ldots\ldots (4)$$

The likelihood function for the bivariate probit model can then be maximized to estimate the parameter β and γ, as well as the correlation ρ. Table 1 describes the explanatory variables used in this study.

Table 1
Variable List and Description

Variable	Description	Type	Value	Expected sign	
				HBs	TPs
Dependent Variable					
Hermetic bags adoption	Used, not used	Dummy	(1, 0)		
Tarpaulins (TPs) adoption	Used, not used	Dummy	(1, 0)		
Independent Variables					
x_1 = Sex	Gender of household head	Nominal dichotomous	(1, 2)		
x_2 = Age	Years since the household was born	Continuous			
x_3 = Education level	Different stages of formal education	Categorical		+	+
x_4 = Household size	Number of household members	Continuous		+	+
x_5 = Farming experience	Number of years of farming	Continuous		+	+
x_6 = Income	Amount of money earned per capita per year	Continuous			+
x_7 = Trialability	The ability to test an intervention on a small scale: Low, moderate or high	Ordinal	(0, 1, 2)	+	+
x_8 = Performance of technology	Practical use of tools to improve the desired outcome: Low, moderate or	Ordinal	(0, 1, 2)	+	+
x_9 = Technology mastery	Effective use of technology: Low, moderate, or high	Ordinal	(0, 1, 2)	+	-
x_{10} = Belonging to a social group	Multiple individuals who connect and possess similar qualities: Low, moderate, or high	Ordinal	(0, 1, 2)	-	+
x_{11} = Maize price at harvest	Farm harvest price: Low, moderate or high	Ordinal	(0, 1, 2)	-	+
x_{12} = Off-farm income	Capacity of off-farm income to substitute for purchases of technology from maize income: Low, moderate or high	Ordinal	(0, 1, 2)	+/-	+/-
x_{13} = Information acquisition	The task of capturing relevant information about postharvest handling: low, moderate, and high.	Ordinal	(0, 1, 2)	-	+
x_{14} = Extension services	Offering of postharvest technical advice to farmers: Low, moderate or high	Ordinal	(0, 1, 2)	+	+
x_{15} = Credit constraints	Inability of the household head to borrow against future income: Low, moderate or high	Ordinal	(0, 1, 2)	+	-

The Factor Analysis (FA) results indicated in supplementary material 1 provide critical insights for preparing data for the Bivariate Probit Model (BPM) by addressing multicollinearity and simplifying the dataset. By retaining 16 factors with eigenvalues greater than 1, the analysis captured significant variance, ensuring that only essential dimensions were included in the BPM. This process enhanced the model's precision and explanatory power. FA effectively summarized correlated variables into fewer factors, mitigating multicollinearity issues. The first four factors alone explained 71% of the variance, indicating their importance in predicting the data's underlying structure (Tanaka & Matsui, 2023). The use of FA allows for a more efficient selection of variables, as it reduces the number of predictors while retaining critical information. By including only the most informative factors, the BPM can provide more accurate estimates, as it reduces noise from redundant variables.The high eigenvalues of the retained factors suggest that they captured substantial information, enhancing the model's explanatory capabilities (Küçükalkan, 2023). On the contrary, while FA aids in simplifying the dataset, it may also lead to loss of nuanced information from individual variables, which could be critical in certain analyses. Thus, a balance was struck between simplification and retaining essential data characteristics.

The Factor Loading (FL) results in supplementary material 2 provided critical insights into the relationships between observed variables and underlying factors, particularly in the context of model interpretation and variable selection. The strong negative loadings of variables like TPTP 1 (trialability)and IFTP3 (Hired labour cost) on factor 1 suggest a significant association with this factor, indicating their relevance in the analysis. This relationship aids in understanding which variables contribute meaningfully to the model, while the uniqueness values highlight the proportion of variance not explained by the factors, guiding the removal of less informative variables. Variables TPTP 1 and IFTP3 exhibited strong negative loadings on factor 1, indicating a robust relationship with this underlying factor (Vs *et al.*, 2024). Variables with high uniqueness are often excluded to enhance model fit and interpretability, streamlining the analysis (Raulgaonkar, 2021). On the contrary, while factor analysis simplifies complex relationships, it may overlook unique contributions of certain variables, potentially leading to exclusion of valuable information in specific contexts. This highlights the importance of balancing factor reduction with the retention of significant variables.

IV. FINDINGS & DISCUSSION

As seen in the abstract and in the introduction to this paper, the objectives of this paper were to assess the extent of adoption of tarpaulins and hermetic bags among smallholder maize farmers, analyse motivational factors for adoption of tarpaulins and hermetic bags for maize drying and storage, and determine influence of motivational factors on adoption of tarpaulins and hermetic bags for maize drying and storage. This chapter gives results which are aligned with the objectives, in sections 4.1, 4.2 and 4.3.

4.1 Smallholder maize farmers who adopted uses of Tarpaulins and Hermetic bags

In order to achieve the first objective of this paper, the numbers and frequencies of smallholder maize farmers who had adopted the uses of tarpaulins and hermetic bags for drying and storing maize, respectively, were calculated. Prior to obtaining the numbers, the extent of adoption of those technologies was expressed in terms of frequencies, and the respondents were divided into two groups: those who had not adopted any of the technologies (No adoption = 0), and those who had adopted either tarpaulins or hermetic bags (Adoption = 1). Table 2 shows the numbers and per cents of households in the two groups during the agricultural season 2021/2022.

Table 2
Farmers who had Adopted Uses of Tarpaulins and Hermetic Bags

Use of technologies adopted	Yes		No	
	n	%	n	%
Tarpaulins for drying maize	124	34.0	241	66.0
Hermetic bags for storing maize	82	22.5	283	77.5

As seen in Table 2, about one third (34.0%) of the smallholder maize farmers surveyed had adopted tarpaulins for drying maize, while 66.0% had not. The adoption was commendable because tarpaulins provide a clean, controlled surface for drying maize, which could significantly reduce post-harvest losses caused by contamination and moisture (Kaminski & Christiaensen, 2014). Studies have shown that farmers using tarpaulins could improve the quality of their maize, leading to better market prices (Gizachew *et al.*, 2021). Due to these benefits of using tarpaulins for drying maize, the percentage of farmers who had adopted tarpaulins was expected to be much higher than that. The cost of tarpaulins, which the farmers said was relatively high, was among the main factors for the low adoption. This is supported by literature which says that the cost of tarpaulins could be prohibitive for many small-scale farmers (Affognon *et al.*, 2015). Limited awareness and knowledge about the benefits and proper use of tarpaulins were also other hindrances of tarpaulins adoption (Kumar & Kalita, 2017).

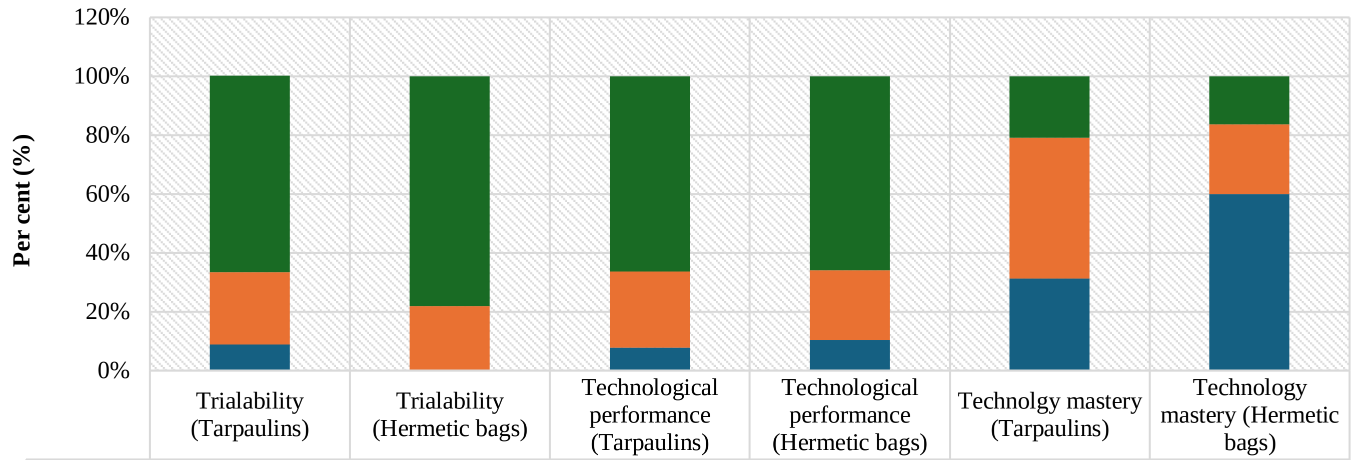
More than one-fifth (22.5%) of the farmers surveyed had adopted hermetic bags for storing maize, while 77.5% had not. The adoption per cent is commendable since using hermetic bags is highly effective in preventing pest infestation and maintaining grain quality during storage by creating an airtight environment (Murdock & Baoua, 2014). The use of hermetic storage technology could substantially reduce post-harvest losses and improve food security (Murdock & Baoua, 2014). Despite these benefits, the per cent of the farmers who had adopted the use of hermetic bags was very small. Similar to tarpaulins, the initial cost of hermetic bags could be a barrier, particularly for smallholder farmers (Jones *et al.*, 2011). The adoption might also be influenced by traditional storage practices and uncertainty about new technologies (Fuglie & Kascak, 2001).

4.2 Smallholder Maize Farmers' Motivational Factors for Adoption of Tarpaulins and Hermetic Bags

Smallholder maize farmers' motivational factors for adoption of tarpaulins and hermetic bags were determined using an index summated scale which comprised 26 items, divided into three categories of technological (3 items), economic (6 items) and institutional (4 items) factors for adoption of each of the two technologies studied: uses of tarpaulins and hermetic bags for drying and storing maize, respectively. For each of the items, the respondents were required to answer low, moderate or high to reflect the extents to which the items motivated them to adopt uses of tarpaulins and hermetic bags. The frequencies of the scores on the scale's items are presented in sub-sections 4.2.1 to 4.2.3.

4.2.1 Extents to which Technological Factors Motivated Adoption of Tarpaulins and Hermetic Bags

The frequencies of respondents' opinions on the extents to which technical performance, trialability, and effectiveness of technologies motivated them to adopt uses of tarpaulins and hermetic bags are presented in Figure 1.



	Trialability (Tarpaulins)	Trialability (Hermetic bags)	Technological performance (Tarpaulins)	Technological performance (Hermetic bags)	Technolgy mastery (Tarpaulins)	Technology mastery (Hermetic bags)
High	66.60%	78.10%	66.30%	66.00%	20.80%	16.40%
Moderate	24.70%	21.90%	26.00%	23.60%	47.90%	23.60%
Low	8.80%	0.00%	7.70%	10.40%	31.20%	60.00%

Figure 1
Technological Factors for Tarpaulins and Hermetic Bags Adoption

Two-thirds (66.6%) of farmers found tarpaulins highly trialable, meaning that they could test them before full-scale adoption. Hermetic bags had an even higher trialability (78.1%), with no reporting low trialability. This suggests that farmers found it easy to experiment with both technologies before committing to them. These findings align with Rogers' Diffusion of Innovations Theory, which emphasizes trialability as a crucial factor influencing technology adoption. According to Rogers, when innovations can be tested on a small scale before full adoption; they are more likely to be accepted. Similarly, Rizzo *et al*. (2024) found that trialability reduces financial risk, making farmers more comfortable with new agricultural technologies.

The findings indicated that 66.3% of farmers perceived tarpaulins as having high technological performance, while 66.0% of farmers reported the same for hermetic bags. However, 10.4% of farmers found hermetic bags ineffective, suggesting performance inconsistencies. This could be due to improper usage, poor storage conditions, or limited knowledge about the best storage practices. According to Doss (2006), performance consistency is crucial for long-term technology adoption. If farmers experience variability in performance, they are less likely to continue using the technology. Similarly, Gollin and Rogerson (2010) found that mixed perceptions about technology effectiveness could hinder widespread adoption.

Farmers provided mixed feedback regarding tarpaulin effectiveness for maize drying: 20.8% of respondents found tarpaulins highly effective; 47.9% viewed them as moderately effective; 31.2% rated their effectiveness as low. Farmers who found tarpaulins moderately or poorly effective cited issues such as uneven drying, unfavourable weather conditions, and difficulties in managing large drying areas. This indicates that adoption could be improved through better training on optimal tarpaulin use. Similarly, 60.0% of respondents faced significant storage challenges with hermetic bags, likely due to their high prices. According to Asfaw *et al.* (2012), high costs are a major deterrence to technology adoption, even when the long-term benefits outweigh initial expenses.

Findings from key informant interviews and focus group discussions (FGDs) also reinforced the financial constraints and awareness challenges faced by farmers:

> *"Farmers like to use tarpaulins and hermetic bags to avoid using insecticides and pesticides, but because of the high prices, they only purchase a few."*(District Agricultural & Livestock Development Officer, Sumbawanga District, 14th December 2022).

The above view of a Key Informant Interviewee was in line with the consensus of an FGD below:

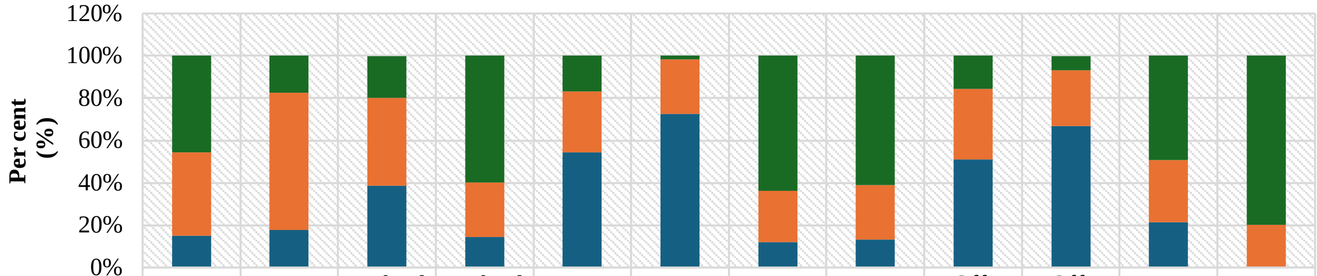
> *"We use a small number of hermetic bags to store maize for household consumption but rely on polypropylene bags for maize meant for sale. We would prefer using hermetic bags to avoid pesticides,*

*but due to their high costs, we cannot store all our maize in them."(*Majimoto Ward FGD session, Mpimbwe D.C., 11th January 2023).

These quotations highlight cost as a major limitation to using tarpaulins and hermetic bags , suggesting the need for financial support, subsidies, or credit facilities to increase adoption rates.

4.2.2 Economic Factors for Tarpaulins and Hermetic Bags Adoption

The bar chart in Figure 2 illustrates frequencies of adoption of tarpaulins and hermetic bags by smallholder farmers, based on various economic factors. The responses are segmented into three levels: High, Moderate, and Low. Below is an analysis of each economic factor in terms of the extent to which it motivated the farmers interviewed to adopt uses of tarpaulins and hermetic bags.



	Farm size (Tarpaulins)	Farm size (Hermetic bags)	Technological cost (Tarpaulins)	Technological cost (Hermetic bags)	Labour cost (Tarpaulins)	Labour cost (Hermetic bags)	Affordability (Tarpaulins)	Affordability (Hermetic bags)	Off-farm income (Tarpaulins)	Off-farm income (hermetic bags)	Maize price at harvest (Tarpaulins)	Maize price at harvest (Hermetic bags)
High	45.8%	17.3%	19.7%	59.7%	16.7%	1.6%	63.8%	61.1%	15.6%	6.8%	49.3%	79.7%
Moderate	39.2%	64.9%	41.6%	25.8%	28.8%	25.8%	24.1%	25.8%	33.2%	26.3%	29.3%	20.3%
Low	15.1%	17.8%	38.6%	14.5%	54.5%	72.6%	12.1%	13.2%	51.2%	66.8%	21.4%	0.0%

Figure 2
Economic Factors for Tarpaulins and Hermetic Bags Adoption

Tarpaulin adoption was higher among large-scale farmers (45.8%), while hermetic bag adoption was higher among moderate-scale farmers (64.9%). These findings suggest that larger farms benefit more from tarpaulin use, while moderate-sized farms find hermetic bags more cost-effective for storage. This aligns with Rizzo *et al*. (2024) and Mausch *et al*. (2021), who found that farmers with larger land sizes were more likely to invest in improved postharvest technologies.

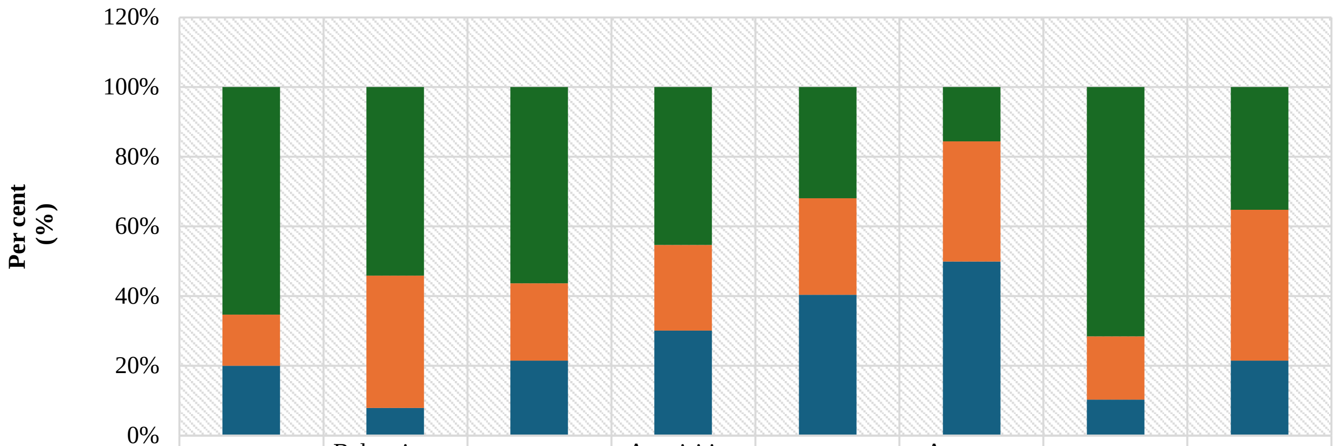
Nearly 60% of the farmers interviewed rated hermetic bags as highly expensive, making affordability a major adoption constraint; 41.6% found tarpaulins expensive, though they were still more affordable than hermetic bags. According to Doss (2006), high initial costs discourage adoption, even when long-term benefits exist. Similarly, Sheahan & Barrett (2017) emphasized that the cost barrier is one of the main reasons for low adoption rates of agricultural technologies.

About 72.6% of farmers found hermetic bags labour-intensive, compared to 54.5% for tarpaulins. Since hermetic bags require proper filling, sealing, and careful storage, they are perceived as more labour-intensive, limiting adoption. Mausch *et al*. (2021) found that technologies requiring additional labour face lower adoption rates in smallholder farming systems.

Two-third (66.8%) of farmers cited limited off-farm income as a barrier to adopting hermetic bags, and 51.2% reported the same for tarpaulins. Off-farm income plays a critical role in investment in new technologies. Asfaw *et al*. (2012) found that farmers with diversified income sources are more likely to adopt new agricultural innovations.

4.2.3 Institutional Factors for Tarpaulins and Hermetic Bags Adoption

The bar chart in Figure 3 illustrates the adoption frequencies of tarpaulins and hermetic bags by smallholder farmers, based on various institutional factors.



	Belonging to a social group (Tarpaulins)	Belonging to a social group (Hermetic bags)	Acquisition of information (Tarpaulins)	Acquisition of information (Hermetic bags)	Access to extension services (Tarpaulins)	Access to extension services (Hermetic bags)	Credit constraints (Tarpaulins)	Credit constraints (Hermetic bags)
High	65.20%	54.00%	56.20%	45.20%	31.80%	15.60%	71.50%	35.10%
Moderate	14.80%	38.10%	22.20%	24.70%	27.70%	34.50%	18.10%	43.30%
Low	20.00%	7.90%	21.60%	30.10%	40.50%	49.90%	10.40%	21.60%

Figure 3
Institutional Factors for Adoption of Tarpaulins and Hermetic Bags

More than five-eighths (65.2%) of farmers in social groups had adopted tarpaulins, while 54.0% of farmers in social groups adopted hermetic bags. Farmers who participated in social networks, cooperatives, or farmer groups were more likely to adopt both technologies due to shared knowledge and collective purchasing power. This supports Mwangi and Kariuki (2015), who found that peer influence and information sharing encourage technology adoption.

About two-fifths (40.5%) of farmers cited limited extension support as a barrier to tarpaulin adoption, and 49.9% reported the same for hermetic bags. According to Singh *et al*. (2015), farmers who receive frequent extension visits are more likely to adopt improved storage and drying techniques. Nearly three-quarters (71.5%) of farmers cited lack of credit as a major barrier to adopting tarpaulins, and 43.3% cited the same for hermetic bags. Diagne and Zeller (2001) found that access to microloans significantly increased the likelihood of agricultural technology adoption.

4.3 Relationship between Motivational Factors and Tarpaulins and Hermetic Bags Adoption

The study categorizes smallholder maize farmers based on their adoption of postharvest technologies: tarpaulins for drying (34.0% adoption, 66.0% non-adoption) and hermetic bags for storage (22.5% adoption, 77.5% non-adoption). This classification provides a clear understanding of technology uptake and its influencing factors.

Table 3 presents the results of bivariate probit regression. The bivariate probit regression analysis identified key socio-demographic and economic factors influencing the adoption of tarpaulins (TP) for drying and hermetic bags (HB) for storage**.** Significant variables (e.g., sex, age, income, farming experience, household size) highlight major adoption drivers. Marginal effects (dy/dx) indicate the probability change due to each factor. Model fit statistics (Chi-square, AIC) confirm joint estimation validity. This analysis clarifies adoption motivations and informs targeted interventions.

Table 3

Bivariate Probit Regression Results for Adoption of Tarpaulins and Hermetic Bags

Variable	**Adoption of TP**		**Adoption of HB**	
	Coef.	**dy/dx**	**Coef.**	**dy/dx**
Sex	1.132*** (0.232)	0.379*** (0.075)	-2.668*** (0.328)	-0.273*** (0.079)
Age	0.028 (0.022)	0.01 (0.007)	-0.146*** (0.054)	-0.015** (0.006)
Farming experience	-0.034 (0.022)	-0.011 (0.007)	0.112** (0.051)	0.011** (0.005)
Education level	0.073 (0.124)	0.024 (0.042)	-0.339 (0.224)	-0.035 (0.024)
Household size	0.006 (0.041)	0.002 (0.014)	0.165** (0.068)	0.017** (0.009)
Income per capita	-0.351** (0.174)	-0.118** (0.058)	0.774*** (0.274)	0.079** (0.033)
Trialability	0.182 (0.14)	0.061 (0.047)	0.474 (0.326)	0.048 (0.035)
Farmers' perception about performance of technology	-0.435*** (0.133)	-0.146*** (0.045)	0.2 (0.341)	0.02 (0.034)
Technology familiarity & Mastery	-0.259** (0.122)	-0.087** (0.041)	0.288 (0.264)	0.029 (0.027)
Trialability	0.03 (0.217)	0.01 (0.073)	0.997** (0.445)	0.102** (0.046)
Farmers' perception about performance of technology	-0.657*** (0.154)	-0.22*** (0.051)	-0.18 (0.247)	-0.018 (0.025)
Technology familiarity & Mastery	-0.21 (0.13)	-0.07 (0.044)	-0.84** (0.34)	-0.086*** (0.032)
Maize price at harvest	0.402*** (0.118)	0.135*** (0.039)	-0.133 (0.188)	-0.014 (0.019)
Off-farm income	0.161 (0.142)	0.054 (0.047)	-0.547** (0.279)	-0.056* (0.031)
Belonging to a social group	-0.021 (0.119)	-0.007 (0.04)	0.932*** (0.245)	0.095*** (0.028)
Acquisition of information	-0.225** (0.115)	-0.075** (0.038)	-0.195 (0.211)	-0.02 (0.021)
Access to extension services	-0.194 (0.121)	-0.065 (0.04)	0.391** (0.199)	0.04* (0.023)
Credit constraints	0.601*** (0.159)	0.201*** (0.052)	0.223 (0.25)	0.023 (0.026)
Acquisition of information	0.455*** (0.115)	0.152*** (0.038)	-0.504*** (0.183)	-0.051** (0.021)
Constant	2.98 (2.958)		-10.953** (4.81)	
athrho	**-10.15 (389.964)**			
LR test of rho=0: chi2(1) = 31.3172 Prob > chi2 = 0.0000				
Mean dependent var	0.225		**SD dependent var**	0.418
Number of obs	365		**Chi-square**	189.128
Prob > chi2	0		**Akaike crit. (AIC)**	518.406

*** p<.01, ** p<.05, * p<.1

The results in Table 3 show a gender difference in adoption: Being male significantly increased the likelihood of adopting tarpaulins. The coefficient of 1.132, significant at the 1% level, suggests that men were 37.9% were more likely to use tarpaulins. This may be due to men's involvement in drying processes and their control over financial resources. In contrast, being male reduced the likelihood of adopting hermetic bags. The coefficient of -2.668, also significant at the 1% level, shows that men were 27.3% less likely to adopt this technology. Women, who are traditionally responsible for grain storage, were more inclined to adopt hermetic bags.

Age had an insignificant effect on tarpaulin adoption, with a coefficient of 0.028, implying that older and younger farmers were equally likely to adopt tarpaulins. Age negatively influenced hermetic bag adoption. The coefficient of -0.146, significant at the 1% level, indicates that each additional year of age reduced the likelihood of adoption by 1.5%. Older farmers might be more resistant to adopting new storage methods, preferring traditional techniques.

Experience did not significantly influence tarpaulin adoption (-0.011, insignificant), indicating that both more experienced and less experienced farmers perceived tarpaulins similarly. However, farming experience had a positive and significant influence on hermetic bag adoption (0.011, significant at the 1% level). Experienced farmers were more likely to adopt hermetic bags due to their recognition of the long-term benefits of improved grain storage.

Higher income negatively influenced tarpaulin adoption. For every unit increase in income, the probability of adoption decreased by 11.8%. Wealthier farmers might have access to alternative drying methods. Wealthier farmers were 7.9% more likely to adopt hermetic bags, indicating that financial capacity played an important role in long-term storage technology adoption.

Negative perceptions significantly reduced adoption of tarpaulins (coefficient = -0.435, significant at the 1% level). The marginal effect of -0.146 suggests that an increase in negative perception led to a 14.6% decrease in the likelihood of adoption. Perceptions had no significant effect on hermetic bag adoption (coefficient = 0.2, insignificant), implying that other factors, such as financial and institutional support, could be more influential.

Increased information access significantly promoted adoption of tarpaulins (coefficient = 0.152, significant at the 1% level), increasing the probability by 15.2%. Surprisingly, increased information access negatively influenced hermetic bag adoption (coefficient = -0.051, significant at the 5% level), reducing the likelihood by 5.1%. This could be due to information misalignment with farmers' needs.

Farmers facing credit limitations were 20.1% more likely to adopt tarpaulins (coefficient = 0.601, significant at the 1% level). This suggests that tarpaulins were seen as an affordable postharvest technology. On the contrary, credit constraints had no significant effect on hermetic bag adoption (coefficient = 0.223, insignificant), implying that adoption was driven more by awareness and financial capacity rather than access to credit.

Social group membership had an insignificant influence on tarpaulins (coefficient = -0.007), suggesting that peer influence was not a key driver. Social group membership positively influenced hermetic bag adoption (coefficient = 0.932, marginal effect of 9.5%), highlighting the role of social networks in technology uptake.

4.4 Discussion

The study confirms the gendered nature of technology adoption. The findings align with findings by Mpiira *et al.* (2024), who reported that men's higher financial autonomy enables them to adopt capital-intensive technologies like tarpaulins. On the contrary, women's traditional roles in postharvest management align with their greater adoption of hermetic bags. Similar trends have been reported in other studies where men prioritise mechanisation, while women focused on storage and processing innovations. Gender-sensitive agricultural interventions should be developed. For example, targeted financial support for women could increase hermetic bag adoption.

The study's findings on age differences confirm prior research by Taku-Forchu *et al*. (2023) and Rwebangira *et al.* (2022), which showed that older farmers are slower to adopt storage technologies due to entrenched traditional practices. In contrast, tarpaulin adoption appears to be age-neutral, possibly due to its simplicity. Training programmes should specifically target older farmers to encourage the adoption of hermetic bags.

The positive relationship between experience and hermetic bag adoption aligns with Ainembabazi and Mugisha (2014), who found that experienced farmers better recognise long-term benefits. However, experience had no influence on tarpaulin adoption, possibly due to perceived ease of use.

The negative relationship between income and tarpaulin adoption suggests that wealthier farmers invest in alternative drying methods, supporting findings by Julie (1999). The positive impact of income on hermetic bag adoption aligns with Rwebangira *et al.* (2022) who argued that wealthier farmers are more willing to invest in advanced storage solutions. Similarly, credit access was a key determinant of tarpaulin adoption but not for hermetic bags, supporting findings by Balana & Oyeyemi (2022). Subsidising hermetic bags for low-income farmers could enhance adoption.

The strong negative influence of perception on tarpaulin adoption aligns with Liu and Liu (2024), who found that farmers' subjective assessments strongly influence their willingness to adopt visible technologies. In contrast, hermetic bag adoption was less influenced by perception, implying that economic and social factors play bigger roles. Additionally, social networks played a key role in hermetic bag adoption but not tarpaulin use. This aligns with Zheng *et al*. (2022), who noted that peer influence enhances technology uptake for complex innovations.

V. CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

The findings showed that the smallholder maize farming households which had adopted tarpaulins for drying maize were 34.0%, while those which had adopted hermetic bags for storing maize were 22.5%. The low rates of adoption were mainly due to financial constraints and lack of awareness of the benefits of using the technologies. If these constraints and others are not solved, low adoption of the technologies is likely to linger on.

Motivational factors, including high trialability and perceived effectiveness, strongly motivated adoption of tarpaulins for drying maize and hermetic bags for storing maize. Economic factors, such as affordability and income level, played a crucial role in adoption decisions, whereby farmers with higher incomes were more likely to adopt hermetic bags, while those facing financial constraints were more likely to opt for tarpaulins. Adoption decisions are multifaceted, influenced by both technological attributes and economic realities.

Gender, credit constraints, and access to extension services significantly influenced adoption of tarpaulins and hermetic bags, with male farmers being more likely to adopt tarpaulins but less likely to adopt hermetic bags, likely due to traditional gender roles in postharvest management. Social networks and access to information had mixed influence, whereby social group membership encouraged hermetic bag adoption but had no significant effect on tarpaulin adoption. Technology adoption is not uniform across all farmers; gender roles, financial access, and social dynamics play crucial roles.

5.2 Recommendations

Local Government authorities, non-governmental organisations and development agencies should provide subsidies or financial incentives to farmers for purchasing tarpaulins and hermetic bags. Moreover, awareness campaigns about benefits and uses of tarpaulins and hermetic bags for drying and storing maize, respectively, should be conducted through agricultural extension services and farmer groups to increase the adoption of the two technologies.

Agricultural extension services, financial institutions and microfinance organisations, and farmer cooperatives should conduct training programmes highlighting the benefits and ease of use of tarpaulins and hermetic bags and support financial access through credit schemes and cooperative financing.

Research institutions and universities, and community-based organisations should strengthen farmer groups to facilitate collective purchasing of tarpaulins and hermetic bags, sharing knowledge about those technologies, and improving access to extension services to provide hands-on demonstrations about using the same technologies.

Conflict of interest

The authors have no conflict of interest about this paper.

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