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Adoption and Economic Benefits of Harvest and Post-Harvest Loss Management Technologies in the Maize and Rice Value Chain in Tanzania

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Abstract

Reducing harvests and post-harvest losses is among the government's priority agenda to address the challenges of food security, poverty, and nutrition in Tanzania. Using survey data from different actors along the maize and rice value chain in Tanzania, this study (1) assessed the advanced technologies and traditional technology for managing crop harvest losses adopted by smallholder farmers and market actors, (2) determined the crop losses at different actors in the value chain, (3) evaluated the willingness of actors in adopting the technologies for crop harvest and post-harvest technology, and (4) assessed the economic benefits of advanced technologies and traditional technology for post-harvest losses in the study area. The study employed a cross-sectional research design whereby the interview method was used for data collection. Mult-stage random sampling techniques with three stages were employed to select a sample of 180 respondents. Data analysis employed in this paper included both descriptive and inferential analysis. The results indicate that the majority of respondents used traditional technology for crop harvest practices and advanced technology for post-harvest practices. The results also show that respondents who use advanced technology incur a lower loss than those who use traditional technology. The results also show that the majority of actors experience difficulties with the availability, accessibility, and affordability of the advanced technology, although they use it in post-harvest practice. The binary probit model result indicates that age, education, and value chain economic activities significantly influence an actor decision to adopt technology for harvest and post-harvest losses. Therefore, the government should provide subsidies for crop harvesting technology, especially combined harvesters, to enhance availability, accessibility, and affordability for farmers. Moreover, the agricultural development programs should focus on creating education, awareness on crop harvest and post-harvest loss technologies for reducing loss.

Keywords: Harvest and Post-harvest losses, Technology, Maize, Rice, Value Chain, Tanzania

1.0 Introduction

Cereal grains contribute around 50% of the global food requirement. Out of that, 60% of the grain is produced in developing countries, while 40% of the cereal grain is produced in developed countries (FAO, 2024). Only 5% of the cereal grain produced in developed countries is wasted along the value chain. While in developing countries, grain losses account for 20% of production in the market (Awika, 2011; Gorska-Warsewicze, 2023). The biotic and abiotic factors contribute to huge losses of cereal grain in developing countries (Junaid, 2024). In developed countries, the handling process typically leads to low cereal grain losses. Advanced technologies often reduce cereal grain losses in developed countries, unlike in developing countries, where technologies are traditional-based, which is ineffective in protecting against grain loss (Kumar, 2017; Nath, 2024). It is also observed that storage facilities do not maintain the optimal moisture and temperature for cereal grain quality (Mendoza *et al.*, 2017; Ali *et al.*, 2021; Mutungi *et al.*, 2023). According to FAO (2018), advanced technologies have a strong association with the reduction of post-harvest losses.

In Sub-Saharan Africa (SSA), cereal production increases by approximately 75% annually, while cereal grain loss grows between 10% and 20% annually. The grain losses in SSA are generally higher than the world's average cereal grain losses, making it hard for the African continent to improve food security and the livelihood of the growing population (Shee *et al.*, 2019; FAO, 2024). The quantity and quality losses can occur at any stage in the post-harvest practice (FAO, 2019; Nyiawung, 2019). The losses used in this paper refer to a percentage of the amount remaining from the previous stage of the post-harvest operation. Hodges *et al.* (2011, 2012), Folayan (2013), Bala *et al*. (2010), Rehema *et al.* (2021), and Totobesola *et al*. (2022) analyze food losses in Africa as caused by ineffective processing facilities, biotic and abiotic factors, and lack of knowledge among the actors. It is also perceived that smallholder farmers of cereal grain have little knowledge or are unaware of losses that can reduce their welfare (Abass *et al.,* 2014; Kaminski and Christiaensen, 2014; Midega *et al*., 2016; Olakiumide, 2021).

Maize and rice crops are basic foods and cash crops for livelihood and income generation for smallholder farmers and the Tanzanian population. Maize and rice provide food, livestock feeds, and income in the long run, while food production is crucial to ensure food security and regular income for farmers in the short run. An increase in grain losses needs special attention as it might have an implication for the country's food security, since the eastern zone of Tanzania which the study undertaken is the one of the producers of cereal crops in the country; it accounts for over 35% of the total annual production of maize and rice in the country (NBS and MoA, 2020). Ndwata *et al*. (2022) and Mutungi *et al*. (2023) reported that maize and rice post-harvest losses range between 5%-40% annually. The most significant causes of high post-harvest losses are pests, rodents, and spill-outs. Other losses occurred due to improper handling/inefficiencies in post-harvest operations (Jones *et al*.,2011; Ndwata *et al.,* 2022). The post-harvest losses are outlined as a significant problem among smallholder producers (Zorya,2011; FAO,2013; Ndwata *et al*., 2022; Mutungi *et al*., 2023).

In Tanzania, various initiatives have been undertaken by actors such as TechnoSave Tanzania, World Vision, the International Institute of Tropical Agriculture, and Helvetas Tanzania to improve postharvest management. However, empirical data on the impact of these initiatives on harvest and postharvest management among smallholder farmers, particularly maize and rice producers, are lacking. Studies such as those by Abass *et al.* (2014), Mutungi (2023), Twilumba *et al.* (2020), and Ndwata *et al.* (2022) have attempted to examine the adoption and impact of improved postharvest technologies, mainly on technology use, causes of postharvest losses, and the effect of these technologies, but much remains to be learned on the subject. For example, little information exists to explain the accessibility and availability of advanced technologies to minimize harvest and post-harvest losses throughout the value chain.

This study, therefore, aims to investigate the effect of affordability, accessibility, and availability of advanced technology for crop harvest and post-harvest practices for maize and rice farmers in Tanzania. In addition, this paper addresses the following issues: (1) Identifies the advanced technologies and traditional technology for crop harvest losses adopted by smallholder farmers, (2) determines the advanced technologies and traditional technology for post-harvest losses adopted by market actors (3) determines the crop losses at different actors in the value chain of maize and rice cereal crops (4) evaluates factors influencing actor decisions to adopt the technologies for harvest and post-harvest in Tanzania, and (5) assesses the economic benefits of advanced technologies and traditional technology for post-harvest losses in Tanzania.

2.0 Materials and Methods

2.1. Materials

The study was conducted in five wards, which were Kilosa, Mkwatani, Mbumi, Mtendeni, and Kimamba, located in Kilosa district in the Morogoro region. These areas have potential for cultivating maize and rice because of the geographical characteristics of tropical climates and semi-arid climates. This study employed a cross-sectional study design and a comprehensive survey. This research design was used because it is fitted to show the facts of the situation, that is, crop harvest and post-harvest practices, which help us to give the overall picture as it is at the time of the study. The population of this study involved actors engaged in the maize and rice value chain. The leading actors sampled for this study were maize and rice producers, followed by other actors, who were processors and transporters. A sample size of 180 respondents was determined with the following proportionate size: Farmers = 130, Processors = 14, Transporters = 24, both Farmers and Processor respondents = 2, both Farmers and Transporter respondents = 5, both a Processor and Transporter respondents = 3, both a farmer, processor and transporter respondents = 2. A multi-stage random sampling procedure was used to obtain the sample size of the respondents. The first stage involves selecting a district. At the second stage, five wards were purposively selected: Kilosa, Mkwatani, Mbumi, Mtendeni, and Kimamba. At the third stage, villages near the town and far from the town centre were purposefully selected from each ward. Selections of villages are based on the presence of farmers, processors, and transporters of maize and rice in respective areas. A structured questionnaire collected primary data from farmers, processors, and transporters. The data or information collected through a questionnaire survey were technology affordability, accessibility and availability during crop harvest and post-harvest practices, data of modes of transport of crops, methods used to store produce, processing methods, storage period, storage facilities, data of the quantity of maize and rice subject to spoilage/decay during crop harvest and post-harvest. The secondary data used in this study came from the Kilosa District Agricultural Officer.

2.2. Methods

2.2.1. Descriptive Analysis

Descriptive analysis was used for analyzing the data whereby frequencies and percentages were calculated. Inferential analysis using a binary probit model was employed to show the causal relationship between dependent variables (willingness of actors to adopt crop harvest and post-harvest technologies) and independent variables (socio-economic characteristics of respondents). The binary probit model with marginal effect was used to examine the causal relationship between willingness to adopt technology and socio-economic characteristics. However, to avoid repetition in discussions, the results of the marginal effects are only discussed, as they can indicate both the sign and magnitude of each variable in the model.

2.2.2. Analytical model

To examine the influence of the socio-economic characteristics of respondents on the willingness to adopt technology for crop Harvest and post-harvest losses, a binary probit model with marginal effect was used. This model was used since the dependent variable of willingness to adopt technology was a dichotomous decision of being willing to adopt with a value of 1 or not with a value of 0. The analytical model is stated as follows:

$$Y_i = \beta X_i + \mu_i \quad \text{.................................[1]}$$

Where the attributes in question [1] represent:

Y_i = 1, if the actor is willing to adopt technology for crop harvest or post-harvest

Y_i =0, if the actor makes a choice not willing to adopt technology for crop harvest or post-harvest

μ_i = Error term

Therefore, the probity regression [2] describing the relationships between the dependent variable and the explanatory variables is postulated, where β's are regression coefficients and Ɛ is an error term.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon_n \quad \text{.......... [2]}$$

Where Y = Technology adoption decision, X_i= Independent/Explanatory factors

β_i= Coefficient of variable, Where i=1, 2, 3…

Table 1: Description of Variables and Measurement

Variable	Descriptions
Dependent variable	
Technology adoption decision (Y)	Binary variable 1= if at least one advanced technology adopted, 0 if no advanced technology adopted
Independent variables	
Age (X_1)	A continuous variable representing the actual age of the actors
Education (X_2)	Dummy variable 1= if actors have attained education, 0=otherwise
Marital status (X_3)	Dummy variable 1 = if actors has married, 0= otherwise
Gender (X_4)	Dummy variable 1= if actors are female, 0=otherwise
Main economic activity (X_5)	Dummy variable1= if actors are farmers, 0 = otherwise
Value chain economic activity (X_6)	Dummy variable 1= if actors are farmers, 0= otherwise
Relationships to household head (X_7)	Dummy variable 1=if actors are head, 0= otherwise

3.0 Results and Discussion

3.1. Demographic Characteristics

Results from Table 2 show that the study sample comprises 180 value chain actors. Their background characteristics were established by looking at their gender, age, marital status, education level, main economic activities, type of crops cultivated/harvested, and relationship to the head of households. The results reveal that most of the respondents had lower levels of education. Also, more than half of the respondents who were involved in the value chains were males who were married and their main economic activity was farming of rice and maize. A similar finding was reported that males were more dominant in agriculture and farming was the main economic activity (Mroto & Jecknoniah, 2015). The study also found that older people are more engaged in the agro-value chain than the youth. A similar finding was reported that youth are less involved in agriculture (Lekunze et al., 2011). The findings give us the implication that in the maize and rice value chain, higher level of education is still needed for the actors as the facts that skills, knowledge and familiarity with improved technologies are connected with education. Therefore, value chain actors need to be educated to be in a better position to adopt and use skills and technologies acquired from education to reduce losses. Father, we cannot ignore the youth involvement in the value chain, as they are familiar with today's new technologies and modern farming practices, which could be applied to reduce losses.

Table 2: Demographic Characteristics of the Respondents

Gender of Respondent	**Frequency**	**Percentage**
Male	111	61.7
Female	69	38.3
Age of respondent		
15-35	37	20.6
36-55	96	53.3
56-75	43	23.9
76-85	4	2.2
Marital status		
Married	136	75.6
Single	19	10.6
Divorced	11	6.1
Widow	14	7.8
Education level		
None	21	11.5
Primary	131	71.6
Secondary	27	14.8
Diploma	2	1.1
Degree	2	1.1
Main Economic Activity		
Farming	119	65.0
Livestock keeping	2	1.1
Farming & livestock keeping	16	8.7
Civil servant	2	1.1
Others	44	24.0
Types of Crop Cultivated/Harvested		
Maize	37	20.5
Rice	42	23.5
Maize and Rice	101	56.0
Relationship to the Head of Household		
Head	140	77.7
Husband	39	21.7
Son	1	0.6
Total	180	100.0

The findings in Table 3 reveal that three-quarters of the respondents were involved in farming as an economic activity. Also, the respondents who were involved in the processing are few which is 7.7 percent. But to reduce post-harvest losses and also to facilitate value addition in the value chain, we expect the number of processors to be large as the number of farmers increases. The finding by Terafa &Abass (2012) warned about this situation by indicating that any increase in farming productivity without an increase in processing, storage, and handling from surplus harvested will lead to postharvest losses greater than 40%.

Table 3: Value Economic Activities of the Respondents in Value Chain

Economic Activities	Frequency	Percentage
Farming	130	72.2
Processing	14	7.8
Transporting	24	13.3
Farming & Processing	2	1.1
Farming & Transporting	5	2.8
Farming, Processing & Transporting	2	1.1
Processing & Transporting	3	1.7
Total	**180**	**100.0**

3.2. Advanced Technologies and Traditional Technology for Crop Harvest Losses Adopted by Farmers

3.2.1. Technologies adopted to harvest the crops

Findings on the technology adopted to harvest the crops in Table 4 show that more than three-quarters of the respondents used manual methods or traditional methods during crop harvest. They use hand cutting tools such as sickles, knives, and cutters which are labour intensive, and the results slow the process which may lead to large losses. This is because advanced technology (machines) is not available or affordable. Furthermore, the method of harvesting crops has implications for crop losses. As it is reported by respondents from the field, using manual or traditional methods leads to large amounts of crop losses during harvesting. Also, a finding by Tefera *et al*. (2012); Ndwata *et al*. (2021); and Mutungi *et al.* (2023) shows that loss due to crop harvesting in the farm in Tanzania ranges from about 5% to 40% due to poor harvesting practices and tools.

Table 4: Technology Adopted by Farmers to Harvest the Crops

Technologies Adopted	Frequency	Percentage
Traditional (Manual)	127	97.7
Advanced (Machine)	3	2.3
Total	**130**	**100.0**

3.2.2. Types of Containers Used by Farmers for Harvesting

The findings in Table 5 show that the majority of respondents used sacks as containers for harvesting, and some respondents used rigid plastics. However, most of the respondents questioned whether the quality of the container was low. Findings by Tefera *et al.* (2012) indicate that losses due to traditional containers or packages range to 1.8%.

Table 5: Types of Containers for Harvesting

Container	Frequency	Percentage
Sacks	91	50.6
Rigid plast	34	18.9
Others	58	32.2

Findings based on multiple responses

3.3. Advanced Technologies and Traditional Technology for Post-Harvest Losses Adopted by Market Actors

Findings on the technology adopted by marketing actors (farmers, processors, transporters) for post-harvest in Table 6 show that more than three-quarters (82.8%) of the respondents used advanced methods for post-harvest losses. This is different from crop harvest losses. On crop harvesting, respondents used more traditional technology of hand- cutting tools such as sickles, knives, traditional storage silos while in post-harvesting, respondents used more advanced technology of combine harvesters, special plastic bags (pics) and fumigation powder. The reasons behind which were given by respondents during the interview are that despite the high cost of purchasing advanced technology to control post-harvesting losses, respondents commented that they are motivated and forced to use advanced technology such as special plastic bags (pics), fumigation powder, etc., to be free from grain pest killers and to be assured with food security for the future. This finding is similar to that of Mendoza et al. (2017); Ndwata *et al*. (2021) which indicated that actors use advanced technology for managing post-harvest losses and managed to reduce losses by 98%. Furthermore, the findings by Okoedo-Okoije & Onemolease (2019) warn about the risk of the high cost of advanced technology, as it limits actors' adoption of improved technology.

Table 6: Technology adopted by Marketing Actors for post-harvest losses

Technology	Frequency	Percentage
Advanced technology	149	82.8
Traditional technology	31	17.2
Total	**180**	**100.0**

3.3.1. Drying technology adopted by respondents during post-harvest losses

Table 7 shows that all respondents used the open sun as renewable energy to dry the crops. The reason behind it was that the sun is free and the only technology available in the area compared to biogas, biodiesel, and solar. Therefore, the implication of these findings is that, at the time of drying, the respondents applied traditional technology of drying grains in open sun. This method is affected by bird attacks and moisture or rainfall which lead to loss resulting from birds' attacks and loss by mould growth on the affected grain, respectively. However, this finding is similar to Ndwata *et al*. (2021) which indicated that 100% of the respondents interviewed use open sun drying.

Table 7: Renewable energy resources used in drying crops

Responses	Frequency	Percentage
Sun	156	100.0
Total	156	100.0

3.3.2. Storage technology adopted by respondents during post-harvest losses

The findings on the storage technology adopted by respondents in Table 8 show that the majority of respondents had adopted advanced technology rather than traditional technology. These advanced technologies are special storage plastic bags (pics) followed by fumigation powder, super grain bags, and metallic silos. This finding is similar to the study of Kimenju and De Groote (2010 & 2013) in Tanzania and Kenya, which indicated that more than 93% of farmers used advanced technology as a common one to control pests during storage and it reduced food losses to 98%. However, it contradicts with findings of Ndunguru *et al.* (2016) who indicated that 86 % of small-scale farmers in Tanzania have little knowledge of using advanced technology for storage.

Table 8: Storage technology adopted by respondents for post-harvest losses

Technology	Frequency	Percentage
Special storage plastic bags (pics)	45	35.2
Fumigation powder	34	26.6
Super grain bags	28	21.9
Silo technology	12	9.4
Village storage warehouse/godown	10	7.8
Sacks	3	2.3

Findings are based on multiple responses

3.3.3. Transporting Technologies and Package Technology Used for Transportation of Crops to Collection or Selling Point

Table 9 shows that the majority of the respondents used motorcycles as a means of transporting crops. Motorcycles were preferred by the farmers as they were cheap and available in rural areas. However, motorcycles are suitable for those farmers with a minimal number of harvested sacks. For the packaging technology during transporting crops, most respondents used sacks, followed by rigid plastics. These are the common packages used in the village to transport crops, as they are cheap and available. This finding implies that using sacks and motorcycles as open means of transport subjects the grains to bad weather, especially when it rains. This phenomenon leads to losses of grain by decay or mould growth. Cattaneo *et al*. (2021) find that the percentage losses range from 5% to 19% in the distribution due to unsuitable packaging and inefficient means of transport. Also, a similar finding by Ndwata *et al*. (2021) indicated that the respondents in Chemba and Kondoa in Tanzania use more than one method of transport to transport crops from farms to collection centers/markets.

Table 9: Transporting Technologies and Package Technology Used for Transportations of Crops to Collection or Selling Point

Transport Technology & Package Technology	Frequency	Percentage
Transport Technologies		
Motorcycles	94	51.4
Mkokoteni/oxen cart	43	23.5
Open pick up	22	12.0
Bicycle	17	7.8
Human transportation	9	4.9
Package Technology during Transportation		
Sacks	95	51.9
Rigid plastic bags	47	25.7
Pliable plastic bags	18	9.8
Others	6	3.3

Findings based on multiple responses

3.3.4. Technology applied before grain storage

Table 10 shows that the respondents use both traditional (open sun, manual sorting) and advanced technologies (fumigation powder) during the preparation of grain for storage. Traditional technologies (open sun) are used for drying while sorting (manual sorting) for removing waste. The advanced technologies (fumigation) used for storage processes. The respondents have much concerns about the improved technology on storage, while the process before storage, such as drying and sorting left to traditional ways. Therefore, to remove the post-harvest losses, the emphasis on the use of advanced technologies should be on both processes: before and during storage.

Table 10: Technology applied before grain storage

Technologies	Frequency	Percentage
Open Sun Drying	108	59.0
Manual Sorting	38	20.8
Fumigation powder	64	34.9
Others	7	3.8

Findings based on multiple responses

3.4. The Crop Losses at Different Actors in the Value Chain of Maize and Rice Cereal Crops

The finding on the crop losses that occur at the actors described in Table 11 shows that the losses are less than 10 percent. This finding is similar to the finding of Tefera *et al.* (2012) in Manyara and Kilimanjaro, Tanzania who indicated that poor harvesting practices and tools on maize lead to a loss of 1.5 to 5.9%, which is less than 10 percent. The finding on the quantities of losses that occur at the actors described in Table 11 shows that the losses are less than 10 percent. This finding is similar to the finding of Tefera *et al.* (2012) in Manyara and Kilimanjaro, Tanzania who indicated that poor harvesting practices and tools on maize lead to a loss of 1.5 to 5.9 percentage, which is less than 10 percent. The losses at the farm during harvesting and sorting we expect to be higher due to the use of traditional methods (manual technology). However, the low loss might be care taken by actors to lower risk of loss in order to maximize the gains during the process. Therefore, if these actors could apply advanced technology, losses might be removed or reduced completely. Other processes such as market or collection, during transport, and during the value addition process experience fewer percentages losses too. Despite losses being low, the poor handling and delay in produce delivery by these actors are the reasons for this loss (Ndwata *et al.*, 2021; Mutungi *et al.*, 2023).

Moreover, less time was spent on keeping crops in temporary storage at the farm, as indicated in Figure 1 below. This implies that the majority of the farmers spend less time, which was less than a week to store the crop temporarily at the farm. This finding, as also indicated by Khan & Balach (2010) implies that the longer the time spent on temporary storage the higher the chance of losses subject to the risk of bird attacks, wild pigs, rodents, termite killers, microbes and toxins, and other factors such as rainfall. Also, a similar finding by Ndwata *et al*. (2021) indicated that fear of theft makes farmers spend less time to store the crop at the farm.

Table 11: The Crop Losses at different Actors in the Value Chain

Actors Losses	percentage losses	Frequency	Percentage
Losses occur on the farm during harvesting	Less than 10%	101	72.7
	Between 10% to 20%	36	25.9
	More than 50%	2	1.4
	Total	139	100
Losses occur during sorting	Less than 10%	100	64.1
	Between 10% and 20%	33	21.2
	20% to 40%	23	14.7
	Total	156	100
Losses at temporary storage at the farm	Less than 10%	104	74.8
	Between 10% and 20%	19	13.7
	20% to 40%	16	11.5
	Total	139	100
Losses for poor handling in market/store	Less than 10%	111	71.1
	Between 10% and 20%	33	21.2
	20% to 40%	12	7.7
	Total	156	100
Losses occur during the value-addition process	Less than 10%	120	76.3
	Between 10% and 20%	27	17.9
	20% to 40%	9	5.8
	Total	156	100
Losses from transport	Less than 10%	23	67.6
	Between 10% and 20%	8	23.6
	20% to 40%	2	5.9
	More than 50%	1	2.9
	Total	34	100.0

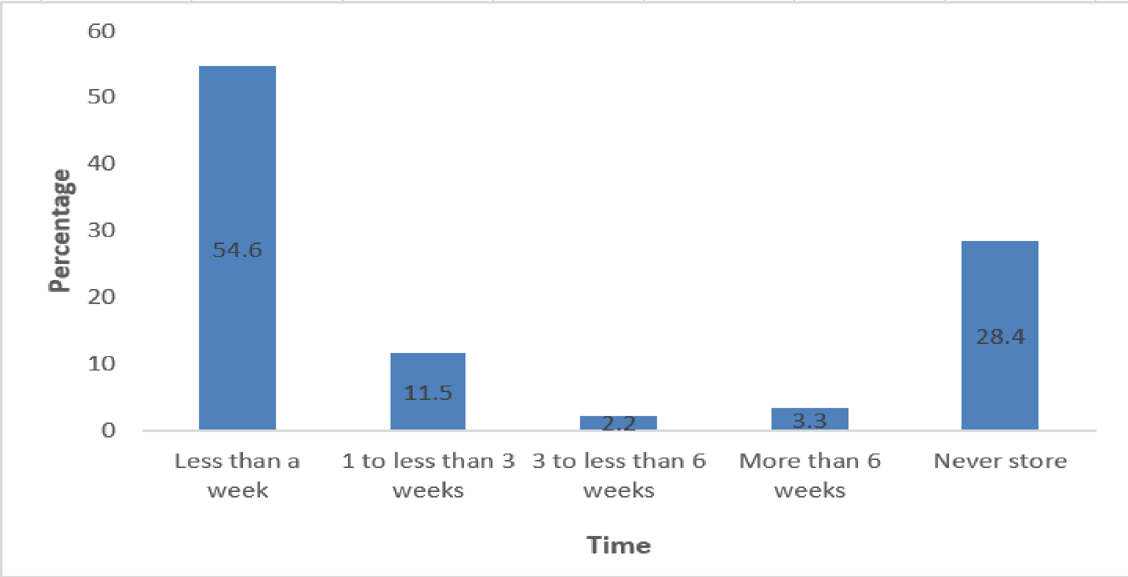

Figure 1: Time to store crops Temporary on the Farm

3.5. Harvest and Post-Harvest Technologies Adoption

The findings on the respondents' adoption and payment of technology for harvest, sorting, drying, packaging, and handling in Table 12 show that the majority of respondents adopt and pay for technology for harvesting, transport, sorting, drying, packaging, handling, and processing. The reasons behind this are that particularly technology advances reduces the amount of grain loss and shortens the time of harvesting compared to traditional technology.

Table 12: Respondents who adopt and pay for technology

Technology Adoption Decision	Responses	Frequency	Percentage
Respondents who adopt technology for harvest and handling	Yes	165	91.7
	No	15	8.3
	Total	**180**	**100**
Respondents who pay technology (harvest, sorting, drying, packaging)	Yes	164	91.1
	No	16	8.9
	Total	**180**	**100**

3.5.1. Influence of Socio-Demographic Characteristics of Respondents on Adopting Technology for Harvest and Post-Harvest Losses

The binary probit model was used to examine the influence of the socio-economic characteristics of the respondents on the technology adoption decision for crop harvest and post-harvest losses. Some variables in the model as shown in Table 13 significantly influence the decision of the actor to adopt technology for harvest and post-harvest practices in the study area. Such variables were age, education, and value chain economic activities. However, marital status, gender, main economic activities, and relationship to the head of household did not influence the willingness of actors to adopt technology. The reason for the insignificance is that there is not enough evidence to conclude the change of these variables (marital status, gender, main economic activities, and relationship to the head of household) is associated with the change in the dependent variable. Therefore, this result presents parameter estimates or coefficients that may not be used for interpretation, and marginal effect analysis was performed as indicated in Table 14.

Table 13: Probit Regression Results

Number of Observations = 180
Pseudo R Square = 0.1587
Log of likelihood = -68.228905
Prob > chi2 = 0.0015

Willingness of Actors in Adopting Technology	Coefficient	Robust Std. Err.	z	P>z
Age	-1.057457	0.505077	-2.09	0.036
Education	0.810560	0.335644	2.41	0.016
Marital status	0.149809	0.342660	0.44	0.662
Gender	0.189083	0.366283	0.52	0.606
Main economic activities	0.524234	0.294851	1.78	0.075
Relationship to the household head	0.649274	0.402548	1.61	0.107
Value Chain economic activities	0.765456	0.296874	2.58	0.010
Constant	2.859495	2.006516	1.43	0.154

Level of significance ** represents 5%

3.5.2. Marginal Effect Analysis

Table 15 shows the result of marginal effect analysis in which marginal effects at the means of the probit regression with their respective standard errors. However, to avoid repetition in discussions, the results of the marginal effects are only discussed as they can indicate both the sign and magnitude of each variable in the model. This insight is provided by analyzing the marginal effects, which were calculated as the partial derivatives of the non-linear probability function, evaluated at each variable.

Table 14: Marginal Effect Analysis

Willingness of Actors in Adopting Technology	dy/dx	Robust Std. Err.	z	P>z
ln Age	-0.2234	0.1045	-2.14	0.033
Education	0.2294	0.1150	1.99	0.046
Marital status	0.3302	0.0784	0.42	0.674
Gender	0.0388	0.0739	0.53	0.599
Main economic activities	0.1207	0.0707	1.71	0.088
Relationship to the household head	0.1634	0.1165	1.40	0.161
Value Chain economic activities	0.1933	0.0859	2.25	0.024

Level of significance ** represents 5%

The findings on age in Table 14 above show a negative relationship and statistically significance between technology adoption decisions and the age of respondents. This indicates that an increase in age led to the probability of a decrease in the decision of the actor to adopt technology for harvest and post-harvest during the sample period of the study. The probable reason is that agriculture in Tanzania is dominated by aged farmers who rely on traditional practices of agriculture and they are reluctant to use modern farming technology due to the technology affordability problem. The finding by Kinyanyi (2014) in Kenya found that age had a significant positive influence on technology adoption.

The findings on education in Table 14 above show a positive relationship and statistically significance between technology adoption decisions and the education of respondents. This indicates that an increase in the level of education of the respondents increases the probability of the decision to adopt technology for harvest and post- harvest. The probable explanation is that higher education attained by the respondents makes them know the importance of implementing advanced technology in minimizing losses. The finding by Ndwata *et al*. (2021) indicated that a low level of knowledge/ education among the farmers remains a main obstacle to adopting post-harvest practices.

The findings on marital status in Table 14 above show a positive relationship and are statistical insignificant. This indicates that being married increases the probability of the decision to adopt technology for harvest and post-harvest. Even without statistical significance, the positive relationship suggests that married respondents are more open to technology adoption. Therefore, the intervention programs should target married households as they are more open to technology adoption for loss reduction. This finding is similar to Kinyangi (2014) in Kenya, who found a positive relation that was statistical insignificant between marital status and technology adoption in agriculture. However, these findings contradict findings conducted in Tanzania by Kaliba *et al.* (2018) who found that there is a positive relationship with statistical significance between marital status and technology adoption.

The findings on gender in Table 14 show a negative relationship and statistically insignificant between the decision to adopt technology for harvest and post- harvest and the gender of respondents. This indicates that being a female decreases the probability of adopting technology for harvest and post-harvest. The probable explanation for the negative and even insignificant is that female households are limited in decision making power for technology choice and use. Therefore, agricultural programs or interventions to ensure equal decision making power for both males and females must be in place. Therefore, the female has little impact on agriculture decision in the study area. Other findings with similar results of negative but statistical insignificance between gender and technology adoption are Gebre *et al.* (2019) who studied gender and technology adoption on maize in Ethiopia , and Gebre *et al.* (2022) who investigated gender and technology on productivity in Malawi . This study contradicts with Kinyangi (2014) in Kenya, who found that gender had a positive relationship and statically significant influence on technology adoption.

The findings on main economic activity in Table 14 show a positive relationship and are statistically insignificant between main economic activity and technology adoption decision. This indicates that being a farming activities increases the probability of decision to adopt technology for harvest and post-harvest. The more the farming activities matters to the respondent income the more likely to adopting technology to reduce loss for the essence of maximizing gains. However, the presence of statistical insignificance from this finding it's possible that non farming activities sources influences decision to adopt the technology by providing capital to buy the technology. This finding is similar with study conducted in Tanzania that of Mutungi (2023) who concludes that there was a positive relationship between the main economic activity with post-harvest technology adoption.

The findings in Table 14 above show a positive relationship and statistically significant between the decision to adopt technology for harvest and post- harvest and value chain economic activities of the respondents. This indicates that being a farmer and value chain economic activities as farming increases the probability of a decision to adopt technology to reduce harvest and post-harvest losses during the sample period of the study. In this regard, this farmer also regnognizes the importance of reducing of reducing post- harvest losses. This implies that to continue reducing post-harvest losses, the agricultural training on adopting post-harvest technologies should target farmers who conduct farming activities.

The findings on the relationship to the household head in Table 14 above show a positive relationship and statistically insignificant between the decision to adopt technology and the relationship to the household head. This indicates that being a head of household increases the probability of a decision to adopt the technology for harvest and post-harvest in the study area. However, statistical insignificant means that any agricultural intervention should not target household relationships but instead other factors, e.g., income, education, and access to information. The probable explanation is that the head of the household is the decision-maker in the family compared to the other ranks within it.

3.6. Availability, Accessibility, and Affordability of Advanced Technologies for Managing Crop Losses

Despite the majority of the respondents' use of advanced technologies for post-harvest losses, particularly for storing the crops. It is quite different for advanced technologies for managing crop losses. The result in Table 15 shows that the majority of the respondents experience difficulties in the availability and accessibility of advanced technology for managing crop losses in the study area. One of the reasons is technologies such as combine harvesters for crop harvest and maize crushing machines are not available in the villages and sometimes to access them, they are required to rent them at a high cost. Also, the result shows that the amount of money the majority of the respondents can afford to pay for technologies is less than TZS 500,000/= which implies that for advanced technologies that involve a huge amount of money to purchase, it will be difficult for the respondent to afford. Therefore, the government must subsidize that technology. The findings in India by Kassie *et al*. (2017) and in Tanzania by Ndwata *et al*. (2021) indicated that the high initial cost of advanced technology led to poor adoption of the actors to use improved technologies.

Table 15: Availability, Accessibility, and Affordability of Advanced Technologies for Managing Crop Losses

Availability &Accessibility	Responses	Frequency	Percentage
Availability of Advanced Technology for Managing Crop Losses	Yes	38	21.1
	No	142	78.9
	Total	180	100
Accessibility of Advanced Technology for Managing Crop Losses	Yes	37	20.6
	No	143	79.4
	Total	180	100
Amount of Money Respondent Afford to Pay for Buying Technology	Less than TZS 500,000	115	63.9
	TZS 500,000 to TZS 1,000,000	31	17.2
	More than TZS 1,000,000	34	18.9
	Total	180	100.0

3.7. Assess the Economic Benefits of Advanced Technologies and Traditional Technology for Post-Harvest Losses in the Study Area

Table 16 shows that the respondents who use advanced technology on post-harvest losses, especially special plastic bags (pics), fumigation powder, incurs less loss (loss less than one plastic bag) compared to those who use traditional technology which incurs loss of more than two plastic bags. The reason revealed by respondents is that traditional methods such as keeping the crop in the shade, silo, sisal sacks, and on the house, roofing are subjected to loss caused by rodents, termite killer, Scania, and birds and it decays due to bad weather. This finding is similar to that of Mendoza *et al*. (2017), Ndwata *et al*. (2021), which indicated that actors who use advanced technology for managing post-harvest losses have managed to reduce losses to 98% compared to those who use traditional technologies.

Table 16: Estimated quantity of loss during post-harvest during using advanced technology and traditional technology

Estimated Losses	Frequency	Percentage
Advanced Technology Estimated loss		
Loss of less than one plastic bag	128	71.1
Losses equal to one plastic bag	23	12.8
Losses equal two plastic bags	14	7.8
Losses more than two plastic bags	15	8.3
Total	180	100.0
Traditional Technology Estimated loss		
Loss of less than one plastic bag	49	27.2
Losses equal to one plastic bag	29	16.1
Losses equal two plastic bags	25	13.9
Losses more than two plastic bags	77	42.8
Total	**180**	**100.0**

4.0 Conclusions

Tanzania is among the sub-Saharan African countries that experiences cereal losses ranging from 5% - 40% annually from production to marketing, as shown in the literature. From this study, the findings show that the quantity losses at different actors in the value chain are less than 10% at each actor investigated. Moreover, the findings of this study show that the technology used by the farmers for crop harvest practices is traditional technology which leads to much more losses of more than two plastic bags at a time of harvesting. However, in the area of post-harvesting practices, the findings show that the marketing actors managed to use advanced technology for managing post-harvest losses, and cereal grain losses are less than one plastic bag on estimation. Despite using advanced technology, the finding shows that the availability, accessibility, and affordability of this technology are still a problem for actors. Furthermore, the findings of probit regression show that education significantly influences the willingness of actors to adopt technology. This means that education enables the actor understand how losses can affect their welfare. Furthermore, variable age and value chain economic activities significantly influence the willingness of actors to adopt technology for crop harvest.

Based on the findings, the following are the recommendations:

i. Intervention should be done in the area of crop harvest practices on the farm to reduce the losses by subsidizing the advanced technology tools such as combined harvester machines to make them available to farmers for harvesting. It is recommended that advanced technology reduces losses to about 98% when used.

ii. To meet the food security agenda due to high population growth, interventions by the government on the accessibility, availability, and affordability of advanced technology to the value chain actors must take place as advanced one reduces losses to around 98%.

iii. Smallholder farmers of cereal grain should be given an education or knowledge or awareness of how losses can reduce their welfare. This is because variable education significantly influences the adoption of technology. As a level of education increases, the actors' willingness to adopt advanced technology increases; finally, cereal grain losses are reduced to 98%.

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