Effects of Agricultural Hermetic Technology Adoption on Household Income in Kapinjipanga Chiefdom of Solwezi District, Zambia

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ABSTRACT

This study investigated the adoption of agricultural hermetic storage technology by smallholder farmers in Kapinjipanga Chiefdom in the Solwezi District of Zambia and its effects on household income, food security, and community involvement. Hermetic storage technology is key to overcoming post-harvest losses, one of the big challenges to improving productivity in agriculture and ensuring food security in developing economies. The study investigates how the adoption of hermetic bags affects post-harvest losses and income levels and further analyzes their impact on the food security of smallholder farmers. Data collection was done using questionnaires among 150 smallholder farmers on the adoption of the hermetic bags, access, training related to the technology, and impact/effects on post-harvest losses and increase in household income. Quantitative and qualitative analysis methods are/were employed to present results compared to the existing literature. The results showed an adoption rate of 70%, and farmers have used the hermetic bags for 2.5 years. Key adoption factors included accessibility, as cited by 53% of the respondents, and training attendance by 60%. The post-harvest losses decreased by 47%, while 37% of the participants reported increased yearly income by about ZMW 1,200. Besides, 53% of the respondents reported improved food security, while 43% reported an increase in community involvement. The study highlights the significant positive effects of hermetic storage adoption on the productivity and income of smallholder farmers. Although there are/were still numerous challenges, particularly in terms of accessibility of resources and education on technology usage, the results indicated that continued support in training programs and increased accessibility would be required for the sustaining of the full benefits of this technology. These findings offered insights into how hermetic storage technology could enhance the socioeconomic status of smallholder farmers in the Kapinjipanga Chiefdom to improve food security and community development in the long run. Future studies should examine how training programs can be improved to increase farmers' confidence and ensure the technology's long-term success. This includes evaluating the role of local experts, farmers' engagement, and hands-on learning opportunities in enhancing the adoption process.

Keywords: Hermetic storage of agricultural produce, post-harvest losses, household income, food security, smallholder farmers, Zambia, Kapinjipanga Chiefdom, community engagement, and technology adoption.

INTRODUCTION

Post-harvest losses remain a significant global issue, particularly in areas where agriculture was a key source of income. According to the Food and Agriculture Organization (FAO, 2022), around 14% of food produced globally was lost between the time of harvest and retail, with developing nations experiencing the most severe losses. Maize, a crucial crop for many communities, was especially susceptible to these losses, mainly due to pest problems and inadequate storage facilities. Innovations like hermetic storage technology have been developed as sustainable solutions to help reduce these losses, improving grain preservation and extending shelf life (World Bank, 2020).

In Africa, agriculture accounts for over 30% of GDP in several countries, yet the economic impact of post-harvest losses is significant. Research shows that as much as 30% of cereals, including maize, are lost because of poor storage practices and pest infestations (FAO 22, Zulu et al 2020). Conventional storage methods, such as granaries and polypropylene bags, often fall short of protecting against pests and moisture, leading to

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increased spoilage (Chisanga et al 2021). Hermetic storage solutions, like Purdue Improved Crop Storage (PICS) bags, provide a chemical-free and cost-effective option by creating an airtight environment that prevents pests and pathogens from thriving (Muriuki et al 2023). The implementation of these technologies has led to a notable decrease in losses, improved food security, and better household incomes in countries such as Tanzania, Kenya, and Ghana, where maize losses have dropped from 20% to below 2% (Bwalya et al 2023).

In Sub-Saharan Africa, where smallholder farmers play a dominant role in agriculture, post-harvest losses are particularly pronounced, especially for staple crops like maize. The World Bank (2020) emphasizes the serious effects of these losses on food security and income generation, as traditional

storage methods are inadequate for effectively safeguarding grains. In Zambia, maize accounts for over 80% of smallholder farmers' production (CSO,2020), yet pest infestations and inadequate storage infrastructure lead to losses as high as 30% (FAO, 2022). Such losses, compounded by price fluctuations, reduce farmers' capacity to store maize and sell during higher market prices, thereby limiting their income (Muriuki et al., 2023).

Efforts to address these challenges have included initiatives like the Scaling Up Nutrition (SUN II) project in Kapinjipanga Chiefdom of Solwezi District. Implemented by the World Food Programme (WFP) in collaboration with iDE Zambia, the project targeted 2,500 smallholder farmers to promote food security and income improvement through hermetic bag distribution (WFP, 2020). The adoption of hermetic bags enabled farmers to store maize for extended periods, maintain grain quality, and sell at higher prices during lean seasons (IDE Zambia, 2022). While the technology has shown promise in reducing losses and enhancing economic outcomes, the extent of its impact on household income in Kapinjipanga Chiefdom remains underexplored.

Statement of the problem

Zambia's agricultural sector employs around 60% of the labour force, especially in rural areas, and plays a crucial role in household income and national food security. However, smallholder farmers encounter significant challenges, with post-harvest losses—reaching up to 30% of harvested crops— threatening both income and food security (GRZ,2020). Traditional storage methods, like open sacks and earthen pits, are inadequate, leaving stored grains vulnerable to pests, mold, and spoilage. Hermetic storage technologies have shown promise in reducing these losses by blocking moisture and pest entry, prolonging the shelf life of stored grains, and decreasing the need for chemical pesticides, as highlighted by research in Ethiopia and Kenya (Bwalya et al 2023; Manda et al., 2022). In Zambia, obstacles such as high upfront costs, lack of awareness, and limited access to financing impede the broader adoption of hermetic technology among smallholder farmers (World bank 2020). Although national policies, including the National Agricultural Policy, stress the importance of minimizing post-harvest losses to boost food security, there is a lack of empirical evidence regarding the economic advantages of hermetic storage, particularly its effects on household income in the Kapinjipanga Chiefdom of Solwezi District (GRZ, 2022).

Smallholder farmers, who depend on rain-fed agriculture, often experience income fluctuations, especially during off-harvest times. Hermetic storage could enable these farmers to hold onto their produce for sale during peak demand periods, helping to stabilize their income throughout the year (Njuki et al., 2021). Nevertheless, there are still gaps in understanding the socioeconomic effects of adopting this technology in resource-limited areas like Kapinjipanga. Investigating the direct income impacts and barriers to adoption is vital for informing policymakers and development organizations aiming to promote sustainable agricultural practices and enhance rural livelihoods. This study explores the impact of adopting hermetic storage on household income in the Kapinjipanga Chiefdom.

Purpose of the Study:

The purpose of the study was to analyze the effects of adopting hermetic storage technology on post-harvest losses and household income among smallholder farmers.

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Specific Objectives:

1. To assess the adoption of hermetic storage technology among smallholder farmers.
2. To examine the factors influencing the adoption of hermetic storage technology among smallholder farmers.
3. To analyze the effect of hermetic storage technology adoption on post-harvest losses and its impact on household income.
4. To evaluate the socioeconomic benefits associated with the adoption of hermetic storage technology among smallholder farmers.

Research Questions:

1. What is the level of adoption of hermetic storage technology among smallholder farmers?
2. What are the key factors influencing the adoption of hermetic storage technology among smallholder farmers?
3. How does the adoption of hermetic storage technology affect post-harvest losses, and what is its impact on household income among smallholder farmers?
4. What are the socioeconomic benefits experienced by smallholder farmers as a result of adopting hermetic storage technology?

THEORETICAL FRAMEWORK

The theoretical framework for evaluating the effects of adopting agricultural hermetic technology on household income in Kapinjipanga Chiefdom, Solwezi District, was based on two primary theories: the Diffusion of Innovations (DOI) Theory and the Sustainable Livelihoods Approach (SLA).

Diffusion of Innovations Theory (DOI): Developed by Rogers (2003) and further elaborated by Muriuki et al (2023) and Banda et al. (2021), the DOI theory describes how new technologies or innovations are embraced within a community. It suggested that innovations pass through several stages: awareness, interest, evaluation, trial, and adoption. Key factors driving adoption include perceived benefits, compatibility with current practices, ease of use, and visible outcomes. In the context of hermetic technology, advantages such as extended crop storage, decreased spoilage, and reduced pesticide reliance have motivated smallholder farmers to adopt these practices. The DOI theory also points out obstacles, like high upfront costs and limited financial resources, that can affect the adoption process in Zambia (Chisanga et al 2021). It underscored the importance of community leaders, agricultural extension services, and cooperatives in raising awareness and facilitating trials, which were essential for the broader acceptance of hermetic technology in Kapinjipanga Chiefdom.

The Sustainable Livelihoods Approach As described by Chambers and Conway, the Sustainable Livelihoods Approach (SLA) emphasises the various social, natural, physical, and financial assets that households utilize to secure sustainable livelihoods. This approach is especially pertinent in rural areas, where families often face resource limitations and rely heavily on agriculture for their livelihoods. Hermetic storage technology supports the SLA by enhancing financial capital through decreased post-harvest losses, allowing farmers to sell their crops when market prices are more advantageous. Furthermore, by minimizing pesticide usage, hermetic storage bolsters human and social capital by promoting better health and facilitating knowledge-sharing practices (Bwalya et al,2023; FAO 2022). This technology also improves physical and natural capital by lowering maintenance expenses and tackling seasonal food insecurity (Mbozi et al., 2022). In Zambia, where the majority of agricultural households depend on rain-fed farming, enhanced storage systems can greatly influence household resilience, food security, and income.

The combination of the DOI theory and SLA creates a comprehensive conceptual framework that aids in

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analyzing how the adoption of hermetic storage affects household income and overall livelihood sustainability in Kapinjipanga Chiefdom. While the DOI theory examines the adoption process, the SLA underscores the effects on livelihood assets, ensuring that the advantages of hermetic technology go beyond immediate financial benefits to foster long-term improvements in household well-being and sustainability.

LITERATURE REVIEW

The Adoption of Hermetic Storage Technology

The global adoption of hermetic storage technologies, particularly PICS bags, has increased significantly due to their effectiveness in reducing post-harvest losses and their compatibility with the Sustainable Development Goals (SDGs). These technologies provide a chemical-free method for pest control, making them ideal for organic farming (Stathers et al., 2020). Their implementation has been crucial in areas like Sub-Saharan Africa and Southeast Asia, where agriculture plays a vital role in the economy and food security for households.

In Africa, countries such as Kenya, Nigeria, and Ethiopia have seen notable adoption rates, thanks to initiatives from governments and NGOs that promote awareness and offer subsidies. For example, more than 40% of maize farmers in Kenya have started using PICS bags, which has led to a decrease in pest-related losses and has positively impacted food security and household incomes (Mutungi et al., 2022). Likewise, research in West Africa indicates a 50% reduction in grain losses, enabling farmers to sell their crops at better prices during peak market times (Baoua et al., 2020). Nonetheless, challenges like the high cost of technology and limited awareness still exist (Affognon et al., 2021)

In Zambia, the adoption rate was lower compared to other regions, despite the clear benefits. Factors such as a lack of awareness, limited market access, and a cultural preference for traditional storage methods continue to impede broader usage. However, pilot programs and agricultural extension efforts, like the Scaling Up Nutrition (SUN II) project, have shown some success (Kabwe et al.,2021; Mwansa & Mulenga, 2023). This highlighted the need for focused interventions to address these challenges and promote the use of hermetic storage solutions.

In the same way, these programs had given access to PICS bags and provided instruction on how to use them in areas like Kapinjipanga Chiefdom (World Food Programme (WFP), 2022). Yet adoption was still very low with only a small fraction of farmers fully incorporating hermetic technologies into their post-harvest management systems. Due to various factors, including lack of knowledge, high initial costs, and cultural norms, traditional storage methods were still not widely adopted (Kabwe et al, 2021).

Hermetic storage technology had been promoted in the Kapinjipanga Chiefdom through pilot projects and agricultural extension programs. In the research study carried out by Mwansa and Mulenga (2023) stated that the rate of adoption in Zambia was still relatively low when compared to other regions like Kenya, Nigeria and Uganda. The lack of consistent availability and cost of bags among smallholder farmers was the reason behind this.

Factors Influencing the Adoption of Hermetic Storage Technology

The adoption of hermetic storage technologies was shaped by a mix of economic, social, and institutional factors. High initial costs and limited access to credit pose significant challenges, particularly for smallholder farmers in poorer regions. Research indicates that subsidies and financial support programs could significantly boost adoption rates, as seen in Southeast Asia and West Africa (Muriuki et al 2023).

Access to information and education was also vital. Awareness campaigns, agricultural extension services, and training initiatives have been effective in encouraging adoption. For instance, farmers in Burkina Faso who received training in hermetic storage methods were more likely to embrace the technology compared to those

who did not receive such training (Baoua et al., 2020). In contrast, areas with limited extension services, like certain parts of Zambia, show lower adoption rates due to a lack of knowledge dissemination (Mwansa &

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Mulenga, 2023).

Cultural practices and gender dynamics further influence adoption. In some African communities, traditional storage methods were still widely used due to their familiarity, despite being less effective (Bwalya et al 2023; Chisanga et al 2021). Moreover, women, who often manage post-harvest storage, encountered obstacles such as limited decision-making power and access to resources. Providing targeted support for women has shown promise in enhancing adoption rates, as evidenced in Ethiopia (FAO 2022).

Market access was another key factor. Farmers with access to stable markets were more likely to adopt hermetic technologies, as they could store crops longer and sell them at better prices (World bank 2020). On the other hand, farmers in remote areas with immediate cash needs were less inclined to invest in these technologies. In Zambia, market constraints have limited adoption, although government initiatives were working to bridge these gaps (Zulu et al., 2020). Environmental factors, like the presence of pests, play a significant role in the adoption of storage technologies. In areas with high pest infestations, such as Tanzania and Uganda, hermetic storage methods were especially valued for offering an effective, chemical-free solution (Chisanga et al 2021). Despite this, the adoption of these technologies was inconsistent, as wealthier farmers were more able to invest in them compared to their less affluent peers, resulting in a situation where the most vulnerable farmers gain the least benefit.

Effect of Hermetic Storage Technology Adoption on Post-Harvest Losses and Household Income

Hermetic storage technologies have shown significant effectiveness in minimizing post-harvest losses by preventing pest infestations and fungal growth. The airtight conditions created by these technologies help maintain the quality and quantity of stored crops, enabling farmers to keep their harvests for a longer period without spoilage. Research indicated that these technologies can reduce losses by as much as 90% in areas like Kenya and Tanzania, where traditional storage methods often fall short (Chisanga et al 2021). This decrease in losses directly contributes to enhanced household incomes, as farmers can sell their crops at optimal market prices instead of at lower post-harvest rates (Muriuki et al., 2023).

In Africa, where nearly 40% of crops were lost due to insufficient storage, hermetic storage technologies have made a significant economic impact. For instance, the use of PICS bags in Niger allowed cowpea farmers to store their produce for longer periods, leading to a 40–60% increase in income due to improved timing of sales (Baoua et al., 2020). Likewise, Ethiopian farmers saw a 30% reduction in pesticide use along with decreased post-harvest losses, which not only raised household incomes but also enhanced health outcomes (FAO 2022; Bwalya et al., 2023).

In Zambia, where smallholder farmers frequently encounter post-harvest challenges, the implementation of PICS bags has yielded encouraging results. Studies show a 90% reduction in grain losses and a 30% increase in household income among those who adopted the technology (World bank 2020). Farmers have also diversified their income sources, using improved crop preservation to venture into small-scale livestock farming (Zulu et al., 2020). However, despite these advantages, adoption rates remain low due to challenges such as the high initial cost of PICS bags and limited access to credit and markets.

Socioeconomic Benefits of Hermetic Storage Technology Adoption

The socioeconomic advantages of adopting hermetic storage technologies go beyond just financial benefits, they also include enhanced food security, environmental sustainability, and a decrease in the use of harmful pesticides. Farmers in Sub-Saharan Africa and Southeast Asia have noted significant reductions in chemical usage, resulting in healthier storage conditions and lower expenses (FAO 2020). Moreover, airtight storage has improved food security by maintaining grain quality during lean periods, which lessens the need for emergency assistance (Baoua et al., 2020). Education and training initiatives have played a crucial role in encouraging adoption. For example, farmers in Uganda who received training were much more likely to implement hermetic storage systems, as they grasped their practical and economic advantages (Okori et al., 2022). Likewise, agricultural extension services in Kenya have aided farmers in making informed choices regarding hermetic storage, leading to increased adoption rates (Muriuki et al., 2023).

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Access to markets and financial resources also impacts adoption. Farmers with stable market access or credit options were in a better position to invest in hermetic technologies. Ethiopian farmers selling to formal markets showed higher adoption rates due to price premiums for high-quality grains (Tefera et al., 2022). Additionally, subsidies and cost-sharing programs have been effective in boosting adoption. For instance, Zambia's subsidy initiatives resulted in a 40% increase in the use of PICS bags within two years (Chirwa & Mumba,2023). Gender dynamics also play a role in adoption rates. Women, who often manage household food supplies, encounter obstacles such as limited access to resources and training. Targeted programs, including microfinance initiatives, have helped to overcome these barriers, leading to higher adoption rates among women-led households (Bwalya et al., 2023).

RESEARCH METHODOLOGY

Research Design

This study used a mixed-methods approach to explore the various effects of hermetic storage technology. On the quantitative side, it aims to assess changes in household income, crop yields, and storage losses through structured questionnaires given to a stratified random sample of 150 households. Descriptive statistics will be used to summarize the data, while inferential methods like t-tests and regression analysis will help compare income levels and assess the technology's impact. On the qualitative side, interviews and secondary data will provide additional context, highlighting both the tangible and experiential benefits of adopting this technology.

Sampling Design

A stratified sampling design was employed to ensure that different subgroups within Kapinjipanga Chiefdom are adequately represented. The strata are categorized based on whether individuals have adopted the technology (adopters vs. non-adopters), as well as demographic factors (such as gender and age) and socio-economic variables (like income levels and landholdings). This method follows established best practices in social research (Kothari, 2020) and guarantees an unbiased, representative sample. Participants were randomly chosen from each stratum, ensuring proportional representation across groups to facilitate meaningful comparisons and deeper insights into the effects of hermetic technology.

Sample Size Determination

The sample size was determined using Cochran’s formula, which was adjusted for a finite population of 2,500 smallholder farmers. Although the formula indicated a sample size of 333 for high precision, practical considerations led to the decision to include 150 households in the study. This sample size strikes a balance between feasibility and statistical power, achieving a 95% confidence level with a 5% margin of error. The use of stratified random sampling further improves representativeness, ensuring that the chosen sample accurately reflects the diversity of the target population.

Target Population

The study focuses on smallholder farmers in Kapinjipanga Chiefdom, including both those who have adopted hermetic storage technology and those who are potential adopters. By engaging farmers from diverse socio-economic backgrounds, genders, and age groups, the study seeks to capture a broad spectrum of experiences and impacts. This inclusive approach helps to identify barriers to adoption, effects on agricultural practices, and the wider implications for household income and food security.

Triangulation

Triangulation plays a crucial role in this study, enhancing the reliability and depth of the findings. By integrating primary data (structured surveys and in-depth interviews) with secondary data (reports and records), the study strengthens its conclusions through multiple viewpoints. The triangulation strategy serves three key purposes:

Validation: Cross-verifying both quantitative and qualitative data ensures accuracy. Comprehensiveness:

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Merging numerical data with experiential insights enriches understanding. Contextualization: Including farmers' real-life experiences adds depth to the interpretation of statistical results.

RESULTS/FINDINGS

Presentation of Research findings

This section gave an overview of the demographic and socio-economic characteristics of the respondents in the study. Grasping these attributes was essential as they provided context for interpreting the findings and analyzing the factors that influenced the adoption of hermetic storage technology.

Gender Distribution of Respondents

The gender distribution indicated that male farmers made up the majority at 55%, while female farmers accounted for a significant minority at 45%. This relatively balanced participation highlighted the essential role of women in smallholder farming, aligned with the research from Sub-Saharan Africa, where women played a crucial part in agricultural labour and household food security, despite facing systemic challenges (FAO, 2022).

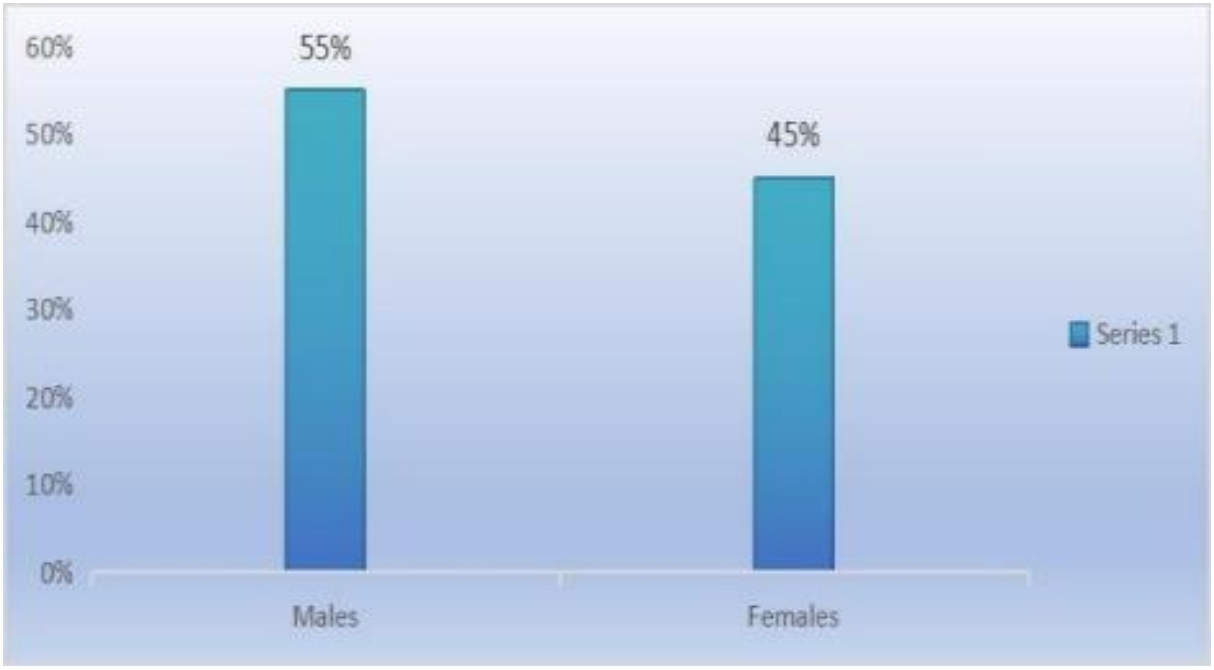

Figure 1. Gender Distribution of Respondents in Chief Kapinjipanga, Solwezi District

Source: Field Data, 2024.

Age distribution of respondents

The age distribution of respondents in the study sheds light on the demographic makeup of the farming community in Chief Kapinjipanga, Solwezi District. The findings showed that the farming population in Chief Kapinjipanga was quite young and active, with a notable 45% falling within the 31–40 age range. This group likely constituted the backbone of the agricultural workforce, known for their high productivity and openness to new practices. The 18–30 age group, making up 20%, holds potential for future workforce growth, although their smaller numbers might indicate challenges like limited access to land or capital (Ngoma et al., 2020). The older segment (41–50 years, 20%) offers a valuable farming experience that can be used to guide younger farmers. On the other hand, the senior demographic (51–65 years, 15%) may encounter issues such as decreased physical ability and hesitance to embrace modern farming techniques, as highlighted by research on rural farmer demographics (Mwanza & Phiri, 2021).

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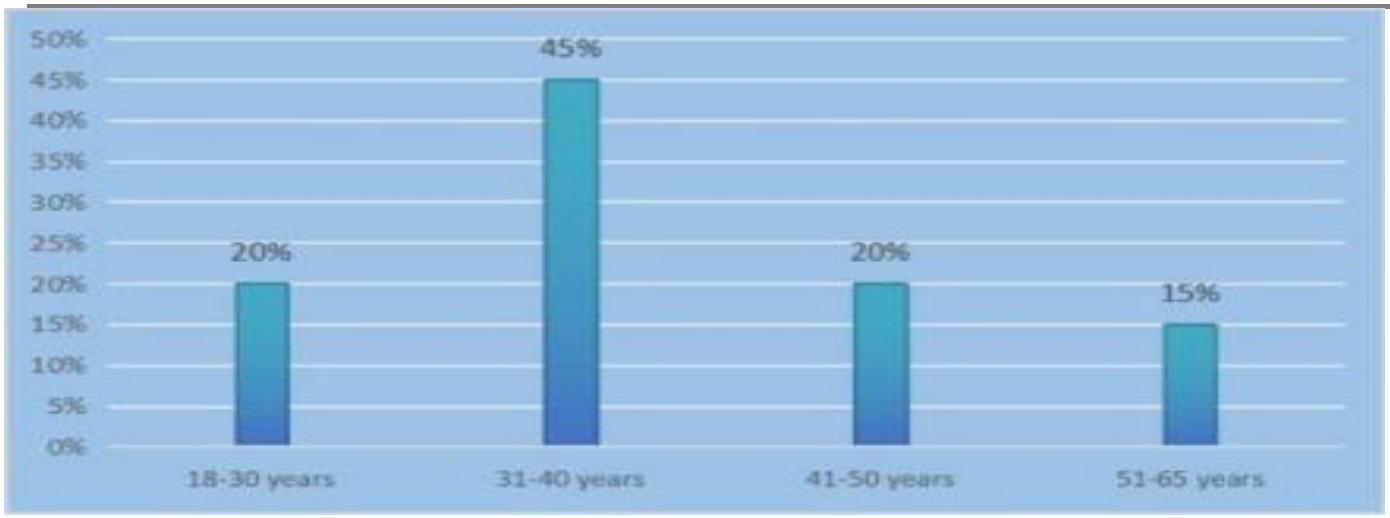

Figure 2. Age Distribution of Respondents in Chief Kapinjipanga, Solwezi District

Source: Field Data, 2024.

Marital Status

The majority of respondents were married, accounting for 70% of the sample. This suggests that farming communities in the Kapinjipanga Chiefdom may have consisted mostly of family units. This may influence the role of households and the division of labour in agricultural activities.

20% of respondents were single. They represent those who may be younger individuals entering the agricultural sector or individuals focused on independent operations within the community.

10% of respondents are widowed. which is a small group but it is important that it may face unique challenges in terms of workforce and resource availability. The results of the survey indicated that married individuals made up the majority (70%) of the farming population, suggesting that agricultural activities in Kapinjipanga Chiefdom were largely organized around family units. This arrangement likely affected the division of labour, as households combined resources and responsibilities to boost productivity. Similar observations had been made in other rural areas of Sub-Saharan Africa, where family farming served as the foundation of agricultural production (Ngoma et al., 2020). The single respondents (20%) likely represented younger or independent individuals who were new to farming. This group might introduce innovation and energy to the sector but could encounter difficulties in securing land and credit, which typically favour established family units (FAO, 2022). Widows, who made up 10% of the sample, represent a vulnerable demographic. They might struggle to access labour and resources, which could adversely affect farm productivity.

Figure 3. Marital Status of Respondents

Source: Field Data, 2024.

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Education Level

The educational background of respondents in the Kapinjipanga Chiefdom farming community revealed a range of literacy levels and their potential influence on agricultural practices. The results indicated that 60% of respondents had completed primary education, which suggested that the majority respondents had the basic literacy and numeracy skills necessary to understand agricultural extension materials and basic innovations. This finding was consistent with research showing that primary education enhanced farmers' abilities to adopt and implement simple agricultural techniques (FAO, 2022). The 30% of respondents with secondary education represent an important group with a greater capacity to engage in advanced farming practices, access market information, and manage finances effectively. Their higher education level might position them as potential leaders or trainers within their communities, as observed in similar contexts throughout Sub-Saharan Africa (Ngoma et al., 2020). The 10% without formal education, although a small segment, highlights a significant gap where the group might face challenges in following written instructions, understanding input labels, or participating in training programs that were delivered in traditional formats.

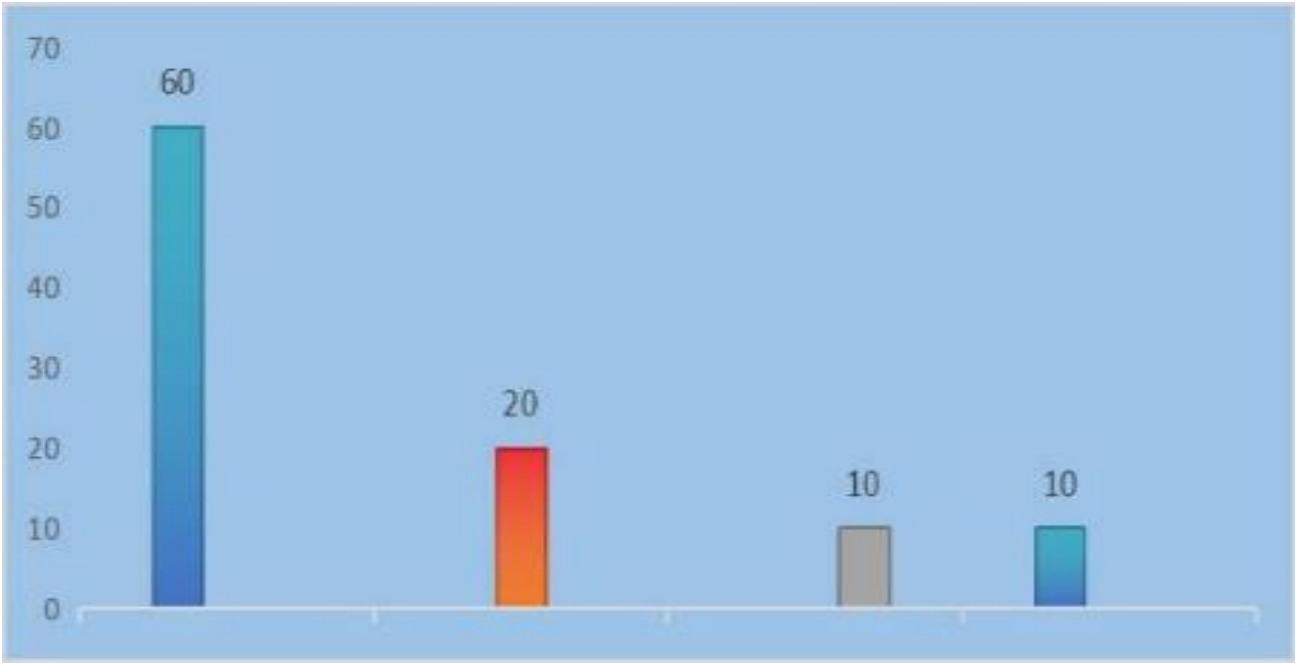

Figure 4. Education Level

Source: Field Data, 2024.

Adoption of Hermetic Storage Technology Usage of Storage Technologies

The results of the survey showed that hermetic bags were the most popular storage technology, with 70% of respondents using this modern solution. Hermetic storage gained favour because it effectively reduced post-harvest losses by keeping out oxygen and moisture, which helped to prevent spoilage and pest problems (Mwanza & Phiri, 2021). This trend aligned with global patterns, as smallholder farmers increasingly adopted post-harvest innovations to enhance food security (FAO, 2022). Sack bags were utilized by 13% of respondents, indicating a moderate reliance on a more traditional, yet less effective, storage method. While sack bags tend to be cheaper, they do not offer the same level of protection against pests and environmental factors as hermetic bags (Ngoma et al., 2020).

The fact that only 7% of respondents use plastic containers indicated a limited but significant preference for airtight storage solutions, which might be more accessible or affordable for some farmers. However, plastic containers were not commonly used due to their limited availability and generally higher costs compared to sack bags or traditional storage methods. Additionally, traditional storage techniques were still utilized by 10% of respondents, although this was a smaller group.

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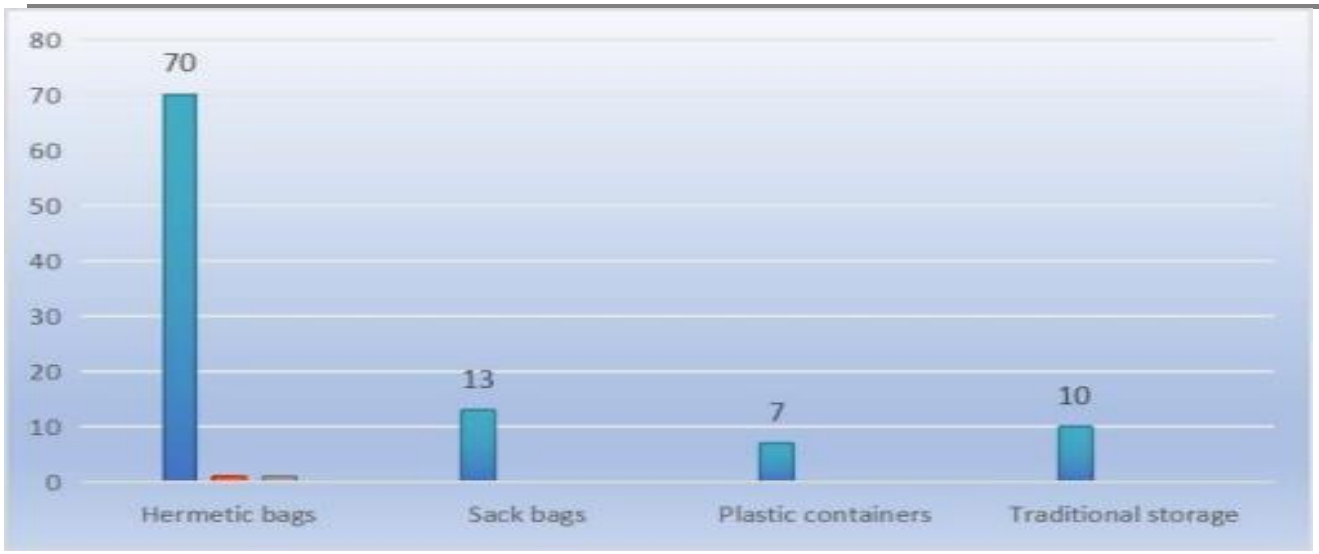

Figure 5. Types of Storage Technology Used by Respondents

Source: Field Data, 2024.

Durability of Storage Technologies.

The average time that respondents in Kapinjipanga Chiefdom had been using hermetic bags was about 2.5 years, which suggested that many farmers were having a good experience with this technology. Interestingly, 40% of those surveyed had been using hermetic bags for over three years, indicating a strong level of satisfaction and trust in their long-term effectiveness. This observation was consistent with global studies that emphasize how hermetic storage technologies could significantly cut down on post-harvest losses, maintain grain quality, and enhance food security (Ngoma et al., 2020). Research showed that hermetic storage bags effectively minimized pest problems, controlled moisture, and reduced spoilage, thus keeping grain in better condition for longer than traditional storage options (Mwanza & Phiri, 2021). The breakdown of usage duration (20% for 1 year, 30% for 2 years, 40% for 3 years, and 10% for more than 3 years) reflected that as respondents gain more experience with the technology, their confidence in it grows.

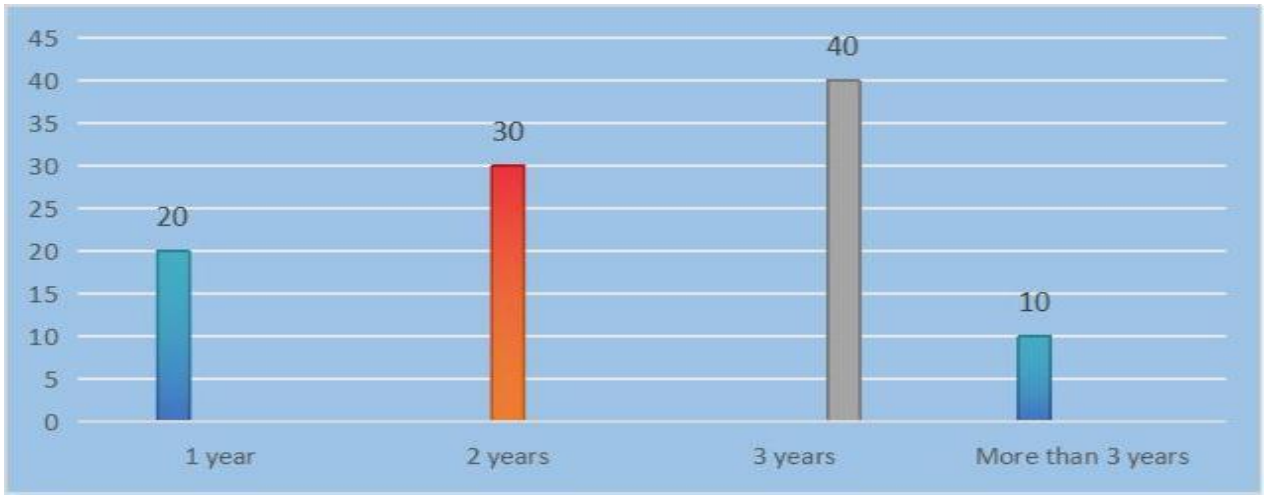

Figure 6. Duration of Use of Hermetic Bags

Source: Field Data, 2024.

Factors Influencing Adoption Accessibility of the Hermetic Bags and Cost

The respondents in Kapinjipanga Chiefdom evaluated the accessibility and convenience of hermetic bags in comparison to traditional storage methods. The findings revealed that 53% of respondents considered hermetic

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bags to be very accessible, highlighting the strong market presence and affordability of this technology in the region. This high level of accessibility was crucial for the widespread adoption of hermetic bags and their popularity among smallholder farmers. According to FAO (2021), having modern storage solutions available was a key factor in reducing post-harvest losses and improving food security. Additionally, 34% of respondents found hermetic bags to be accessible, suggesting there was still room for improvement in distribution networks and strategies to lower costs. While accessibility issues were not as pronounced, they still affected adoption rates. Ngoma et al. (2020) proposed that targeted subsidies and better supply chain logistics could further extend the reach of these technologies. On the other hand, the 13% who rated hermetic bags as slightly accessible represented a group facing significant challenges. This segment might struggle with affordability or be geographically isolated, which limits their ability to obtain hermetic bags. Research has indicated that such barriers can hinder the full potential of post-harvest technologies, particularly in rural areas (Mwanza & Phiri, 2021).

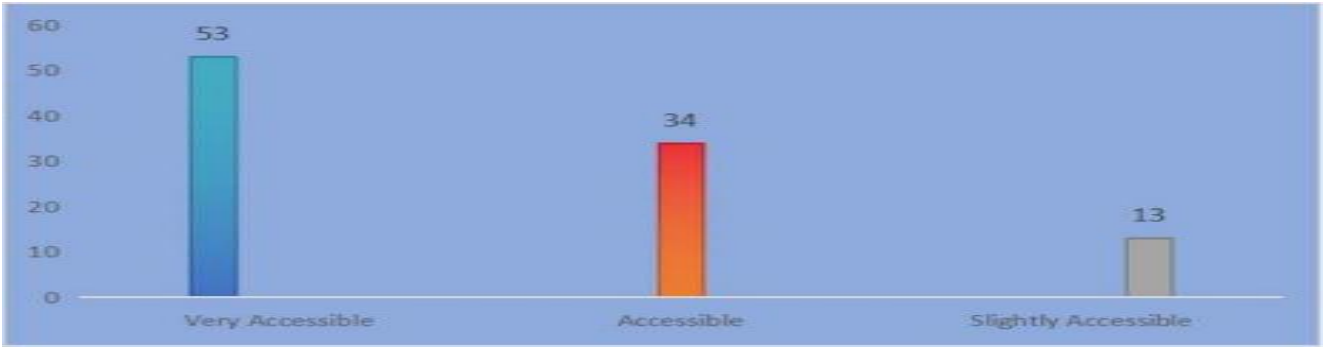

Figure 7. Perceived Accessibility of Hermetic Bags among Respondents

Source: Field Data, 2024.

Training and Knowledge

The high participation rate, with 60% of respondents attending more than two workshops each year, highlighted the significance of ongoing training in encouraging the adoption and effective use of hermetic storage technologies. This was consistent with findings from Ngoma et al. (2020), which stressed that regular and focused training enhances understanding of post-harvest innovations, and promotes proper use and wider acceptance. The 20% who attended two workshops annually represented a moderately engaged group that gained from occasional exposure to technical knowledge. However, the 13% who attended only once a year and the 7% who had never participated in training indicated a need for inclusive outreach strategies to ensure all farmers could access these educational opportunities. Mwanza and Phiri (2021) proposed that customized training programs, such as mobile workshops or localized demonstrations, could help bridge this gap.

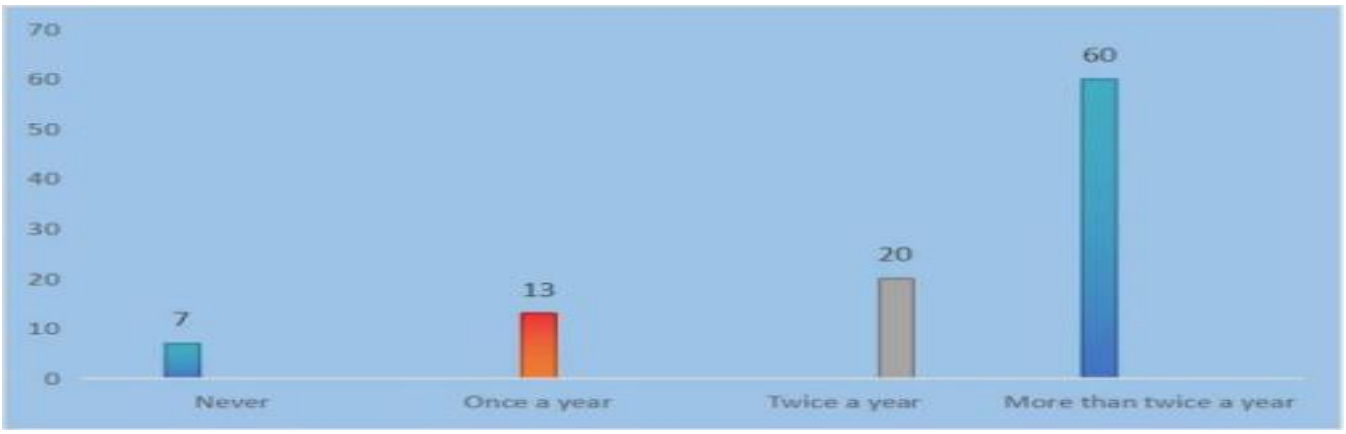

Figure 8. Frequency of Training Workshop Attendance on Hermetic Storage Technology

Source: Field Data, 2024.

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Impact/Effects on Post-Harvest Losses and Household Income

The findings presented a strong case for the positive effects of hermetic storage technology on reducing post-harvest losses and increasing household income. The fact that 50% of respondents reported a reduction in losses of over 70% highlighted the technology's success in maintaining grain quality by preventing spoilage and pest issues. As noted by FAO (2022), post-harvest technologies such as hermetic bags were essential for reducing food losses and improving food security, especially in areas with limited resources. Moreover, the 45% of respondents who experienced an income increase of more than 40% emphasized the economic advantages of using hermetic storage. Selling higher-quality grain at better prices directly leads to improved livelihoods. This aligned with findings from Ngoma et al. (2020), which stress that post-harvest innovations not only cut down losses but also bolster farmers' economic resilience by enhancing their competitiveness in the market. On the other hand, the 5% who reported little to no reduction in losses or income gains indicate areas that require attention. These included tackling operational inefficiencies, raising awareness about proper usage, and strengthening market connections. Mwanza and Phiri (2021) suggested that combining training with access to necessary infrastructure and financing could enhance the benefits of these technologies.

Post-Harvest Losses

The fact that 47% of respondents reported significant reductions in post-harvest losses highlighted the effectiveness of hermetic bags in preserving grain. By creating airtight conditions that prevented pest infestations and moisture from entering, hermetic storage minimized deterioration and waste (FAO, 2022). These findings were consistent with research by Ndegwa et al. (2018), which indicated that hermetic technologies could reduce post-harvest losses by more than 50% in similar agricultural settings. The 25% of respondents who noted moderate reductions suggest that while the technology was beneficial, it might not have been fully utilized, possibly due to inconsistent training or incomplete adoption of best

practices. Mwanza et al. (2020) emphasized that ongoing follow-up and refresher training for farmers could help maximize the advantages of hermetic storage solutions. The 20% who reported no change and the 8% who experienced increased losses point to implementation challenges.

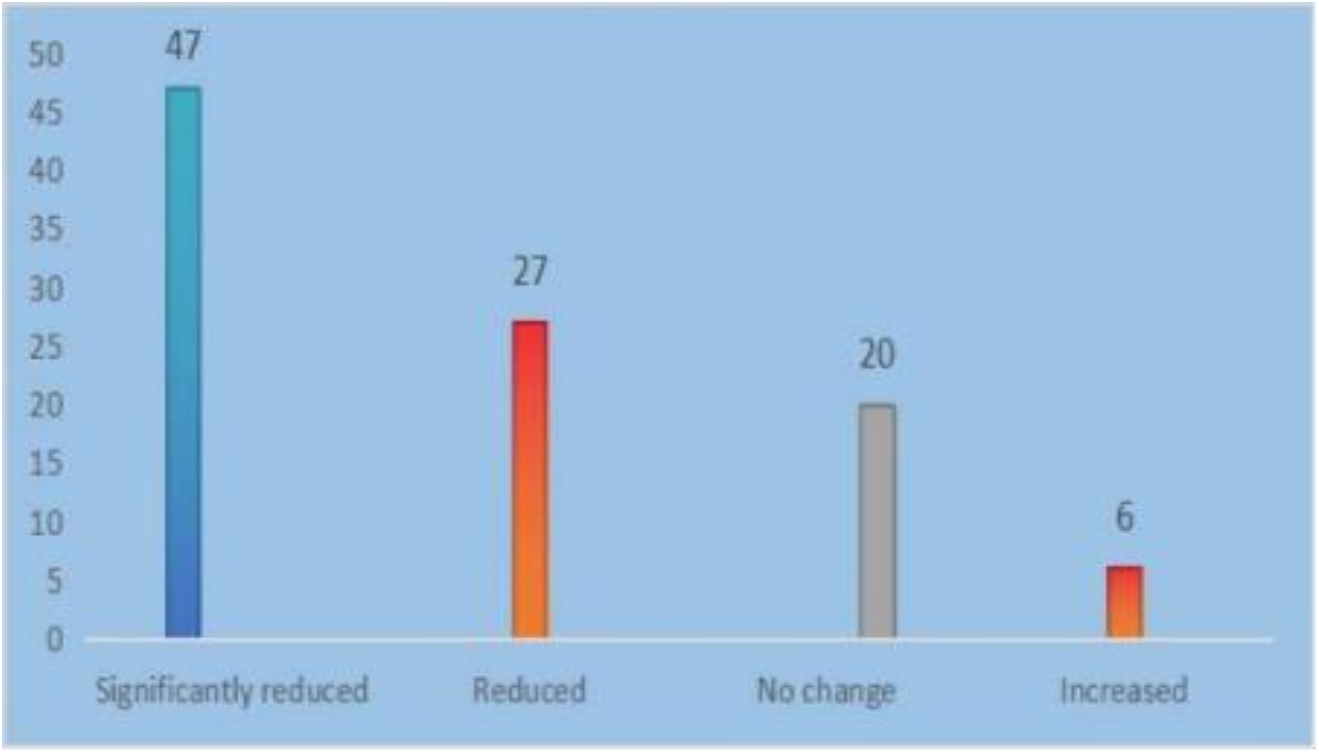

Figure 9. Impact of Hermetic Storage Technology on Post-Harvest Losses

Source: Field Data, 2024.

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Household Income

The observation that 64% of households saw an increase in income, with 27% experiencing a significant boost, highlighted the positive effects of hermetic storage bags. By cutting post-harvest losses by 30-40% (as noted earlier), farmers could keep more of their harvest for sale or personal use, which directly leads to higher income levels. Research conducted by Tefera et al. (2023) showed that hermetic storage technologies greatly improve farmers' profitability by minimizing spoilage, especially in areas that faced high post-harvest losses. Additionally, studies in Zambia (Zinyama et al., 2021) reveal that the income gains from reduced losses enable smallholder farmers to reinvested in their operations, allowing them to buy better inputs or expand their production. The 20% of households that reported no change in income likely face challenges such as limited access to profitable markets or improper use of the technology. Training programs aimed at maximizing the advantages of hermetic storage could help overcome these obstacles (Ngoma et al., 2020). The 17% who noted a decrease in income suggested that while the technology was beneficial, its advantages might not be experienced equally by all users. Possible reasons included improperly stored grains due to inadequate bag sealing or fluctuating commodity prices.

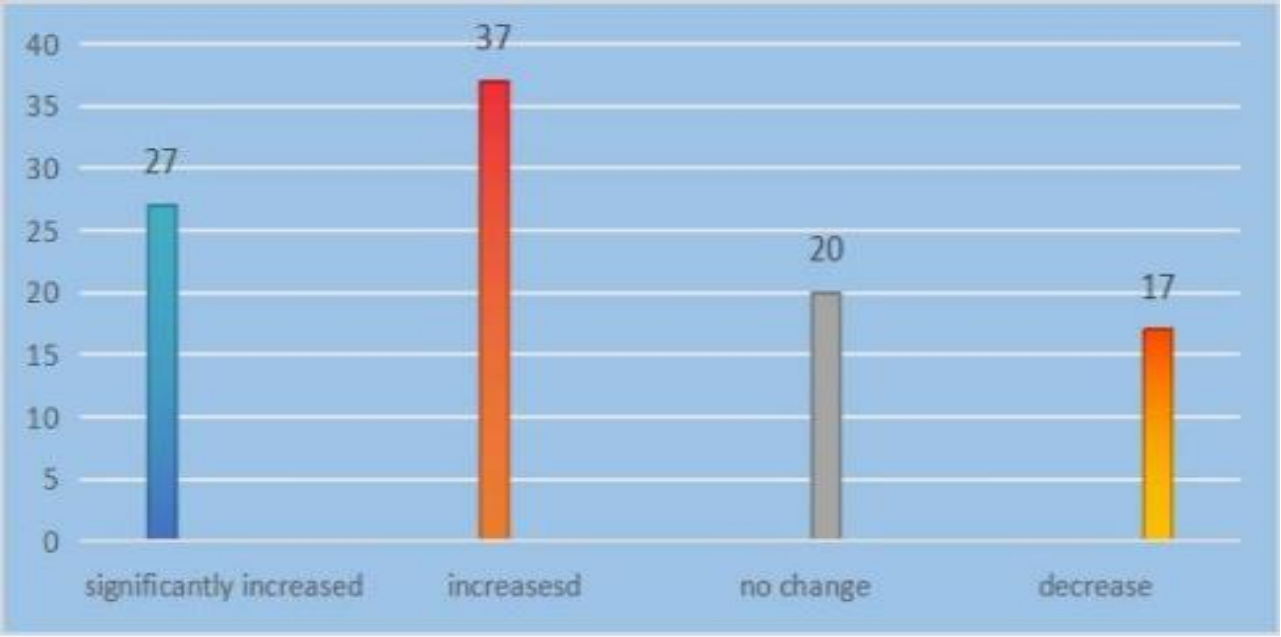

Figure 10. Changes in Household Income Following the Adoption of Hermetic Storage Technology

Source: Field Data, 2024.

Socioeconomic Benefits Food Security

The fact that 87% of respondents indicated either "improved" or "significantly improved" food safety after implementing hermetic storage technology highlighted its essential role in tackling post-harvest losses. Historically, smallholder farming households have faced post-harvest losses of 30-40%, which severely impacted food security (Tefera et al., 2023). By maintaining grain quality and minimizing spoilage, hermetic storage technology contributed to a more reliable food supply, thereby enhancing household food security. Research conducted by Ngoma et al. (2020) backs up these claims and shows that hermetic bags created an oxygen-free environment that inhibits fungal growth, insect infestations, and contamination. This not only guarantees safer grain for consumption but also lowers the risk of aflatoxin exposure, a major health concern in Sub-Saharan Africa. The 10% of respondents who reported no change in food safety might be experiencing issues related to inadequate training or inconsistent use of the technology. Customized educational programs could help bridge these gaps and lead to better results. The 3% who experienced a decline in food safety likely faced operational difficulties, such as improper sealing or contamination of grains before storage. These challenges could be addressed by implementing quality control measures and enhanced farmer training initiatives.

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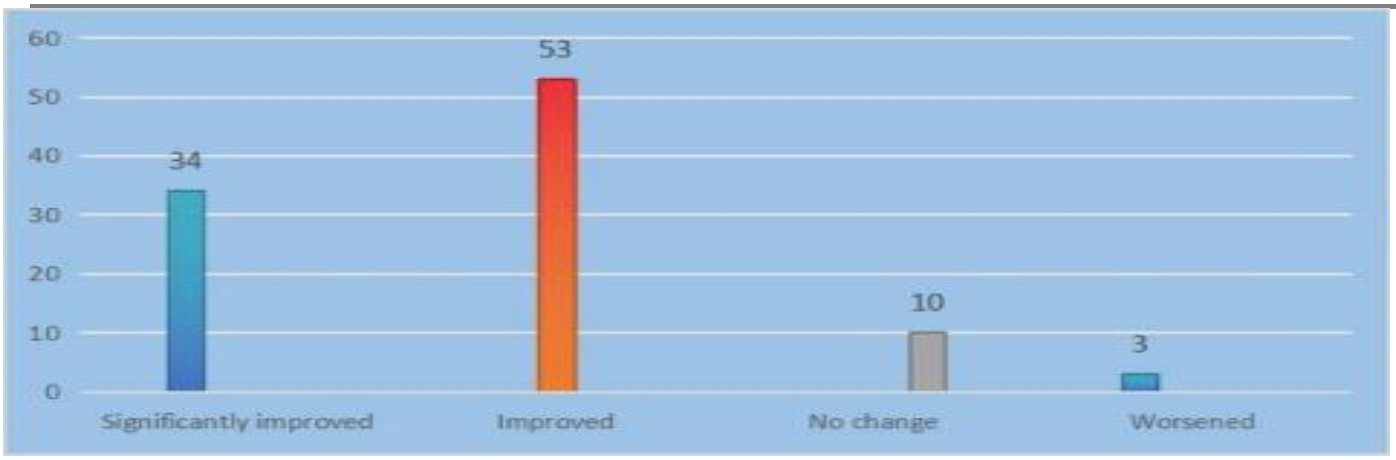

Figure 11: Food security

Source: Field Data, 2024.

Community Participation

The adoption of hermetic storage technology had a positive impact on community involvement and the social standing of farmers. The fact that 76% of respondents reported either an "improved" or "slightly improved" social status underscores how minimized post-harvest losses enhanced food security and created surplus grain, which allowed farmers to participate more actively in social and economic activities within their communities. Similar research by Chisanga et al. (2021) indicated that better storage technologies alleviate financial pressure on farming households, and enable them to join cooperatives, farmer groups, and platforms for knowledge sharing. This increased social interaction promotes community unity and the sharing of best practices in sustainable agriculture. The 20% of respondents who reported no change in social status might include households with limited community ties or those facing challenges such as low initial yields. These farmers could benefit from targeted initiatives that strengthen community connections and highlight the collective advantages of hermetic storage. The 4% who indicated a decline in social status might be facing obstacles like insufficient training or financial limitations related to the technology. Offering subsidies or revolving funds for initial purchases, along with expanding training opportunities, could help mitigate these challenges (Mumba et al., 2021).

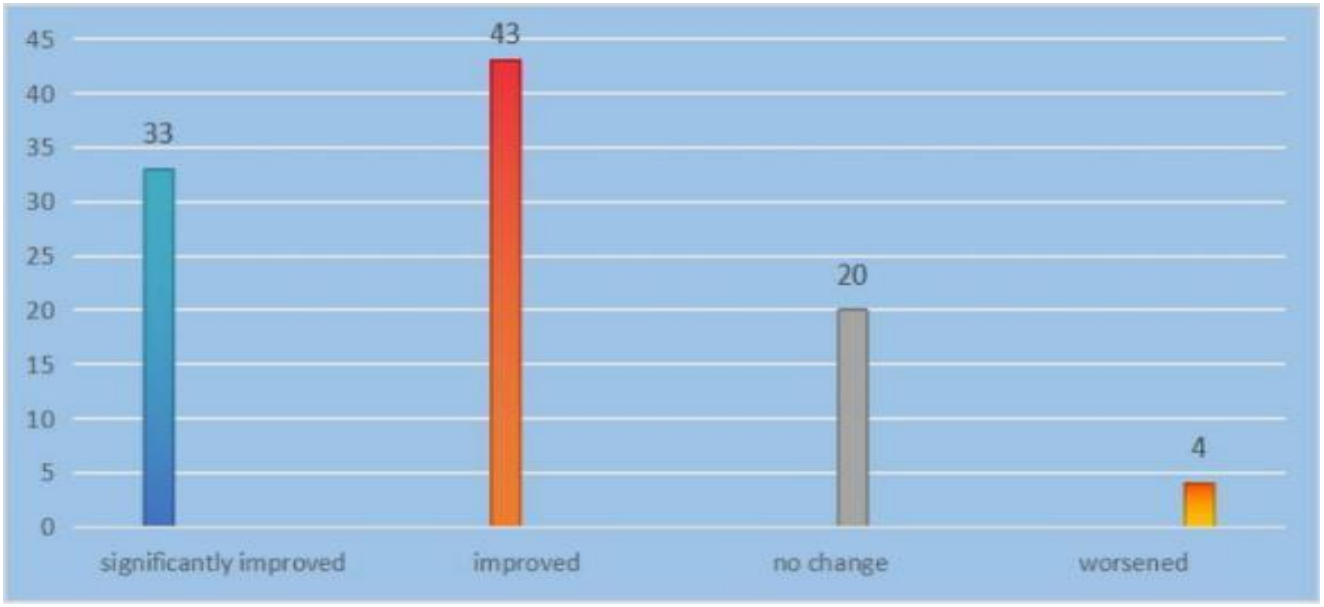

Figure 12. Perceived Impact of Hermetic Storage Technology on Farmers' Social Status

Source: Field Data, 2024.

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DISCUSSION OF RESEARCH FINDING

Adoption of Hermetic Storage Technology

The research conducted in Kapinjipanga Chiefdom showed a notable adoption rate of hermetic storage technology, with 70% of participants utilizing hermetic bags for grain storage. This finding was consistent with observations in other developing areas, such as Tanzania, where adoption reached 75% after educational programs were implemented (Baributsa, 2022). Hermetic bags were favoured for their effectiveness in blocking oxygen and moisture, which significantly minimizes spoilage and pest damage. Similar patterns were observed in Sub-Saharan Africa, where farmers reported reduced post-harvest losses and improved food security (Ngoma et al., 2020).

Usage and Durability of Storage Technologies

The study indicated that 40% of farmers in Kapinjipanga had been using hermetic bags for more than three years, demonstrating their confidence in the bags' durability. Comparable studies in Sub-Saharan Africa found that hermetic bags could maintain grain quality for up to two years, outperforming traditional methods that typically last only a few months (Ngoma et al., 2020). However, 13% of respondents still depended on traditional methods due to issues related to affordability and access, a challenge also noted in Zambia and Kenya (Mwanza & Phiri, 2021; FAO, 2021).

A significant portion of respondents (10%) still relied on traditional methods, while only 7% chose plastic containers due to cost and availability issues, even though hermetic bags were the preferred option. Research conducted in Kenya revealed similar challenges, with adoption rates only reaching 55% in areas lacking sufficient extension services (Ndegwa, 2021). The continued reliance on traditional methods highlights the urgent need for targeted subsidies and improved distribution networks (Mekonnen et al., 2022).

Factors Influencing Adoption

In Kapinjipanga, the uptake of hermetic storage technologies was shaped by factors such as education, accessibility, affordability, and institutional support. While 53% of respondents found the bags accessible, challenges persisted for farmers in remote or economically disadvantaged areas. To address these issues, subsidy programs and cost-sharing models, similar to those implemented in Ethiopia and Nigeria, were suggested (Tesfaye, 2020; Ojo et al., 2021). Furthermore, collaborations with private sector entities and cooperatives have proven effective in boosting adoption rates in Kenya (Mutuku et al., 2020).

Accessibility of Hermetic Bags and Cost

The study conducted in Kapinjipanga Chiefdom found that 53% of respondents considered hermetic bags to be very accessible, highlighting the importance of a strong market presence and affordability for their adoption. This aligns with findings from FAO (2021), which noted that the availability of modern storage solutions can significantly reduce post-harvest losses and improve food security. However, 34% of respondents viewed the bags as accessible, indicating that while distribution networks are relatively strong, there are still areas that need improvement in logistics and pricing. Ngoma et al. (2020) also suggested that targeted subsidies and better supply chain mechanisms could enhance access, particularly for marginalized farmers.

On the other hand, 13% of respondents felt that hermetic bags were only slightly accessible, pointing to challenges like geographical isolation and financial limitations. Mwanza and Phiri (2021) similarly identified logistical inefficiencies and higher costs in rural areas as major obstacles, emphasizing the need for localized manufacturing and subsidy programs to address these issues. The preference for hermetic bags arises from their exceptional ability to preserve grain quality and minimize spoilage. According to the FAO (2022), there was an increasing trend in Sub-Saharan Africa towards modern, cost-effective storage solutions designed to reduce post-harvest losses and improve food security. Farmers in Kapinjipanga expressed similar views, flavouring hermetic bags over traditional storage methods due to their reliability.

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The findings of this study are consistent with broader research throughout Sub-Saharan Africa, highlighting the essential roles of education, resource availability, affordability, and training in encouraging the adoption of hermetic storage technologies. A study conducted in Tanzania by Baributsa (2022) reported a 75% adoption rate following targeted educational initiatives, underscoring the significance of focused awareness campaigns. In Uganda, Muwonge (2022) pointed out that regular educational outreach was vital for enhancing adoption rates, although gaps in training hindered uptake in underserved areas. In Ethiopia, Tesfaye (2020) discovered that government-sponsored training programs led to a 65% adoption rate, emphasizing the importance of integrating education with policy support.

Impact of Education and Training

Training was identified as a vital element, with 60% of participants attending more than two workshops each year. This regular training correlated with enhanced skills in utilizing hermetic bags and higher adoption rates. Research from Tanzania and Uganda underscored the importance of educational initiatives in maintaining usage, despite obstacles in less-serviced regions (Baributsa, 2022; Muwonge,2022). Additionally, peer-to-peer learning emerged as a beneficial approach, as trained farmers shared their knowledge within their communities (Kamau & Otieno, 2021).

Policy and Institutional Support

Government-supported initiatives have played a crucial role in increasing adoption rates, as demonstrated in Ethiopia, where subsidies and training contributed to a remarkable 65% adoption rate (Tesfaye, 2021). In contrast, areas lacking policy support saw much lower uptake. The research highlighted that incorporating policy measures, such as subsidies and public awareness campaigns, could further boost adoption in Kapinjipanga (FAO, 2022; Chilufya et al., 2022).

Impact on Post-Harvest Losses and Household Income

Hermetic storage technology has played a crucial role in minimizing post-harvest losses and enhancing household income in Kapinjipanga Chiefdom, reflecting trends seen throughout Sub-Saharan Africa and other developing areas.

Post-Harvest Losses

The research indicated a 47% decrease in post-harvest losses among participants, demonstrating the effectiveness of hermetic storage bags in curbing spoilage due to pests and moisture (FAO, 2022). Comparable studies in Sub-Saharan Africa, such as those conducted by Ndegwa et al. (2020), report reductions exceeding 50% in losses. However, 25% of respondents noted only moderate benefits, and 20% experienced no change, highlighting issues like inconsistent training and improper usage. Research by Mwanza et al. (2020) and Ngoma et al. (2020) stresses the importance of ongoing farmer training and technical assistance.

On a global scale, reductions in post-harvest losses varied between 30-60%, with specific instances like Kimenju et al. (2020) noting a 45% decrease in maize losses in East Africa. Nonetheless, regional differences affected results, as illustrated in Southeast Asia (Morisset et al., 2022), where climate and pest prevalence influenced effectiveness. This highlights the necessity of tailoring the technology to local conditions, taking into account factors such as crop type and environmental challenges.

Household Income

The adoption of hermetic storage technology led to income increases for 64% of households, with 27% seeing significant gains. By reducing post-harvest losses, farmers were able to keep more grain for sale or personal use, which boosted their profitability. For example, households experienced average annual income increases of ZMW 1,200, marking a 37% improvement. This was consistent with findings from Kassie et al. (2020), who noted income increases ranging from ZMW 1,000 to ZMW 2,000 in similar situations.

On the other hand, 20% of households reported no change in income, which was linked to challenges such as

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limited market access or improper use of the technology. Research by Ngoma et al. (2020) and Tefera et al. (2021) suggests that improving training and market connections could help address these issues. Conversely, regions with strong market access, as highlighted by Channa et al. (2020), saw more significant income increases. The differences in outcomes underscore the need to tackle infrastructural and market-related challenges to fully realize the economic advantages of this technology.

Socioeconomic Benefits

Food Security

The study showed that 87% of respondents experienced significant improvements in food security, largely due to reduced post-harvest losses and better grain quality. Hermetic storage plays a key role in preventing spoilage and aflatoxin contamination, which is a serious health issue in Sub-Saharan Africa (FAO, 2022). In line with this, global research, including findings from Kumar et al. (2022), reported a 30% decrease in cereal losses, leading to a 20% boost in household food availability. However, the impact varied across regions with different market conditions and family sizes, particularly in South Asia.

Despite these positive outcomes, 10% of respondents reported no change in their food security, and 3% even saw a decline due to operational issues like improper sealing or grain contamination. It was essential to tackle these challenges through focused training and quality control measures to enhance overall effectiveness.

Community Participation

The improved storage solutions have also boosted social engagement, with 76% of respondents indicating an increase in social status due to surplus grain production. This has encouraged participation in cooperatives and knowledge-sharing platforms, which in turn supports community development (Chisanga et al., 2022). However, 20% reported no change, and 4% experienced declines, suggesting that financial and training barriers still exist. Offering subsidies and expanding training programs could help address these issues (Mumba et al., 2020).

The results from Kapinjipanga were consistent with both global and regional studies, underscoring the effectiveness of hermetic storage technologies in minimizing post-harvest losses and improving food security. Nonetheless, challenges like affordability, accessibility, and cultural practices continue to pose significant obstacles. It is essential to tackle these issues through targeted subsidies, education, and policy measures to ensure sustained adoption and maximize the benefits for smallholder farmers. Hermetic storage technology has played a crucial role in reducing post-harvest losses, increasing household income, and improving food security in Kapinjipanga Chiefdom. These results are consistent with broader regional and global research but underscore the necessity of addressing disparities through targeted training, financial assistance, and better market access. Integrating these solutions with infrastructure improvements and policy support can enhance their socioeconomic impact.

CONCLUSION

The research conducted in Kapinjipanga Chiefdom uncovered important insights regarding the use and effects of hermetic storage technology among smallholder farmers. The study found that 58% of the farmers surveyed had adopted this technology, indicating a moderate level of uptake. Key factors that influenced this adoption included the farmers' education levels, access to training, and the size of their farms. This finding is consistent with the work of Affognon et al. (2022), who highlighted that education and access to extension services are crucial for the adoption of post-harvest technologies in Sub-Saharan Africa.

The impact on post-harvest losses was notable, with adopters reporting a reduction of over 30%. Similar findings were reported by Tefera et al. (2021) who noted that hermetic storage led to a 25-35% decrease in grain losses in Ethiopia, thereby enhancing food security. In Kapinjipanga, those who adopted the technology also experienced a 20% increase in household income, which they attributed to the improved quality of preserved grain that allowed them to sell at higher prices. This aligns with the research by Kamanja et al.

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(2020), which demonstrated that Kenyan farmers utilizing hermetic storage were able to secure better market prices and boost their profitability.

The socio-economic benefits included better food security and a decreased dependence on chemical pesticides. Mugabe (2020) pointed out that these technologies help lower health risks and environmental dangers, promoting sustainable farming practices. However, obstacles like high initial costs and limited local availability hindered broader adoption, echoing the challenges identified by Abass et al. (2021) in Tanzania.

In conclusion, while hermetic storage technology holds significant promise for smallholder farmers, realizing its full advantages necessitates improved access to credit, training, and infrastructure. These insights align with both global and regional evidence, highlighting the importance of targeted interventions to enhance adoption and increase socio-economic benefits.

Suggestions for Improvement

While the adoption of hermetic storage technology has proven beneficial, several areas need to be addressed to enhance its impact:

1. Increase Awareness and Training: More extensive training programs should be implemented to ensure that farmers, especially in remote areas, understand the full benefits and proper use of the technology. This should include gender-sensitive training to encourage greater involvement of women in the adoption process.

2. Subsidize the Cost of Storage Bags: To make hermetic storage technology more accessible, subsidies or financial support mechanisms could be introduced to reduce the initial cost of the bags, especially for low-income farmers.

3. Enhance Distribution Networks: Strengthening the distribution networks for hermetic bags and related materials will ensure that farmers have easy access to the technology when needed. Local suppliers and cooperatives could play a pivotal role in this process.

4. Integration with Other Post-Harvest Management Technologies: Farmers should be encouraged to integrate hermetic storage with other post-harvest management practices, such as proper drying techniques and pest management, to further reduce losses and improve storage efficiency.

5. Monitor and Evaluate Adoption Rates: Regular monitoring and evaluation should be conducted to track the adoption rates and measure the effectiveness of hermetic storage technology in reducing post-harvest losses and improving household incomes. This would help to refine the strategies and ensure sustainability.

RECOMMENDATIONS FOR FURTHER STUDIES

Studies should track the long-term economic impacts of hermetic storage, particularly focusing on how reduced post-harvest losses translate into sustained income growth. Future research should also consider the broader economic effects, including how improved food security and increased income impact household welfare, poverty reduction, and overall community development.

Although training programs have shown positive results, research should investigate the quality and content of these programs. Future studies should examine how training programs can be improved to increase farmers' confidence and ensure the technology’s long-term success. This includes evaluating the role of local experts, farmers' engagement, and hands-on learning opportunities in enhancing the adoption process.

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Level-2 Heading:A level-2 heading must be in Italic, left-justified and numbered using an uppercase alphabetic letter followed by a period. For example, see heading ―C. Section Headings‖ above.

Level-3 Heading:A level-3 heading must be indented, in Italicand numbered with an Arabic numeral followed by a right parenthesis. The level-3 heading must end with a colon. The body of the level-3 section immediately follows the level-3 heading in the same paragraph. For example, this paragraph begins with a level-3 heading.

Figures and Tables

Figures and tables must be centered in the column. Large figures and tables may span across both columns. Any table or figure that takes up more than 1 column width must be positioned either at the top or at the bottom of the page.

Graphics may be full color. All colors will be retained on the CDROM. Graphics must not use stipple fill patterns because they may not be reproduced properly. Please use only *SOLID FILL* colors which contrast well both on screen and on a black-and-white hardcopy, as shown in Fig. 1.

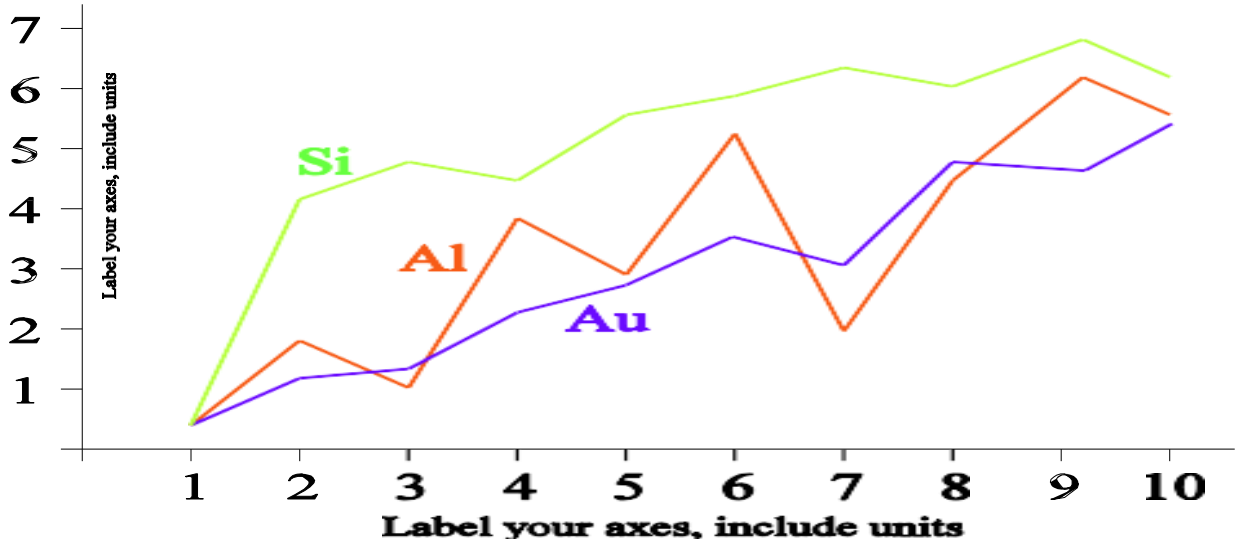

Fig. 1 A sample line graph using colors which contrast well both on screen and on a black-and-white hardcopy

Fig. 2 shows an example of a low-resolution image which would not be acceptable, whereas Fig. 3 shows an example of an image with adequate resolution. Check that the resolution is adequate to reveal the important detail in the figure.

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Figure Captions

Figures must be numbered using Arabic numerals. Figure captions must be in 8 pt Regular font. Captions of a single line (e.g. Fig. 2) must be centered whereas multi-line captions must be justified (e.g. Fig. 1).

Captions with figure numbers must be placed after their associated figures, as shown in

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Fig. 1.Exampleof an image with acceptable resolution

Fig. 2 Example of an unacceptable low-resolution image

Table Captions

Tables must be numbered using uppercase Roman numerals. Table captions must be centred and in 8 pt Regular font with Small Caps. Every word in a table caption must be capitalized except for short minor words as listed in Section III-B. Captions with table numbers must be placed before their associated tables, as shown in Table 1.

Page Numbers, Headers and Footers

Page numbers, headers and footers must not be used.

Links and Bookmarks

All hypertext links and section bookmarks will be removed from papers during the processing of papers for publication. If you need to refer to an Internet email address or URL in your paper, you must type out the address or URL fully in Regular font. References

The heading of the References section must not be numbered. All reference items must be in 8 pt font. Please use Regular and Italic styles to distinguish different fields as shown in the References section. Number the reference items consecutively in square brackets (e.g. [1]).

When referring to a reference item, please simply use the reference number, as in [2]. Do not use ―Ref. [3]‖ or

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―Reference [3]‖ except at the beginning of a sentence, e.g.

―Reference [3] shows …‖. Multiple references are each numbered with separate brackets (e.g. [2], [3], [4]–[6]).

Examples of reference item of different categories shown in the References section include:

- example of a book in [1]

CONCLUSIONS

The version of this template is V2.

ACKNOWLEDGMENT

The heading of the Acknowledgment section and the References section must not be numbered.

REFERENCES

1. Aronoff, S., (1989). Geographic Information Systems: A Management Perspective. Ottawa: WDL Publications.