

**PERFORMANCE OF HERMETIC BAG TECHNOLOGY IN REDUCING MAIZE  
STORAGE LOSSES AND FACTORS AFFECTING LOW ADOPTION AMONG  
SMALL-HOLDER FARMERS**

***A Dissertation Submitted to the Sokoine University of Agriculture in Fulfilment  
of the Requirements of Master of Science in Post-Harvest Technology and  
Management.***

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**April 2023**

## EXTENDED ABSTRACT

Post-harvest storage losses of maize grain have a negative impact on the livelihood of smallholder farmers and the national economy at large. The majority of rural communities' maize farmers in developing countries rely on indigenous maize storage methods. These methods are ineffective in minimizing grain losses caused by insect infestation. Maize storage damaging insects such as larger grain borers and maize weevils are linked to these huge losses. Additionally, the use of synthetic insecticides and botanicals to control these insects has not benefited farmers but has instead adversely affected human health and the environment.

Hermetic storage technology such as hermetic bags is a modern maize grain storage technique that effectively and efficiently reduces insect infestation and other grain storage deterioration factors. This technology is a non-chemical grain storage approach that works on the hermeticity principle. Several research has been conducted to evaluate the effectiveness of this technology globally. However, in Tanzania the studies regarding the investigation of the effectiveness of hermetic bags are limited. Most and recent studies concentrated on comparing the effectiveness of PICS bags with conventional maize storage methods. The current study focused on evaluating the effectiveness of AgroZ and PICS brands of hermetic bags in suppressing maize weevils in stored maize grain. The experiment was set out at the Entomology Laboratory storeroom, Department of Crop Science and Horticulture, Sokoine University of Agriculture for a period of 180 days. The experiment comprised of three treatments; such as AgroZ, PICS, and Polypropylene bags. The treatments were arranged in a completely randomized design each replicated three times. Prior to commencement of the experiment, each bag was filled with 20kg of maize grain and artificially infested with maize weevils at a rate of 1 insect per kg. After every 30 days of storage, samples were taken from each treatment and sieved to separate insects from grains. Live and dead insects for each sample were counted and recorded; damaged and sound grains also were manually counted, weighed, and recorded. Using the sub-sample moisture content of each sample was obtained by using the oven drying method. Additionally, randomly selected 100 grains from each sample were planted in trays for determination of seed germination potential. Boxall equations were employed for the quantification of grain damage and weight loss percentages. Statistical analysis was performed by using Genstat 15.1, and Tukey's HSD to test the means at the significance level of 5%. Mean grain damage and weight loss were significantly different ( $p < 0.05$ ) among hermetic and polypropylene treatments. The AgroZ hermetic bags recorded the lowest weight loss and grain damage mean values of 0.6 and 1.35% respectively. While the PICS bags recorded weight loss and grain damage mean values of 0.8 and 0.93% respectively. After 180 days no live insects were observed in the maize grain stored in hermetic bags. No significant difference in maize grain damage or weight loss was observed among the hermetic bags.

Despite the effectiveness of hermetic bags in reducing maize storage losses, still, the rate of uptake of the technology is seemingly low among maize producers. On these grounds, a survey study was conducted to evaluate the reasons for the low adoption of hermetic bags among maize farmers. A total of 180 respondents were face-to-face interviewed using structured questionnaires. The data were analyzed using descriptive statistics and a binary logistic regression model through SPSS software. The logistic regression model revealed that price, access, training, farmers' experience, and awareness variables positively and significantly ( $p < 0.05$ ) influenced the farmers' decision to use or to use hermetic bags. The

revealed explanatory variables testify the need for the government and non-governmental organizations to intervene.

The findings from this research will benefit maize producers by providing information on the effectiveness of tested hermetic bags, thereby promoting and increasing the utilization of the technology. Additionally, in light of the current study, further research is recommended to be extended into an exploration of the re-usability of these hermetic bags as well as the engineering characterization of their inner liners.

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## **ACKNOWLEDGEMENTS**

First and foremost, I would like to thank the Almighty God for his unending love, guidance, and strength throughout my studies. I couldn't have done it without his help, and I will be eternally thankful. I am grateful to my supervisor, Prof. Valerian Cosmas Silayo, of the School of Engineering and Technology, for agreeing to take on this task. I am grateful for his consistent guidance, encouragement, constructive criticism, and patience throughout my studies. I consider myself lucky to have had the opportunity to work beside him. My sincere gratitude to Prof. Geoffrey Christopher Mrema for allocating his time to give me credible advice and constructive comments that resulted to be among the catalysts for achieving my research work. I'd like to thank the Ministry of Agriculture for their contribution and financial support in my research work; additionally, the fieldwork would not have been successful without the cooperation of Agricultural Field Officers in the villages of Ilonga, Chanzuru, and Msowero; and maize farmers whose contributions enabled me to successfully complete my study. I am especially grateful to my family for their encouragement and financial assistance, which enabled me to complete my studies. Finally, I'd want to thank the lecturers and the entire staff of the School of Engineering and Technology. May the Lord's grace be upon you.

## **DEDICATION**

This dissertation is dedicated to my wonderful mother, Mama Specioza Vedasto; my beloved wife, Pracidia Nyangoma; my son, Elvis Evelius; and my beloved daughter, Rita Evelius, all of whom have supported me during my academic journey.

## DECLARATION

I, Vedasto Evelius, do hereby declare to the Senate of the Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor been currently is currently being submitted to any other institution.

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**LIST OF PAPERS**

1. Evelius, V., Silayo, V., & Mrema, G. (2022). PERFORMANCE OF TRIPLE AND DOUBLE HERMETIC BAGS FOR MAIZE GRAIN. *International Journal of Agriculture, Environment and Bioresearch*, 07(05), 13–24. <https://doi.org/https://doi.org/10.35410/IJAEB.2022.5780>
2. Rwebangira, E. V., Silayo, V. C., & Mrema, G. C. (2022). Factors that influence smallholder farmers ' decisions to use hermetic bag technology for maize grain storage in Kilosa District, Tanzania. *International Journal of Scientific Research Updates*, 04(01), 346–355. <https://doi.org/https://doi.org/10.53430/ijsru.2022.4.1.0141>

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## LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
APHLIS	Africa Post-Harvest Losses Information System
ASABE	American Society of Agricultural and Biological Engineers
CV	Coefficient of Variation
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
HDPE	High-Density Polyethylene
HSD	Honest Significant Difference
LGB	Larger Grain Borer
MLLDPE	Metallocene Low Linear Density Polyethylene
NBS	National Bureau of Statistics
ODK	Open Data Kit
PICS	Purdue Improved Crop Storage
PP	Polypropylene
SE	Standard Error
SPSS	Statistical Package for Social Sciences
SSA	Sub-Saharan Africa
SUA	Sokoine University of Agriculture
TM	Trade Mark
TZS	Tanzania Shillings
USD	United States Dollar
VAT	Value Added Tax
$\mu$	Micrometer
®	The registered trademark symbol
$\sigma$	Sigma
<i>e</i>	Exponential
$\beta$	Slope of the line
<i>df</i>	Degree of Freedom
<i>sig</i>	Significance
<i>CI</i>	Confidence Interval
NGO	Non-Governmental Organization
<i>ha</i>	Hectare
<i>n</i>	Number
$\chi^2$	Chi square
Std.	Standard

## CHAPTER ONE

### 1.0 GENERAL INTRODUCTION

#### 1.1 Background Information

Maize (*Zea mays L.*) is an important global commodity with a growing significance in global agri-food systems. Maize grain consumption accounts for 5% of total human dietary calories and proteins consumed globally (Olaf *et al.*, 2022). Maize is the most widely produced food crop in Sub-Saharan Africa (SSA), accounting for 33 million hectares and food for feeding over 1.0 billion people (FAOSTAT, 2015). Despite the importance of maize grain in food and nutrition security, its production is seasonal, requiring farmers to store grain in a secure manner so as to maintain its availability throughout the year. Post-harvest losses of maize grain, particularly at the storage stage, have been reported to impede maize sub-sector advancement in most developing countries, including Tanzania. Maize losses are reported to be around 20%, with storage insect pest infestations accounting for a considerable fraction ranging from 5 to 10% (Chigoverah and Mvumi, 2016; Alemu *et al.*, 2021). Furthermore, the employment of traditional maize storage methods by smallholder farmers has considerably contributed to such huge grain losses (Omobowale *et al.*, 2015).

Hermetic technology is effective grains storage technique that reduce grain storage losses by controlling insect infestations (Likhayo *et al.*, 2018). The technology is a non-chemical storage that works on hermeticity principle (Okolo and Adejumo, 2017). Hermetic storage technology can be classified into two main types: metal or plastic silos and flexible structures, which are commonly inter woven polypropylene (PP) with an inner hermetic plastic film liner (s). Hermetic bags have been advocated as a common choice throughout SSA, resulting in various interventions by government and other actors (Chigoverah and Mvumi, 2018). These hermetic bags are commercially available in three varieties for instance single layer, double layer, and triple-layer bags. Additionally, these hermetic bags are commercially available with various storage capacities ranging from 50 to 100 kg (Baributsa and Ignacio, 2020). Hermetic bag technology works by restricting air and water from getting into the stored grain from outside (Anankware, 2013). The little population of insect pests already present on the grains consumes the remaining oxygen within the hermetic bag once it is filled with the grain, causing them to go dormant and eventually die (Alemu *et al.*, 2021). On the other hand, these hermetic bags differ in terms of number of inner liners and their thickness that probably may account for the impact on their effectiveness. Despite their merits, hermetic bags are not widely used by majority of smallholder maize farmers (Moussa *et al.*, 2014).

Several studies have demonstrated that high grain losses in developing countries are mostly linked to low adoption of modern and effective storage technologies. The use of probability models to evaluate the reasons for low use of a certain technology has been one of the most important methodological achievements. Models such as *logit*, *probit*, and *tobit* the commonly used to evaluate variables with dichotomous nature. However, among these preference models, logit and probit models are the most widely used. Both model are very similar, and the obtained probability estimates are fairly close (Güneri and Durmuş, 2020). The most basic models are binary options, but there are models that can support more complex options. Logistic regression model has been involved in several research for evaluating the factors for low adoption of post-harvest storage technologies (Bokusheva *et al.*, 2012; Conteh *et al.*, 2015; Djibo and Maman, 2019). Studies on the factors causing poor acceptance of improved storage technologies are critical in developing countries like Tanzania. The current study focused on identification of these factors, the established explanatory variables could serve as a justification for policymakers to intervene.

## 1.2 Problem Statement

Maize is a major staple food crop in most Sub-Saharan African countries, enhancing household food security, income generation, and poverty reduction (Likhayo *et al.*, 2018). In most of these countries, a large quantity of maize is produced by smallholder farmers for self-consumption and partly disposed of on the domestic market (Maziku, 2017). However, huge post-harvest losses retard the development of the maize sub-sector in these countries. According to the African Post-Harvest Information System (2020), maize grain losses in SSA amount to 20% of total maize production, while maize grain losses in Tanzania can be as higher as 18%. Ineffective storage technologies account for 20 to 30% of total maize losses due to storage insect pests such as maize weevil and larger grain borers (Kumar and Kalita, 2017). In most countries, hermetic bag technology constitute a new promising solution for reducing grain storage losses by suppressing proliferation of insect and controlling other storage deterioration variables such as temperature and relative humidity (Baributsa and Ignacio, 2020).

Several studies have been undertaken to evaluate the effectiveness of hermetic storage bag technology globally (Mutambuki *et al.*, 2019; Shaw *et al.*, 2017; Ngwenyama *et al.*, 2020). However, there have been few studies that compared the effectiveness of locally manufactured hermetic bags in the country. The recent research conducted by Kiobia *et al.* (2020) compared the performance of hermetic bags in storage of maize grains under farmer managed conditions found no significant difference between PICS and Grainpro Super Bag. Additionally, the research by Abass *et al.* (2018) on-farm comparison of metal silo and PICS bags also saw no significant difference was observed in their effectiveness. The use of hermetic bags in maize storage improves food security and income while reducing post-harvest losses (Chegere *et al.*, 2020).

More brands of hermetic bags are becoming commercially available as a result of rising demand private sector investment in the industry. AgroZ<sup>®</sup>, and PICS<sup>™</sup> bags are among the most popular hermetic bag brands in the country. However, as the private sector's interest in hermetic bags grew, plastic businesses entered the market, developing or imitating existing hermetic bags. In addition, because some brands use single or double liners inside the woven bags, the durability of hermetic bags might vary by manufacturer. For instance, AgroZ is made up of single inner liner with thickness of 90µm while PICS bags is made up two inner liners with thickness of 80µm each (Baributsa and Ignacio, 2020). These characteristics can, in turn, have an impact on the effectiveness and reusability of hermetic bags (Baributsa and Ignacio, 2020). The previous research focused on evaluation of the effectiveness of one brand of locally produced hermetic bag, whereas this study examined two brands. The research focused on evaluating and comparing the effectiveness of AgroZ and PICS bags brands in suppressing maize weevils (*Sitophilus Zeamais*).

Despite the effectiveness of hermetic bags, the technology is not extensively employed by maize producers (AGRA, 2019; Ruzzante *et al.*, 2021). The current study also identified the determinants for low use of hermetic bag technology among the small holder farmers in the study area. Logistic regression model was used to evaluate the impact of each independent variable on the decision of maize farmers in adopting hermetic bag technology. The findings of this study will therefore help smallholder maize farmers gain knowledge about the effectiveness of these hermetic bags, as well as provide justification for the government and other actors in the maize post-harvest value chain to promote the use of hermetic bags, to reduce post-harvest losses in maize grain.

### **1.3 Objectives**

#### **1.3.1 Overall Objective**

The overall objective of the study was to evaluate the effectiveness of two locally manufactured brands of hermetic storage bags on reducing post-harvest storage losses in maize grain and hence generate knowledge that could promote the adoption of the technology among smallholder farmers in maize grain storage and thereby reduce post-harvest losses.

#### **1.3.2 Specific Objectives**

- i. To evaluate the effectiveness of AgroZ and PICS hermetic bags in maintaining quality of stored maize grain.
- ii. To establish drivers of adopting the hermetic bag storage technology.

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**CHAPTER TWO**

**PAPER ONE**

**Performance of Triple and Double Hermetic Bags for Maize Grain Storage<sup>1</sup>**

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<https://doi.org/https://doi.org/10.35410/IJAEB.2022.5780>

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<sup>1</sup> The material contained in this chapter has been published in International Journal of Agriculture, Environment and Bioresearch

**CHAPTER THREE**

**PAPER TWO**

**Factors that Influence Smallholder Farmers' Decisions to Employ Hermetic Bag Technology for Maize Grain Storage in Kilosa District, Tanzania<sup>2</sup>**

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*Article DOI: <https://doi.org/10.53430/ijrsru.2022.4.1.0141>*

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<sup>2</sup>The material contained in this chapter has been published in International Journal of Scientific Research Updates.

## CHAPTER FOUR

### 4.0 GENERAL DISCUSSION

Massive post-harvest storage losses of maize grain pose a significant threat to national food and nutrition security. These losses are mainly triggered by the employment of inadequate post-harvest storage practices. Although maize grain is a non-perishable food crop, its storage is a challenge in developing countries like Tanzania, necessitating investment in advanced storage technology and promoting its intensive use at the household level. Advanced maize storage technology, such as hermetic bags, has been claimed to control damaging storage insect pests without the application of synthetic pesticides. These bags for instance PICS and AgroZ are commonly available in commercial local markets. This study aimed to evaluate the effectiveness of two brands of hermetic bags as well as identify the causes of low acceptance among maize producers.

Prior to the experiment setup each treatment containing 20kg of maize grain was artificially seeded with maize weevils. Grain weight losses in polypropylene bags increased dramatically as a result of weevils (0.56–15.96%) as storage time increased. Maize grain in hermetic treatments; AgroZ and PICS bags showed minor weight loss (2.3%) and (2.5%), respectively, after 90 days of storage and remained below that after storage. A logistic regression model, was employed to estimate the relationship between the adoption of hermetic bag technology and the causes of low acceptability. About ten explanatory variables were added into the logistic regression model to analyze the influence of each variable. The findings demonstrated that price, accessibility, farmer experience, awareness, and training among sampled households all had a significant impact on farmers' decision to employ hermetic bag technology.

The grain loss of maize kept in AgroZ and PICS bags was modest, showing no significant difference ( $p < 0.05$ ) among hermetic treatments. This study backs up previous findings that maize stored in hermetic bags after six months of storage was only marginally damaged by insect pests (Likhayo *et al.*, 2018). Maize grain held in hermetic bags has limited interaction with the environment, which is predicted to inhibit insect infestation and multiplication (Mutambuki *et al.*, 2019). The huge grain losses reported in interwoven polypropylene bags, on the other hand, were driven by the ease of air exchange between the stored produce environment and the outside environment, which favors insect growth (Tivana *et al.*, 2021). Additionally, the results showed that the moisture content of maize kept in AgroZ and PICS bags changed slightly throughout the course of the storage period, indicating a lack of moisture exchange between hermetic bags and the outside environment. Therefore, farmers with low income who cannot afford to purchase seeds after each planting season could employ hermetic bags as an effective and cost-effective seed storage alternative (Tefera *et al.*, 2018; Mutambuki *et al.*, 2019). Although hermetic bags have been shown to be successful in minimizing maize storage losses, they are not widely used by maize producers contributed by several factors.

The logistic regression model revealed that one of the causes of low adoption among sampled households could be contributed to low awareness among farmers of the benefits of hermetic bags. Farmers' awareness grows as they attend more extension sessions and participate in capacity-building training programs. This finding is consistent with prior research findings that farmers who are well-informed and competent are more likely to employ improved storage methods (Mwaijande, 2017). Furthermore, the findings are consistent with past research that has found that farmers who participate in training are more likely to employ improved post-harvest technologies than those who do not (Kattel *et al.*, 2020). Additionally, the high cost and remoteness of hermetic bag selling points were

identified as major causes for the low uptake of the hermetic bag technology. Most smallholder farmers have a low level of income, making it impossible to afford such a high noted price of hermetic bags.

Grain damage and weight loss, on the other hand, could have a negative impact on smallholder farmers, traders, and the national economy as a whole. Maize producers would lose a higher profit margin due to lower grain quality caused by insect damage. Such extreme grain damage renders maize unsafe for human consumption, causing its market value to drop drastically. Farmers usually respond to such losses by using synthetic chemicals to extend the store life of their maize grain. The approach of using these chemicals in grain storage is discouraged as they are associated with high risk to human health and pose a threat to the environment. Modern grain storage methods, such as hermetic bags, could be intensively used so as to reduce the existing level of postharvest losses, consequently improving smallholder farmers' livelihoods and food security. Finally, the findings of the study will help small-holder maize farmers gain knowledge about the effectiveness of locally manufactured hermetic bags in order to promote the adoption of improved maize grain storage technologies, particularly use of hermetic bag technology.

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## CHAPTER FIVE

### 5.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

#### 5.1 Conclusions

In summary, the study sought to evaluate the effectiveness of two brands of hermetic bags, and determine the factors contribute to the low acceptance of technology among maize producers. The results showed that no significant differences were observed in the effectiveness of two brands of hermetic bags. After six months of maize storage, the evaluated two brands of hermetic bags were effective in controlling *Sitophilus Zeamais*. Weight loss and grain damage in hermetic bags were significantly lower than in polypropylene bags. The study reveals that hermetic bag technology is an alternative method that offer farmers a safe, efficient and convenient option for grain storage. Additionally, the technology maintained the grain germination potential above the recommended percentage. Finally, on this point, acceptance and appropriate use of the technology could significantly decrease massive maize grain storage losses, and thus improving farmers' livelihoods and national food security at large so long as the maize is adequately dried and less infested prior to storage.

The logistic regression model, on the other hand, indicated that among the reasons for low adoption of hermetic bags by farmers includes the high cost and inaccessibility of hermetic bags, lack of training and awareness regarding the benefits of the technology. The availability of hermetic bags closer to the farmers' homes at subsidized price could increase adopters of the technology. Moreover, efficient extension services play an important part in the adoption of improved post-harvest storage technologies, as farmers are made aware of the most recent and effective technology. Farmers with experience on the other hand, serve as a model for non-adopters of the technology, allowing them to learn from and be encouraged by the beneficial results of the technology. Finally, the knowledge gained about the effectiveness of the tested brands of hermetic bags, as well as the identified drivers for low technology adoption of hermetic bags, could be used to justify intervention by policymakers and non-governmental actors to promote the technology.

#### 5.2 Recommendations

- i. The price of hermetic bags negatively and significantly affected the farmers' decision in using hermetic bag technology. Therefore, the current study recommends the government to subsidize the materials for manufacturing these bags so as to promote their use.
- ii. Access to credit may encourage more farmers to more use of hermetic bags which may be achieved by the government to establish soft credits to small scale famers at village level.
- iii. Hermetic bags manufacturing plant may be established in the area with high production of maize crop. This would guarantee farmers access of the hermetic bags at low price and hence motivate them to adopt the technology.
- iv. The current study is intended to serve as a starting point for future research into the engineering characterization of hermetic bags inner liners.
- v. Climate change adversely impact the quality and quantity losses of the stored grains as the results of temperature increase which lead to rise in the number of insect pests globally. Further study may be extended to investigate the influence of a surge increase in storage insect pests on the performance of hermetic storage bags as a result of climate change.
- vi. Several studies indicated that the hermetic bag technology considerably reduces maize grain losses; nevertheless, the magnitude of the technology's contribution to

the nation's food security is not yet known, therefore further research is recommended to address this knowledge gap.

- vii. In light of the current study, further research is recommended to be extended into exploration of the re-usability of the locally manufactured hermetic bags.

## APPENDICES

### Appendix 1: Survey Questionnaire

#### The reasons affecting farmers' decision to use hermetic bag.

##### A. General Information

1. Name of Village: .....
2. Name of Ward: .....

##### B. Respondent Demographic Details

- 1) Age of respondent
  - a) 18-25
  - b) 25-35
  - c) Above 35
- 2) Sex of respondent
  - a) Male
  - b) Female
- 3) The marital status of respondents
  - a) Married
  - b) Single
  - c) Divorced
- 4) The size of the respondent's household
  - a) 0-3
  - b) 4-7
  - c) Above 7
- 5) Level of education of respondents
  - a) No education
  - b) Primary education
  - c) Secondary School
  - d) High School
  - e) College/University
- 6) Do you participate in any farmer-related organizations?
  - a) Yes
  - b) No

##### C. Farmer Acceptance of Hermetic Bag Technology

- 7) Do you mainly grow maize?
  - a) Yes
  - b) No
- 8) What is the acreage of a maize farm?
  - a) 0.5 – 1.0
  - b) 1.0 – 1.50
  - c) Above 1.50
- 9) Do you store your maize grain after harvest?
  - a) Yes
  - b) No
- 10) What are the methods of maize storage do you use? Mention them.
  - a) .....
  - b) .....
  - c) .....

- d) .....
- 11) Have you ever heard about hermetic bags?
    - a) Yes
    - b) No
  - 12) If yes, where did you hear?
    - a) On radio
    - b) Friends
    - c) Television
    - d) Agric. Extension officer
    - e) NGO
    - f) Traders
  - 13) Are you currently using hermetic bags to store maize grain?
    - a) Yes
    - b) No
  - 14) What is the distance from your home to the selling point of hermetic bags? .....km
  - 15) What is the price of a hermetic bags?
    - a) High
    - b) Medium
    - c) Low
  - 16) Were you afraid to accept and use hermetic bag technology?
    - a) Yes
    - b) No
  - 17) If you abandoned the hermetic or have never used technology, what were the reasons?
    - a) Too expensive
    - b) Not accessible
    - c) Not effective
    - d) Do not trust the technology
  - 18) What advantages would motivate you to use hermetic storage if you aren't already?
    - a) Improved germination rate for stored seeds
    - b) Improved market access to purchased product
    - c) Improved grain quality for family consumption
    - d) Improved quality in grain resulting in premium price
  - 19) How long have you been using hermetic bags to store maize grain? ..... years.

#### **D. Respondents Benefits from Hermetic Bag**

- 20) How long do you keep maize in the hermetic bag?
  - a) ≤ 6 months
  - b) 7-12 months
  - c) > Above
- 21) For what purpose do you mostly store maize grain?
  - a) Domestic food
  - b) Seed
  - c) Commercial purpose
- 22) How many times have you reused hermetic bags?
  - a) Two seasons
  - b) Three seasons
  - c) Above three seasons
- 23) Have you experienced any grain loss as a result of pest damage?
  - a) Yes
  - b) No

- 24) Do you have access to financing to purchase storage facilities such as hermetic bags??
  - a) Yes
  - b) No

- 25) If Yes, where did you acquire that loan??
  - a) Banks
  - b) Relatives/friends
  - c) SACCOS
  - d) Microfinance

**E. Other Questions**

- 26) When do you normally sell your maize?
  - a) Immediate after harvest
  - b) 3 months after harvest
  - c) Above 3 months after harvest
- 27) What was the average annual income (TZS) from selling stored maize in hermetic bags over the previous three seasons?
  - a) .....
  - b) .....
  - c) .....


## Appendix 2: Certificate of Publication Paper 1

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Sept-Oct, 2022 Volume 7, Issue 5 online publication under ISSN 2456-8643.

With Regards

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published in International Journal of Scientific Research Updates (IJSRU)

Volume (4) Issue (1) of year 2022.

CrossRef DOI:10.53430/ijrsru.2022.4.1.0141

  
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