FARMERS' PRACTICES OF BEAN SEED STORAGE AND THEIR EFFECT ON SEED QUALITY IN NAMBALE SUB-COUNTY, IGANGA DISTRICT

BY

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DECLARATION

I**, ARTHUR NDYAMUHAKI,** do hereby declare that this work is original and has not been presented to any university or institution for any award.

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DEDICATION

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
HDPE	High Density Polyethylene
HS	Hermetic Storage
HYV	High yielding Varieties
PAU	Punjab Agricultural University
PICS	Purdue Improved Cowpea Storage
CRD	Complete Randomized Design
SSA	Sub Saharan Africa
SPSS	Statistical Package for Social Scientists
USA	United States of America
WFP	World Food Program
FAO	Food and Agriculture Organization
PICS bag	Purdue Improved Crop Storage bag
USAID	United States Agency on International Development
AO	Agriculture Officer
GDP	Growth Domestic Product
NARL	National Agriculture Research Laboratories
NARO	National Agriculture Research Organization
CSA	Climate Smart Agriculture
HSD	Honestly Significant Difference

ABSTRACT

Smallholder farmers face significant challenges in preserving bean seed quality due to reliance on customary storage techniques which often fail to protect against common storage pests, leading to substantial losses. Improved storage methods have been shown to enhance seed quality among smallholders. This research assessed the effectiveness of storage techniques after harvesting - Purdue Improved Crop Storage bags (PICS), plastic Silos, and polypropylene bags - in preserving bean seed quality during storage. A total of 205 farmers were randomly sampled to establish farmers' knowledge and practices of bean seed post-harvest handling in Nambale subcounty Iganga District. Four farmers were selected to conduct an experiment on the efficacy of the above-mentioned storage technologies on bean seed quality. Each farmer served as a replicate in a randomized block design experiment, ensuring a comprehensive evaluation. Each candidate storage technology represented a treatment, and data were collected at 15-day intervals over a 90-day period. Moisture content, germination percentage, shrivelled seeds, and bruchid-damaged seed were assessed. The results show that 63 % of farmers predominantly utilized polypropylene bags 0.05% Plastic Silos and 21% PICS bags for storing bean seeds. Recommended seed quality parameters are not always considered because farmers mainly source seeds through informal channels. Significant differences were observed among storage technologies in terms of moisture content, bean bruchid damage, percentage of shrivelled seeds, and seed viability. Plastic Silo storage demonstrated superior performance, maintaining lowest moisture levels (13.29%) compared to polypropylene bags (14.5%). Plastic Silo and PICS bags also exhibited lower rates of bean bruchid damage (0.01 and 0.96%, respectively), and shrivelled

seeds (0.61 and 1.55%, respectively), compared to polypropylene bags. Additionally, Plastic Silo and PICS bags showed higher seed viability (99.6 and 99.00%, respectively), compared to polypropylene bags (94.71%). In conclusion, Plastic Silo storage and PICS bags were found to be more effective in preserving bean seed quality compared to polypropylene bags. However, there persists a reliance on customary storage techniques and informal seed channels among farmers, underscoring the necessity for targeted education and outreach programs to enhance awareness of recommended seed quality parameters and associated storage technologies.

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

The common bean (*Phaseolus vulgaris* L.) ranks as the most extensively grown legume and serves as the second major staple food crop in East Africa, following maize (Mauyo et al., 2007). In Uganda, beans are a critical source of household nutrition and income, contributing 6.1% to the country's agricultural GDP in 2009 (FAO, 2009). Rising domestic and international demand has further increased their importance as both a food and cash crop (Sibiko et al., 2013). Despite this significance, postharvest losses remain a major challenge to bean production and utilization.

Farmers across Sub-Saharan Africa (SSA), Uganda inclusive, face high storage-related losses in both the quality and quantity of bean seed due to insect pests, rodents, and molds (Mutia et al., 2018; Chimbuza et al., 2017). For example, Appert (2019) reported weight losses of 0.2–11.8% caused by bruchid infestation, while Wright et al. (2005) noted increased susceptibility to aflatoxins when beans are poorly dried and stored. In Iganga and the wider Busoga region, bean producers often store seed in polypropylene bags or local granaries, which are highly porous and vulnerable to pests. Such failures in storage systems reduce seed quality, lowering germination potential and market value, which in turn undermines farmers' productivity, incomes, and food security.

Smallholder farmers typically store seed for several months to a year, depending on household consumption and market demand (Sekwao et al., 2018). However, most lack access to proper drying, handling, and improved storage technologies (Kaminski et al., 2018). In Busoga, like in many rural Ugandan regions,

traditional storage practices—such as the use of baskets, cribs, and polypropylene bags—are still dominant, though these often result in abnormal losses. Consequently, the reliance on home-saved seed persists, which perpetuates low productivity and reduced returns.

Hermetic storage technologies have proven to be an effective approach for overcoming these challenges. Solutions such as Purdue Improved Crop Storage (PICS) bags, Super Grain bags, and metal silos maintain airtight environments that limit oxygen and moisture movement, consequently inhibiting insect infestation and mold development (Awuah & Ellis, 2015; Tefera et al., 2017). These methods not only protect seed quality and prolong storage life but also eliminate the need for chemical insecticides, thereby reducing health and environmental risks (Motte et al., 2016). Studies in Uganda and other SSA countries have shown that hermetic storage significantly reduces seed damage and losses compared to conventional storage (Hell et al., 2019).

Given the importance of beans to farmers in Iganga district and the Busoga sub-region, understanding how hermetic storage technologies can mitigate postharvest losses is essential. This study therefore examines the impact of hermetic storage on the quality of bean seed, with particular attention to how improved storage practices may enhance farmers' productivity, income security, and household food availability

1.2 Statement of the problem

Beans are cultivated in all regions of Uganda and Iganga district cultivates and produces one of the largest quantities of beans in the country (Rugumamu, 2019). Despite this, smallholder farmers chronically lack quality seed for

planting in the subsequent seasons. This has been attributed to using unsustainable storage practices which compromises the quality of the seed. Farmers usually rely on using indigenous and ineffective storage practices such as polypropylene bags, sometimes the seed is mixed with pesticides. .These storage methods offer limited protection against the most prevalent storage pests (García-Lara et al., 2019), leading to seed losses of up to 60% (Odjo et al., 2020). Several studies, including those by Brown et al. (2015), Kumar and Kalita (2017), and Tefera (2012), have demonstrated that adopting improved storage technologies enhances food security and nutritional well-being among smallholder farmers.

However, few studies have been done on the efficiency of hermetic storage solutions in reducing insect and fungal damage (Odjo et al., 2020). Famers who store seeds may experience significant losses in both quality and quantity due to the detrimental effects of damage from rodents, insect pests, and mold. Additionally, the sale of poor-quality seeds often results in lower prices for farmers (Mutia et al., 2018; Chimbuza et al., 2017).

There are several initiatives that aim at promoting improved storage facilities such as government initiatives including the parish development model (PDM), agricultural subsidies (ACDP). Despite these, the use and uptake of improved technologies amongst farmers is still low. Information about which of the storage technologies is commonly used in Iganga is limited, and many farmers do not have access to the technologies themselves. As a result, this study aimed to establish the storage practices that are commonly used in Iganga District, and

also evaluate the effectiveness of such post-harvest storage strategies in maintaining bean seed quality.

1.3 Objectives of the study

1.3.1 General Objective

This study aimed to establish and evaluate post-harvest storage options and practices for preserving bean seed quality among smallholder growers in Nambale sub-county, Iganga district.

1.3.2 Specific Objectives

i. To identify post-harvest storage practices used by smallholder farmers and assess their impact on bean seed quality in Iganga district.

ii. To determine the effectiveness of selected post-harvest storage technologies used by smallholder growers in preserving bean seed quality in Iganga district.

1.4 Research question

i. What are the post-harvest technologies used by smallholder growers to preserve bean seed quality in Iganga district?

1.5 Hypothesis

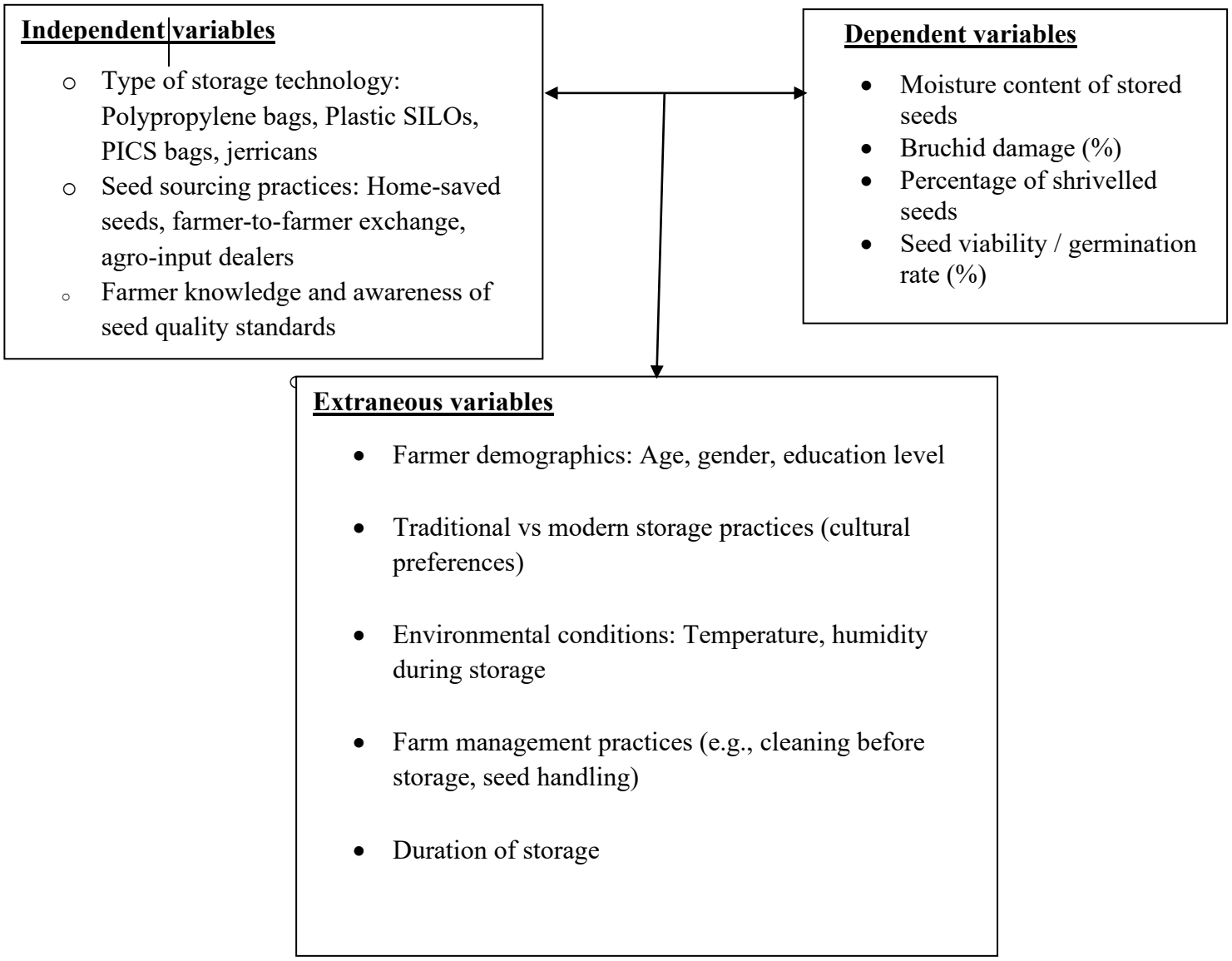
i. Post-harvest storage technologies used by smallholder farmers are equally effective in in preserving been seed quality.

1.6 Justification of the study

Due to the rapid population expansion and shrinking amount of arable land, there is a growing need for food (Limbikani et al., 2018). In any farming system, using high-quality seeds is one of the most critical factors in enhancing agricultural production (Limbikani et al., 2018). The cornerstone of any effective agriculture

program is the production of high-quality seed because it ensures the genetic and physical purity of the crops, produces the desired plant population, guarantees quick growth, and can resist the occurrence of pest and disease incidence to some extent (Maina et al., 2016). It also ensures uniform growth and maturity (Limbikani et al., 2018). High temperatures, high relative humidity, or high moisture content during storage, all have a negative impact on seed quality and speed-up deterioration. The species, storage environment, length of storage time, and initial quality of the stored seeds all affect how much seed degeneration occurs (Maina et al., 2016). Only a limited number of studies have examined this effect, and in Uganda, post-harvest seed storage has been hindered by technological challenges, making it difficult to maintain the quality of food crops and secure high-quality seed. This underscores the importance of adopting proper handling practices and technologies that safeguard seed viability. Investigating improved storage methods is therefore essential, as storage is the critical stage where seed quality is most often compromised after harvest, leading to multiple forms of loss such as deterioration in quality, economic setbacks, and weight reduction (Maina et al., 2016). This study aims to provide insights into the most efficient bean seed storage technologies in terms of their performance. By doing so, it aims to reduce losses incurred during storage, thus improving seed quality, food security, and the livelihoods of smallholder farmers (Maina et al., 2016).

1.7 Conceptual Framework



1.8 Scope of the study

The study evaluated the effectiveness of specific post-harvest storage technologies in preserving the quality of bean seeds. The aim was to devise practical strategies for ensuring the maintenance of seed quality during on-farm storage among smallholder growers in Iganga District. Specifically, it assessed the existing farmer practices for maintaining bean seed quality, examined the quality of bean seeds produced by farmers and determined the effect of post-

harvest handling technologies on bean seeds produced by farmers in Iganga district. The study was conducted between January 2023 and August 2023.

CHAPTER TWO: LITERATURE REVIEW

2.1 Overview

This chapter reviews literature relevant to the present study and discusses its theoretical foundation. The initial section examines the global and Sub-Saharan African (SSA) food security situation, highlighting the need to boost bean production and the constraints encountered by smallholder farmers. The subsequent section focuses on post-harvest technologies commonly employed by bean producers. Grain legumes play a vital role in the traditional diets of many populations around the world (Messina, 1999).

This chapter presents a review of literature that are related to this study and elaborates on the theoretical basis for the study. The first section provides information about the food security situation in world and Sub-Saharan Africa (SSA), the need for increased bean production and the challenges faced by smallholder farmers in bean production. The second section acknowledges the post-harvest technologies used by bean farmers. Grain legumes hold significant importance in the traditional diets of numerous regions worldwide (Messina, 1999).

In Sub-Saharan Africa (SSA), where diets are largely based on carbohydrate staples, grain legumes such as dry beans, cowpeas, and groundnuts provide an affordable source of high-quality protein and essential micronutrients (Ellis & Agrawal, 1988). The common bean is a vital component of production systems and serves as a key source of protein for low-income households in Eastern and Southern Africa (Katungi et al., 2009). Although largely cultivated for

subsistence—particularly by women—about 40 percent of production enters the market, with an estimated value of USD 452 million (Katungi et al., 2009). In Uganda, beans are the second most important crop after maize, cultivated by over 1 million households on nearly 1 million hectares annually (Nakazi et al., 2017). National production is estimated at 464,105 tons per year (FAO, 2012), placing Uganda eighth in global bean production between 2001 and 2010 (Larochelle et al., 2015). Over time, Uganda has registered steady growth in bean production, with a 28.7% expansion in land area and a corresponding 7.7% increase in supply (Larochelle et al., 2015).

Despite this progress, bean production faces several constraints before harvest. Key abiotic factors such as drought stress, soil infertility, and poor crop management practices significantly affect yields (Broughton et al., 2003). In addition, major biotic challenges include diseases like angular leaf spot, anthracnose, and root rots, which cause widespread losses in both yield and quality (Wortmann et al., 1998). Pests such as aphids and bean stem maggot also attack the crop in the field, further compounding production constraints (Abate & Ampofo, 1996). These challenges, combined with limited access to improved varieties, poor extension services, and gender-related constraints in resource allocation, reduce the productivity potential of beans in Uganda.

One major biotic limitation that occurs after harvest and results in considerable losses is insect pest infestation in stored beans (Yêyinou et al., 2018). Such losses manifest both quantitatively, through direct seed consumption, and qualitatively, through contamination with insect feces and residues (Loko et al., 2018). Furthermore, most Ugandan farmers do not differentiate between seed intended

for planting and grain meant for consumption, particularly smallholder rural producers (Latynskiy & Berger, 2016). As a result, harvested beans are consumed, sown, or sold interchangeably (Latynskiy & Berger, 2016). To address these challenges, improved technologies on grain processing, storage, and protection have been developed by NARO, which are also envisaged to be relevant for seed management (Agona & Muyinza, 2002)

2.2. Harvesting and post-harvest practices among bean farmers

2.2.1 The harvesting and drying of beans

In most cases legumes do take a short gestation period before they are harvested (Appert, 2019). Usually, legumes' harvesting is done manually by small holder farmers by hand uprooting (Appert, 2019). It is advisable to harvest crops promptly, preferably right after they reach maturity, with the seeds containing the optimal moisture content of 20–28% for beans. This practice aims to minimize losses during harvesting, as suggested by Appert (2019). When crops are harvested prematurely, they tend to have elevated moisture levels, necessitating extended drying periods or potentially fostering mold growth, leading to heightened expenses or diminished yields (Bourne, 2017). Additionally, harvesting during rainy conditions can raise seed moisture content unexpectedly, potentially triggering premature germination (Bourne, 2017). Conversely, delaying the harvest exposes crops to prolonged field exposure, increasing susceptibility to damage from birds, insects, and mold according to Bourne (2017). Furthermore, harvesting seeds that have been air-dried in the field may result in losses from seed shattering. seeds are typically either field-dried or naturally dried on mats within the homestead yard. However, this drying process is susceptible to losses caused by infestation from insects, as well as heat damage (Appert, 2019). Subsequently, depending on the specific regions, seeds are stored either with pods intact or after threshing, cleaning, and storage in various structures (Bourne, 2017). According to Bourne (2017), smallholder farmers usually carry or use bicycles or bullock carts to deliver collected seeds to their homesteads. Some farmers opt to hire trucks for transporting their seeds,

as noted by Appert (2019). However, during transportation, losses may occur due to seed spillage and bruising (Bourne, 2017). Moreover, if not adequately secured, foreign materials could contaminate the seeds during transit (Bourne, 2017).

2.2.2 The drying of beans

To reduce the number of seeds that break in the field, high moisture content seeds are typically gathered. Nonetheless, most crops have a safe moisture content of less than 13% when stored for an extended period of time (Sawicka, 2020).

For the majority of crops, it is crucial to make sure that the moisture content stays below 15% even during brief storage times of less than six months (Utono, 2013). Lack of drying can cause mold to spread and cause large losses when stored, as noted by Kumar & Kalita (2017). Drying as soon as possible after harvesting is therefore essential for preserving crop quality, minimizing storage losses, and lowering transportation expenses (Aderibigbe et al., 2022).

Drying can be achieved through natural means such as sun or shade drying, or through the use of mechanical dryers, as discussed by Motte et al. (2016). Traditional sun drying is both economical and commonly practiced for drying harvested crops, particularly in developing countries where it remains the preferred method (Motte et al., 2016). According to Sekwao et al. (2018), sun drying presents several challenges: it is weather-dependent, labor-intensive, slow, and leads to significant losses. When seeds are left in the open for sun drying, they become vulnerable to consumption by birds and insects, as well as contamination from stones, dust, and other foreign materials (Sekwao et al., 2018). Incidents of unseasonal rains or cloudy weather can hinder proper drying,

resulting in storage at high moisture levels, which in turn leads to increased losses due to mold growth (Sekwao et al., 2018). For instance, research by Hell et al. (2019) in Zambia and Zimbabwe, as well as by Zuza et al. (2017) in Uganda, found that quality losses of about 3.5% and 4.5% respectively occur during bean seed drying on raised platforms and tarpaulin papers. Certain farmers employ mats or plastic sheets to spread the seeds, a practice noted for its effectiveness in reducing contamination with dust and facilitating the collection of seeds (Kumar & Kalita, 2017). Compared to natural drying techniques, mechanical drying has a number of benefits, such as fewer handling losses, accurate control over hot air temperature, and effective space usage (Kumar & Kalita, 2017). However, these dryers are constrained by high initial and maintenance costs, limited availability in appropriate sizes, and a lack of knowledge among smallholder farmers, particularly in developing countries, about their operation (Kumar & Kalita, 2017). Consequently, smallholders in such regions rarely utilize these dryers (Kumar & Kalita, 2017).

2.2.3 Threshing and Cleaning

According to Kumar & Kalita (2017), the main goal of the threshing procedure is to separate the seeds from the panicles. This detachment is typically achieved through rubbing, stripping, or impact actions, or a combination thereof (Kumar & Kalita, 2017). Threshing can be done with mechanical threshers, animal power, or human labour (e.g., trampling, beating) (Golob et al., 2017). Notably, manual threshing remains the predominant method in developing countries (Golob et al., 2017). Nevertheless, there are a number of issues with the threshing procedure that might result in losses, such as seed spills, insufficient chaff-seed separation, and excessive striking that breaks seeds (Golob et al., 2017).

Delaying the threshing process after harvest can result in substantial quantity and quality losses, as the crop remains exposed to the atmosphere and is highly susceptible to rodent, bird, and insect attacks (Golob et al., 2017; Kalita, 2017). Evidence shows that threshing-related losses typically range between 2 % and 6 % of the harvested grain (FAO, 1994). In rice, losses as high as 0.5 % to 4 % have been documented when threshing is delayed (Adu-Kwarteng et al., 2001). More broadly, post-harvest operations such as threshing, cleaning, and handling can account for up to 30 % of total post-harvest losses in cereals and legumes in sub-Saharan Africa (Hodges et al., 2011). These figures highlight that, as with harvesting delays, lack of mechanization significantly increases the risk of quantity and quality deterioration. Furthermore, a crop left in the field with excessive moisture buildup may make matters worse and even encourage the spread of mold (Golob et al., 2017). Following threshing, the cleaning procedure is carried out to separate entire seeds from broken seeds and other foreign elements, including weed seed and straw, stones, sand, and chaff (Kumar & Kalita, 2017). Among cleaning techniques, winnowing is the most common in underdeveloped nations (Kumar & Kalita, 2017). Another prevalent technique is screening or sifting, which can be executed either manually or mechanically (Holst et al., 2020). Inadequately cleaned seeds have the potential to harm processing equipment, increase insect infestation and mold growth during storage, and introduce undesirable flavor and color (Holst et al., 2020). In addition, a significant portion of seeds is lost through spillage during this process, with quality losses from winnowing reaching as much as 4% of the total yield (Holst et al., 2020).

2.2.4 Storage

Storage is a critical component of the food and seed processing chain and has historically played a key role in ensuring food security and preserving seed for future use (Limbikani et al., 2018). For legumes such as beans, post-harvest storage practices directly influence both seed quality and quantity, which in turn determine productivity and sustainability in smallholder farming systems. If stored correctly, legumes can retain their edible and planting quality for extended periods; however, under typical farmer storage conditions, seeds undergo physical, chemical, and biological changes that compromise quality (Greeley, 2018). Temperature and moisture content are particularly important factors that determine shelf-life, viability, and the proliferation of biological organisms within stored seeds (Greeley, 2018).

In Uganda and across sub-Saharan Africa, smallholder farmers predominantly rely on traditional or indigenous methods to store beans. Common practices include the use of polypropylene bags, jute bags, clay pots, woven baskets, gourds, and cribs, while in some households, seeds are mixed with ash, cow dung, or stored in smoke-filled kitchens to deter pests (Njoroge et al., 2014; Mugo et al., 2020). These methods are widely accessible, culturally embedded, and affordable. Nonetheless, they are generally ineffective against storage pests such as bruchids (Acanthoscelides obtectus), allow moisture fluctuations, and often result in significant seed deterioration over time (De Groote et al., 2013).

To address these challenges, several improved storage technologies have been promoted, including hermetic bags such as the Purdue Improved Crop Storage (PICS) bags, plastic or metal silos, and chemical treatments. Hermetic technologies suppress oxygen within the storage unit, thereby limiting pest survival and fungal growth. Studies consistently show their effectiveness; for example, Ngoma et al. (2024) found that bruchid damage averaged 4% in hermetic bags compared to 43% in polypropylene bags, alongside substantially lower insect populations and weight losses. Metal silos also provide effective long-term protection but are often unaffordable for resource-constrained households (Tefera et al., 2017). Chemical protectants and fumigants reduce pest infestation but pose challenges related to safety, affordability, and correct application (Baoua et al., 2014). Although these improved technologies outperform traditional practices in maintaining seed viability, their adoption remains limited due to high costs, limited availability, lack of awareness, and farmer preference for familiar practices (Ngoma et al., 2024).

The quality of stored seed is influenced by both inherent and environmental factors. Moisture content and temperature are the most critical parameters, as high values accelerate respiration, mould growth, and insect activity (Greeley, 2018). Storage pests and pathogens such as bruchids and fungi directly reduce grain quality through physical damage, loss of germination, and reduced nutritional value. The choice of storage material and the handling practices employed by farmers also influence seed quality outcomes by determining the extent of protection from pests, moisture, and environmental fluctuations (Tefera et al., 2017).

Different storage techniques have been shown to affect bean seed quality, including viability, germination, and physical condition. Hermetic technologies such as silos and PICS bags consistently maintain higher germination rates—often above 90%—compared to traditional polypropylene bags, which can fall below 70% after several months of storage (Abass et al., 2018). Moreover, shrivelling, weight loss, and bruchid infestation are significantly reduced under hermetic conditions. By contrast, traditional methods, though affordable and widely practiced, often lead to reductions in planting value and higher post-harvest losses. Farmers' adoption of improved technologies is influenced by several factors, including household income, gender roles, education, institutional support, and awareness levels (De Groote et al., 2013; Ngoma et al., 2024). Farmers adopt improved storage methods when they perceive clear economic benefits, guaranteed seed quality, and accessibility, whereas they refrain from adoption when constraints related to cost, availability, and knowledge outweigh perceived advantages

2.3 Bean Seed storage technologies available at farmer level in East Africa

2.3.1 Hermetic storage

Seeds are kept secure under hermetic storage, a type of modified atmosphere (MA) (Bokusheva et al., 2018). Other names for it include "air-tight storage," "sealed storage," "sacrificial sealed storage," and "biogenerated MA" (Bokusheva et al., 2018 This method employs tightly sealed structures in which insects, other aerobic organisms within the product, or the product itself, alter the atmosphere through respiratory metabolism, leading to increased carbon dioxide levels and reduced oxygen levels (Cheke & Ward, 2018). The resulting low-oxygen, high-carbon dioxide environment effectively kills aerobic insects and inhibits their further development (Cheke & Ward, 2018).

2.3.2 Purdue Improved Crop Storage (PICS)

The Purdue Improved Crop Storage (PICS) method was first created for the storage of cowpeas. It involves triple-bagging seeds in hermetic conditions, and farmers in sub-Saharan Africa have embraced this technology (Addo et al., 2018). The seeds are contained in thick, double-layered High-Density Polyethylene (HDPE) bags measuring 80 µm, and are tucked within a third polypropylene nylon bag (Addo et al., 2018). These bags consist of one strong layer of high-density polypropylene that is about 78µm thick. They are used as liners in addition to regular polypropylene bags (Suleiman and Kurt, 2015). Once filled with seeds, the bags are tightly sealed, effectively depriving weevils off oxygen and disrupting their metabolic processes, thus impeding water production and ultimately desiccating and killing them (Addo et al., 2018). More than 3 million PICS bags were distributed in West and Central Africa between 2007 and 2013 (Suleiman and Kurt, 2015). In order to prevent harmful pest

infestations, Vestergaard, a Swiss company, produces Zero-Fly bags, which are made of polypropylene and impregnated with insecticide (Suleiman and Kurt, 2015). Polypropylene yarns with pyrethroid integrated into them are used to make these bags (Suleiman and Kurt, 2015). A primary issue with hermetic bags is the necessity for thorough seed drying to prevent mold and seed deterioration (Kimenju and De-Groote 2016).

2.3.3 Metal silo

Metal silos have proven effective in numerous other investigations (Kumar & Kalita, 2017). Yet, their significant initial expense poses a substantial barrier to adoption among smallholders (Kumar & Kalita, 2017). Community-level silos could present an economical alternative, given that the per-unit seed cost decreases as silo size increases (Kumar & Kalita, 2017). Additionally, maintenance expenses for silos are minimal, offering partial compensation for their high initial cost (Kumar & Kalita, 2017). An economic analysis of advanced storage structures was conducted by Kimenju and De-Groote (2016), who found that using metal silos yields more economic benefits than using polypropylene bags, especially in terms of preventing losses. However, they noted that the initial cost of silos outweighs that of polypropylene bags (Kimenju and De-Groote 2016The majority of developing nations in Central America, Africa, and Asia have recently pushed the use of metal silos—airtight storage structures made of galvanized metal sheets—instead of chemicals for storing seeds (Rahmiana et al., 2017). In the Indian subcontinent, these storage structures are commonly referred to as Punjab Agricultural University (PAU) bins (Manandhar et al., 2018). Hermetic storage containers like these successfully eliminate insects and pests from the seeds they hold by creating a sealed environment that

depletes oxygen and produces carbon dioxide through the respiration of living creatures (Manandhar et al., 2018). Additionally, this sealed environment prevents moisture exchange, which reduces the growth of mold (Manandhar et al., 2018). Metal silos, in addition to their effectiveness against rodents, birds, and insects, contribute to reduced mold and pest presence, resulting in improved seed storage conditions and lower storage losses (Waliyar et al., 2015). In contrast to conventional constructions and chemical treatments, metal silos have been proven to be the most effective storage alternative (Waliyar et al., 2015). However, seeds must be dried to a moisture level of less than 14% in order to prevent mold growth and allow cereals to be stored safely in metal silos (Waliyar et al., 2015). Propensity ratings have also been used to evaluate how silo configurations affect the length of bean storage, storage losses, and expenses (Kimenju, 2016). Because of the respiration processes of seeds, microbes, and insects, this causes a sharp decline in the oxygen levels inside the bag (Kimenju, 2016) As a result, levels of carbon dioxide rise, inhibiting the growth of insects, microbes, and seed metabolism, all of which are beneficial to the preservation of the product (Freitas et al., 2016; Barreto et al., 2017; Taher et al., 2019).

PICS Bags (Purdue Improved Crop Storage) have been widely adopted across Africa for grain and legume storage. Their hermetic triple-layer design creates an oxygen-deprived environment that significantly reduces pest activity and mold growth (Baoua et al., 2014; Tefera et al., 2017). Addo et al. (2018) also confirmed their effectiveness in maintaining the quality of cowpeas and beans, making them an affordable and chemical-free option for smallholder farmers.

Plastic or metal silos offer similar hermetic storage benefits but with added durability and scalability. Studies by Kumar and Kalita (2017) and Waliyar et al. (2015) report that silos can reduce storage losses to below 1% and maintain seed viability over longer periods. Their reusability makes them suitable for both household and community-level storage systems.

Polypropylene bags, commonly used by farmers, were included as a control. While they are low-cost and readily available, they are permeable to air and moisture, making stored seeds more susceptible to pest infestation and fungal growth. Mutia et al. (2018) found that up to 60% of seed damage in traditional storage was associated with the use of polypropylene sacks.

Other traditional storage methods, such as jute bags, clay pots, and chemical treatments, were excluded from this study. Greeley (2018) notes that jute bags perform poorly in humid conditions, while Rugumamu (2019) and Bokusheva et al. (2018) highlight concerns around the fragility of clay pots and the health/environmental risks posed by chemical preservatives.

2.4 The quality of bean seed varieties produced and stored by farmers

The following conditions must be met for bush beans: no dirt, no mixing of various bean varieties, no sprouting, no mold, and no obvious insect damage (Ward & Jeffries, 2018). Since quality loss may be expressed in monetary terms, it can be defined as the difference between a product's prospective best price and its actual best quality (Ward & Jeffries, 2018). An estimate of the revenue loss is determined by comparing it to the typical market price of the same product at its highest grade (Ward & Jeffries, 2018). The computations took into

consideration variations in the optimum pricing throughout merchants and locals (Ward & Jeffries, 2018). In a given value chain stage, quality losses are computed using the initial food quantity after subtracting any physical loss (Ward & Jeffries, 2018).

Certain postharvest handling procedures and treatments used after harvest have an impact on the postharvest quality status and shelf life of the bean seeds (Hell et al., 2019). Fruit quality can be maintained after harvest even when it cannot be increased by postharvest handling procedures or treatment techniques (Hell et al., 2019). By using the proper postharvest handling and treatment techniques, the fruit's shelf life can also be increased (Hell et al., 2019). There has been significant quality loss as a result of not following these best practices, particularly in developing nations (Hell et al., 2019). Even though the majority of bean seed handlers in underdeveloped nations do not have access to sophisticated postharvest technologies to address quality losses following harvest, it has been discovered that knowing basic and optimal postharvest procedures might be helpful (Waliyar et al., 2015). Bean seeds were kept in good condition and had their shelf life extended by postharvest management procedures such as harvesting, washing or disinfecting, sorting and grading, packing, storing, and shipping (Waliyar et al., 2015).

In addition to the genetic qualities expressed in the variety, other quality considerations are germination, cleanliness, pest damage, and sometimes seed size (Greeley, 2018). However, these are normally not a major concern, particularly for smallholders (Greeley, 2018). Yes, if a seed does not germinate it will never produce a crop (Greeley, 2018Generally, even farmer-retained seed

tends to have adequate germination capacity to establish a satisfactory plant stand (Greeley, 2018). Since seed often represents a modest investment, poor germination—especially under manual planting systems—can usually be offset by slightly increasing the seeding rate (Greeley, 2018). Farmers can also conduct simple on-farm germination tests (Greeley, 2018). One commonly used approach is the "rag doll" test, where 100 seeds are arranged in a 10 × 10 grid on a piece of cloth (Dick, 2018). The cloth is then rolled, tied at both ends, soaked in water, drained, and kept moist for about three days. Afterwards, it is unrolled to assess germination percentage—while not an official test, it is sufficiently accurate for most farm-level purposes (Dick, 2018).

Maintaining seed cleanliness involves ensuring that it is free from chaff, soil clods, stones, and especially weed seeds (Kereth et al., 2016). Although this can be a significant concern in large-scale mechanized farming, it is less critical for smallholder farmers (Kereth et al., 2016). Non-seed materials such as chaff and stones are generally easy to remove through manual screening (Kereth et al., 2016). Weed seeds, however, require winnowing—a common practice among smallholder communities before planting (Sekwao et al., 2018). Particular attention should also be paid to avoiding contamination by undesirable varieties, such as red rice mixed within the seed lot (Sekwao et al., 2018).

According to Greeley (2018) and Bourne (2017), shrivelled seeds consistently show lower germination rates and reduced storage value, making this a relevant and practical measure of seed condition under varying storage technologies. Scientifically, shrivelled grains often result from moisture loss, internal pest damage like bruchid larvae feeding, or fungal infection, all of which compromise

seed structure and viability. These factors reduce the seed's ability to germinate, lower seedling vigor, and negatively affect marketability.

2.5 The Effect of Post-Harvest Storage Facilities on Bean Seed Quality

Post-harvest storage of legume seeds, including beans, is highly influenced by the storage environment and the properties of the storage facility. The permeability of storage materials, as well as the partial pressures of gases such as oxygen (O_2) and carbon dioxide (CO_2), determine the flow of gases into and out of the container. This gas exchange, together with seed respiration, influences internal CO_2 and O_2 concentrations, which in turn affect seed metabolism and pest survival (Cardoso et al., 2008). High initial seed moisture content can enhance CO_2 accumulation due to increased respiration, although the magnitude of this effect is generally not considered substantial (Cardoso et al., 2008). Temperature is another critical factor, as it directly affects respiration rates, with CO_2 concentrations rising by approximately 1.5% for every 10°C increase (Cardoso et al., 2008).

Hermetic storage technologies, such as metallic silos, Purdue Improved Crop Storage (PICS) bags, Super Grain bags, and other sealed containers, have been developed to address these challenges. When properly sealed, hermetic systems prevent pest infestation and eliminate the need for chemical fumigants, as demonstrated in field trials conducted by the World Food Program in Uganda and Burkina Faso (Costa, 2014; Cheke & Ward, 2018). These systems limit oxygen availability, creating an environment that suppresses insect survival and fungal growth. For instance, metallic silos provide long-term protection against

both pests and disease while remaining durable when coated with corrosion-resistant materials (Kankolongo et al., 2019).

Empirical studies show that improved storage technologies significantly reduce post-harvest losses compared to traditional methods. PICS bags, for example, maintained seed weight, viability, and germination rates over extended storage periods, achieving 95–100% insect mortality in trials across Burkina Faso, Ghana, and Benin (Baoua et al., 2014). Super Grain bags and PICS bags were both effective in maintaining ambient temperature and relative humidity, with Super Grain bags exhibiting slightly lower infestation levels for Callosobruchus maculatus eggs, while PICS bags minimized physical seed damage (Baoua et al., 2013; Chimbuza et al., 2017). Hermetic storage in wheat studies similarly demonstrated superior seed viability (88%) and minimal insect damage (0.33%) compared to metallic bins and gunny bags (Tefera et al., 2017).

Key factors influencing seed storage and quality include moisture content, temperature, storage material, and pest presence. Elevated moisture and temperature accelerate seed respiration, encourage fungal growth, and create favorable conditions for insects, all of which reduce seed viability and germination rates (Greeley, 2018; Cardoso et al., 2008). Storage pests such as bruchids and fungal pathogens directly degrade seeds through physical damage and loss of nutritional content. The choice of storage facility determines the degree of protection from environmental fluctuations, pests, and pathogens, highlighting the importance of hermetic systems in maintaining seed quality (Kankolongo et al., 2019).

Inadequate storage conditions, including porous containers, fluctuating environmental conditions, and insufficient pest control, lead to substantial qualitative and quantitative losses during storage and transportation (Bokusheva et al., 2018). Chemical fumigation may reduce pest pressure but risks leaving harmful residues in seeds, further underscoring the advantage of hermetic storage (Bokusheva et al., 2018). By contrast, controlled-environment storage, combined with biological pest management, significantly reduces losses and maintains germination, seed weight, and viability, thereby improving food security for smallholder farmers (Zuza et al., 2017; Holst et al., 2020).

Despite the proven benefits of improved storage technologies, adoption by farmers is often limited by economic, social, and informational constraints. High upfront costs, limited access to suppliers, low awareness of the benefits, and cultural attachment to traditional practices are major barriers (Ngoma et al., 2024; Kitinoja, 2013). Training and demonstration programs are crucial for successful adoption, as they increase understanding of the advantages and proper use of hermetic technologies (Kitinoja, 2013). Farmers are more likely to adopt improved storage methods when the economic benefits, such as reduced post-harvest losses, enhanced seed quality, and potential income generation, are clear and accessible (Holst et al., 2020; Zuza et al., 2017).

Prior studies consistently show that proper post-harvest handling—including timely harvesting, drying, threshing, cleaning, and appropriate storage—significantly reduces quantitative and qualitative losses in bean seeds. Hermetic storage technologies, such as PICS bags, Super Grain bags, and metallic silos, effectively maintain seed viability, germination, and weight by limiting oxygen, controlling moisture, and suppressing pests and fungal growth, whereas

traditional methods like polypropylene or jute bags often result in high infestation, mold, and reduced seed quality. Key factors influencing storage effectiveness include seed moisture, temperature, storage material, and pest presence. Overall, improved storage methods outperform conventional practices but adoption remains constrained by cost, availability, and awareness.

CHAPTER THREE: MATERIALS AND METHODS

3.1. Study area description

Nambale Subcounty in Iganga District, Eastern Uganda (0.6600° N, 33.4832° E), experiences a tropical rainforest climate characterized by consistently warm temperatures, high humidity, and substantial rainfall throughout the year (Weather Spark, 2023; Climate Data, 2023). Average monthly temperatures range from 21 °C in July to 23.5 °C in February, with daily maximums occasionally reaching 30 °C (Weather Spark, 2023). Rainfall is abundant and bi-modal, with the wettest months being April and November, receiving up to 299–315 mm per month, while the driest month, January, receives around 100 mm (Climate Data, 2023; Nomad Season, 2023). Relative humidity remains consistently high, ranging between 83 % in June and 90 % in November, peaking during the rainy seasons (Nomad Season, 2023). These climatic conditions significantly affect post-harvest seed storage. High humidity promotes moisture absorption by seeds, creating favorable conditions for fungal growth and accelerating quality deterioration. Warm temperatures further increase the rate of seed metabolic activity, reducing viability over time. Additionally, frequent and intense rainfall raises ambient moisture levels in storage facilities, particularly where ventilation or moisture barriers are inadequate, further compromising seed quality. Understanding these climatic factors is therefore crucial for developing effective post-harvest management strategies to maintain seed viability in Nambale Subcounty.

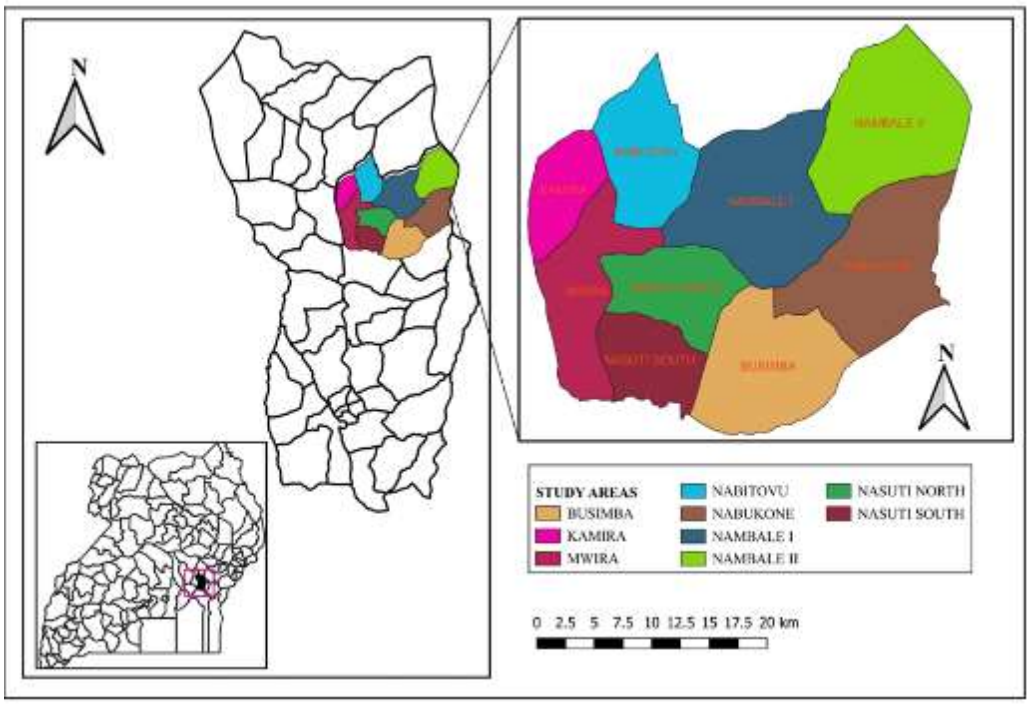


Figure 1. Map showing Nambale Sub-county in Iganga District where study was conducted

3.2 Experimental treatments and design

An experiment was carried out to determine the quality of bean seeds stored by the farmers in Iganga district using different postharvest storage technologies. The treatments were arranged in RCD with each technology replicated four times. The replications were represented by the individual farmers, and as such four farmers were involved in this experiment, each of them using all the three experimental storage technologies. The farmers who grow the same variety NARO bean 6, which is preferred by the market and home consumption (Agona and Muyinza, 2006) were considered for this study. The treatment storage technologies included Purdue Improved Crop storage bag (PICS bag), Plastic silo, and Polypropylene bag (control).

3.3 Rationale for Storage Technology Selection

Three storage technologies were selected for this study based on their relevance to smallholder farming systems, practicality, and scientific evidence of effectiveness in seed quality preservation:

PICS bags were selected for their proven hermetic properties, which limit oxygen and suppress pest and mold development. They are widely adopted in Sub-Saharan Africa for storing legumes, including beans, due to their affordability, chemical-free nature, and suitability for smallholder use. Plastic (or metal) silos were included for their durability and enhanced hermetic sealing capacity. Studies have shown that silos can reduce storage losses to less than 1% and maintain high seed viability over extended periods. Their reusable nature also makes them scalable for individual or community-level storage. Polypropylene bags served as the control because they represent the most commonly used traditional storage method among smallholder farmers in the study area – used by approximately 63% of respondents. Although widely accessible, these bags are permeable to air and moisture, often resulting in high pest infestation and quality deterioration.

Other traditional or chemical-based storage methods—such as jute bags, clay pots, or pesticide treatments—were excluded due to their poor performance under humid conditions, limited scalability, or potential health and environmental risks.

3.4 Seed Sources

Seeds of NARO Bean 6 were sourced from small holder farmers of Nambale Agribusiness Cooperative, Nambale subcounty Iganga District. The seeds had an initial moisture content of 13%, determined using an MMH800 Pinless Moisture Meter; and a germination rate of ≥95% as assessed by the standard rag doll method). All seeds were visually inspected to ensure they were free from bruchid damage and mold before storage.

3.3 Data collection

3.3.1 Establishing the post-harvest storage practices used by smallholder growers to preserve bean seed quality

A sample of 205 smallholder bean growers was purposively selected from three parishes of Nambale subcounty, namely, Nambale, Nasuuti and Mayira using the sample size formula by Memon et al. (2020)

$$N = [z2 * p(1-p)] / e2 \; / \; 1 + [z^2 * p(1-p)] / e^2 * N]$$

Sampling and Data Collection Procedures

The survey

A probability sampling technique was employed to ensure representativeness and minimize selection bias. The study used stratified random sampling, where Nambale Sub-County was divided into distinct strata based on administrative zones or farming communities. Within each stratum, households engaged in bean farming were identified through agricultural extension services and farmer producer organizations such as the Nambale Agribusiness Cooperative.

From these, a proportional random sample was drawn to reflect the population distribution across strata. The sample size was calculated based on Cochran's formula as outlined by Cochran (1977).

which is widely used for large population surveys to achieve a 95% confidence level and a 5% margin of error. This method ensured that the survey captured a representative cross-section of smallholder farmers' seed storage and handling practices.

Data Collection Procedures

Data collection was carried out using structured questionnaires, which were administered through in-person interviews conducted by trained enumerators proficient in the local language. Questionnaires were pre-tested in a nearby area to ensure clarity and appropriateness. Interviews were conducted at respondents' homes or farms at convenient times to minimize disruption.

Ethical considerations

Prior to data collection, ethical approval was secured from [Name of Ethics Committee or Institution]. All participants were clearly informed about the objectives of the study, the voluntary nature of their involvement, the assurance of confidentiality, and their right to withdraw at any stage without any consequences. Informed consent—either written or verbal—was obtained from each respondent before the interviews began.

. Personal identifiers were anonymized during data processing to ensure privacy.

3.3.2 Determining the effectiveness of selected postharvest storage technologies used by smallholder growers in preserving bean seed quality

Before the start of the experiment, bean seeds of NARO Bean 6 were sourced from smallholder farmers belonging to the Nambale Agribusiness Cooperative in Iganga District. The seeds had an initial moisture content of 13%, determined using an MMH800 Pinless Moisture Meter, and a germination rate of ≥95%, assessed using the standard rag doll method. All seeds were carefully cleaned and visually inspected to ensure they were free from mold and bruchid damage before storage.

A total of 100 kg of seed was packed into each of the three storage technologies (PICS bag, plastic silo, and polypropylene bag), giving 300 kg overall. The storage units were hermetically sealed and kept under waterproof storage facilities.

To monitor changes in seed quality, samples were drawn every 15 days for 90 days. On each sampling occasion, 250 g of seed was randomly collected from each treatment for laboratory analysis.

The study focused on four critical parameters of seed quality:

Moisture content – measured by the oven-dry method (103 ± 1 °C for 72 h) following Mekawy (2021).

Germination percentage – assessed using 50 seeds per treatment, replicated four times, following the standard rules for seed testing (Chauhan et al., 2009; Saupe, 2009).

Bruchid damage – determined by counting and weighing damaged seeds from a 200g sub-sample, using the gravimetric method of Compton et al. (1998).

Shrivelling – scored visually as normal or shrivelled from the same sub-sample. Shrivelling was assessed because it is a direct physical indicator of seed deterioration during storage. Unlike bruchid damage, which is pest-induced, shrivelling often results from poor drying, moisture stress, or prolonged storage that compromises seed integrity.

These parameters were selected because they represent the most widely recognized indicators of seed quality in both research and practice. Moisture content directly affects storability and mold development; bruchid damage reflects vulnerability to storage pests; shrivelling indicates physical deterioration due to poor drying or prolonged storage; and germination viability provides the most direct measure of seed performance under favorable conditions. Their selection ensures comparability with international seed quality standards set by ISTA and FAO (2010) while remaining practical for farmer-level application

3.4 Data analysis

For the quantitative survey, data collected through questionnaires were first edited and coded before being analyzed using SPSS. Descriptive statistics were generated and presented in tables and charts to summarize the data. The Chi-square test was employed to determine whether there was a significant association between two categorical variables. For the survey, these categorical variables included, for example, farmer age groups, gender, educational level, and types of post-harvest storage practices (Plackett, 2023).

For the experimental data, one-way analysis of variance (ANOVA) was applied to determine differences among treatments. In the case of storage post-harvest handling technologies, the Tukey's Honestly Significant Difference (HSD) test was used to compare all possible pairs of treatment means to identify which pairs showed statistically significant differences. The analysis of experimental data was conducted using R statistical programming language.

CHAPTER FOUR: PRESENTATION OF RESULTS

4.1 Farmers' post-harvest storage practices for preserving bean seed quality in Iganga district

4.1.1 Demographic characteristics of the respondents

Demographic results showed that the majority of respondents (92.2%) were 30 years and above. The majority of the respondents were female (60%), and similarly the biggest number had attained or completed some level of primary education and these accounted for 58.50% (Table 1).

Table 1. Demographic information of respondents involved the study in Nambale Subcounty, Iganga District

Response	Frequency (N)	Percentage (%)
Gender		
Male	82	40.00
Female	123	60.00
Age		
15-29 (youth)	16	7.80
30 and above (adults)	189	92.20
Level of education		
Did not go to school	9	4.004
Primary	120	58.50
Secondary (O-Level)	65	31.70
Secondary (A-Level)	9	4.004
University / tertiary	2	1.00

4.1.2. Major sources of seed for the famers in Nambale Subcounty

Figure 2 shows that most farmers got their seed from agro-input dealers (46%) followed by those who use own home-saved seed (39%). Other sources of seed included seed loans, fellow farmers, friends, or family and also seed from research activities or projects.

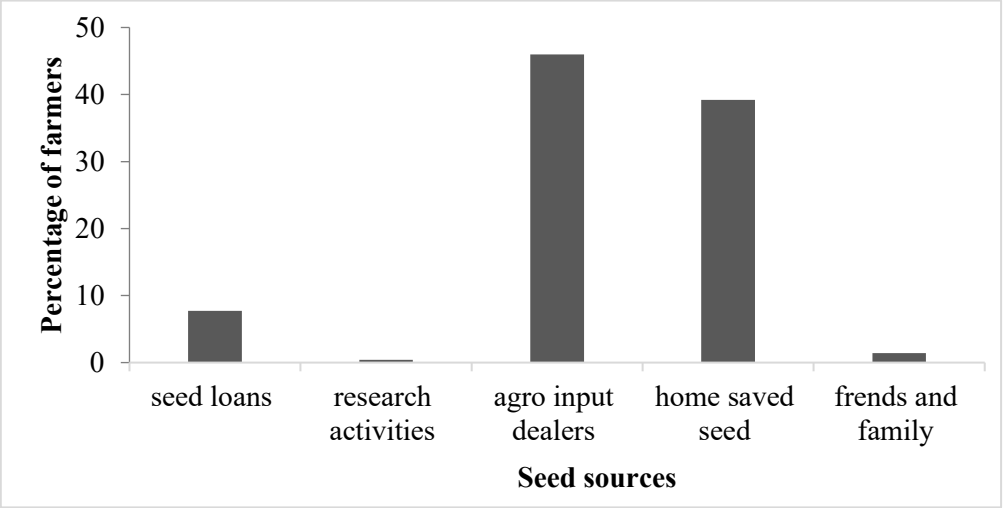


Figure 2. Sources of bean seed for planting

4.1.3. Bean seed storage technologies used by farmers

The dominant storage options to store bean seed are the traditional methods of polypropylene sacs (63%) (Table 2).

Table 2. Methods used by farmers to store their home-saved bean seed

Method of storage	Frequency (N)	Percentage (%)
Polypropylene	129	63.0
Silo	1	0.50
PICS bag	43	21.0
Jerrican	26	12.6
Do not store	6	2.9
Total	**205**	**100.0**

4.1.4. Quality parameters considered by farmers in determining the quality of bean seed

Figure 3 shows the main parameters assessed for seed quality and the percentage of farmers assessing each parameter. Over half (59%) of farmers assess pest damage, while a smaller proportion assess moisture content (8.3%) and diseased/mouldy seeds (14%). Other minor parameters assessed by farmers included seed discoloration, mechanical damage, and viability.

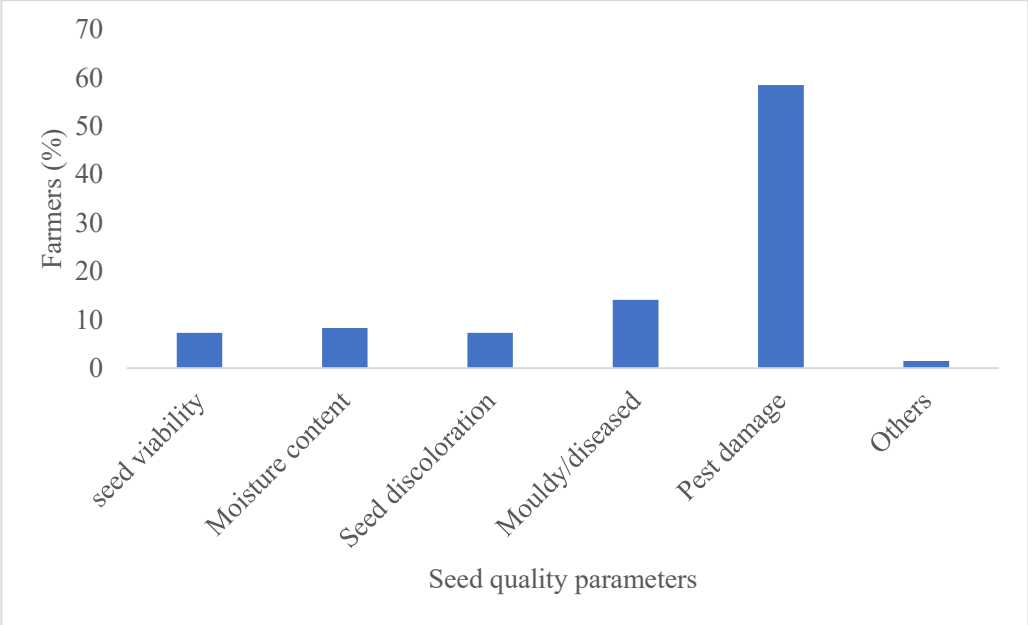


Figure 3. Parameters considered by farmers in determining bean seed quality

Table 3 presents the results from the chi-square test, showing a statistically significant relationship between the two knowledge variables (p = 0.000). This relationship shows that the increasing knowledge of quality parameters may also improve knowledge of post-harvest handling and storage best practices.

	Value	Df	Asymp. Sig. (2-sided)
Pearson Chi-Square	102.927[a]	30	0.000
Likelihood Ratio	51.191	30	0.009
N of Valid Cases	205		

From the chi- square test, the P-value (0.728) indicates that there is no significant relationship between the level of education and farmer knowledge on storage technologies. Therefore, many farmers at different levels of education still do

not have adequate knowledge on the appropriate or recommended storage technologies for post-harvest handling (Table 4).

Table 4. Relationship between level of education and farmers' knowledge and choice of seed storage technologies

	Value	Df	Asymp. Sig. (2-sided)
Pearson Chi-Square	15.812[a]	20	.728
Likelihood Ratio	15.523	20	.746
N of Valid Cases	205		

Farmers' knowledge on seed quality parameters according to the chi-square test does not have a significant relationship with their level of education. With a P-value of 0.18 from the Pearson chi –square test, many farmers whether educated or not do not have adequate knowledge on the recommended seed quality parameters for beans seed storage (Table 5).

Table 5. Relationship between farmers' level of education and knowledge on seed quality parameters

	Value	Df	Asymp. Sig. (2-sided)
Pearson Chi-Square	40.699[a]	24	.018
Likelihood Ratio	41.734	24	.014
N of Valid Cases	205		

4.2 Effectiveness of selected post-harvest storage technologies used by smallholder growers in preserving bean seed quality

4.2.1 Effect of storage technologies on seed quality parameters

Average moisture content over the 90-days storage period differed significantly ($p = 0.010$) among the storage technologies. The Polypropylene had the highest moisture content (14.5%), while the Plastic SILO storage had the lowest of moisture content (13.29%) (Table 6). There was a significant difference in the percentage of bean bruchid-damaged seeds among the storage methods ($p = 0.003$). Plastic SILO resulted in the lowest percentage of damaged seeds at 0.01% whereas polypropylene bag had the highest bean bruchid damage rate of 0.96% (Table 6).

The percentage of shrivelled seeds varied significantly across the storage methods ($p = 0.022$). The plastic SILO had the lowest percentage of shrivelled seeds of 0.61% while the polypropylene bag had the highest been shriveling rate of 1.55% (Table 6). There was a significant difference in seed viability among the storage methods ($p = 0.001$). Both Purdue Improved Crop Storage (PICS) bag and Plastic SILO recorded significantly higher seed viability of 99.00%, 99.62% respectively, compared to Polypropylene bag with 94.71% seed viability.

Table 6. Mean effect of storage technologies on seed quality parameters over a storage period of 90 days

Storage technology	Moisture content (%)	Bruchid-damaged seed (%)	Shrivelled seed (%)	Seed viability (%)
Polypropylene	14.15 ± 0.16 b	0.96 ± 0.09 b	1.55 ± 0.42 b	94.71 ± 0.97 a
PICS bag	13.53 ± 0.11 a	0.24 ± 0.24 a	0.99 ± 0.33 ab	99.00 ± 0.63 b
SILO	13.29 ± 0.13 a	0.01 ± 0.01 a	0.61 ± 0.11 a	99.62 ± 0.16 b
Df	*2*	*2*	*2*	*2*
P-value	*0.010*	*0.003*	*0.022*	*0.001*

Means bearing the same letter are not significantly different (P = 0.05)

4.2.2 Effect of time on moisture content of bean seed stored under different postharvest storage technologies

There was no significant interaction between storage technologies and time (P=0.108) for moisture content. However the initial moisture content at Day 0 was the same (13.5%) for all storage technologies. For polypropylene bag, moisture content increased from 13.5 to 14.05% and remained generally stable up to Day 90. In the Purdue Improved Crop Storage (PICS) bag, the initial moisture content was 13.4%, declined slightly to 13.3% by the 15th day, and thereafter stayed nearly unchanged up to day 45. It then increased from 13.4 to 13.7% at Day 60 which remained generally stable up to day 90. Similar to Purdue Improved Crop Storage Bag, Plastic SILO also showed fluctuations in moisture content over time, but the overall trend appears to be relatively stable, with the moisture content ranging from 13.1 to 13.4% over the 90-day period (Figure 4).

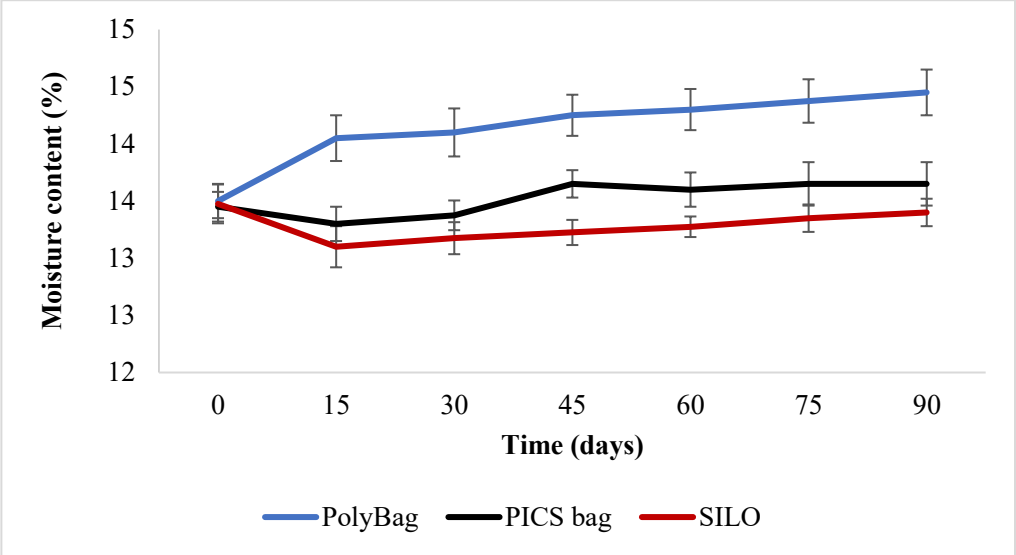


Figure 4. Mean moisture content of bean seed stored in different postharvest storage technologies over a 90-days period

4.2.3 Effect of time on bruchid damage of bean seed stored under different postharvest storage technologies

There was a significant interaction between time and bean bruchid-damaged seed (p=0.001). The percentage of bruchid-damaged seeds in Polypropylene Bag started at 0% on day 0 and increases gradually with percentages rising from 0.65% at day 15 to 1.6% at day 90. The Purdue Improved Crop Storage bag also started with 0% bruchid-damage on day 0 but the percentage of bruchid-damaged seeds remains relatively low throughout the 90-day period, with some fluctuations. Although there is a noticeable slight increase from 0.27% at day 15 to 0.45% at day 90 which is considerably lower compared to Polypropylene Bag. Plastic SILO starts with 0% Bean bruchid-damage and maintains this throughout the first 45 days. There's a small increase in bean bruchid-damage, reaching 0.05% at day 60, but it remains relatively low compared to the other methods (Figure 5).

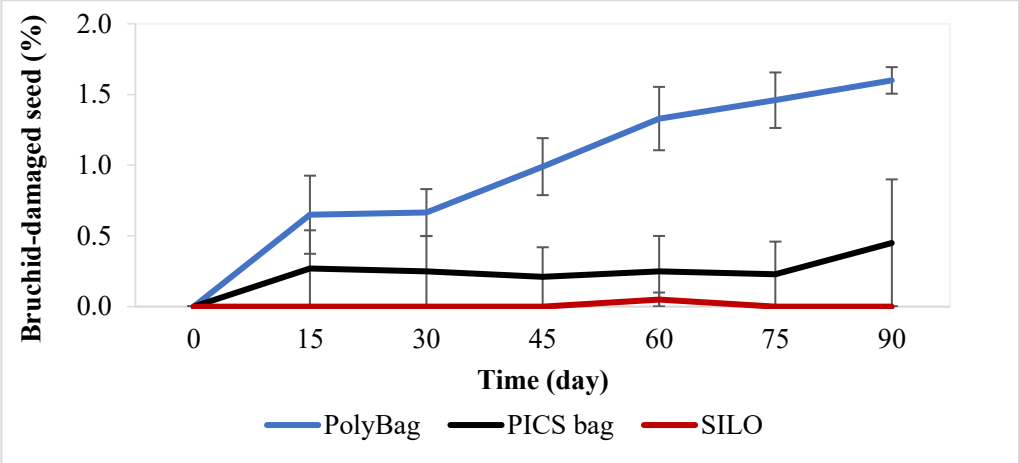


Figure 5. Mean proportion of seed damaged by the bean bruchid recorded under different storage technologies over a 90-days period

4.2.4 Effect of time on shriveling of bean seed stored under different postharvest storage technologies

There was a significant interaction between time and seed shriveling which is indicated by the p-value of P = 0.018**.** The percentage of shriveled seeds in Polypropylene Bag started at 0% on day 0 and increased gradually with percentages rising from 1.06% at day 15 to a peak of 2.48% at day 60, and then decreasing slightly to 2.11% at day 90. The Purdue Improved Crop Storage bag also starts with 0% shriveled seeds on day 0. However there are fluctuations in the percentage of shriveled seeds over time are ranging from 0.82 to 2.05% over the 90 days. In the Plastic SILO, no shriveled seeds were observed at day 0; however, a gradual increase occurred over time, reaching between 0.33% and 1.58% within the 90-day storage period. Therefore The Plastic SILO demonstrates relatively low levels of shriveled seeds compared to Polypropylene Bag and PICS bag (Figure 6).

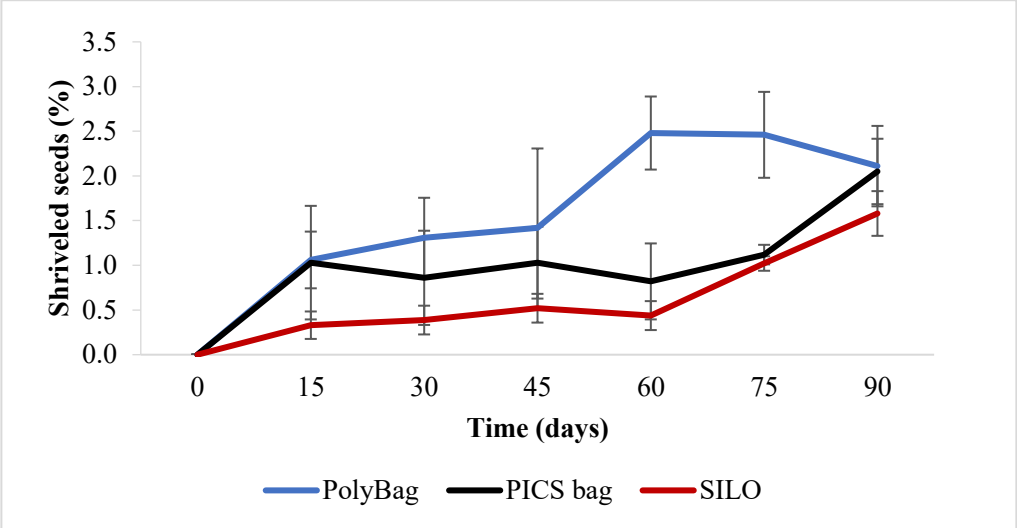


Figure 6. Mean proportion of shriveled seed recorded under different storage technologies over a 90-days period

4.2.5 Effect of time on viability of bean seed stored under different postharvest storage technologies

There was a significant interaction between time and seed viability ($p = 0.003$). Seed viability in a Polypropylene bag started at 100% on day 0 and a declined in seed viability from day 0 to day 45, followed by stabilization around 93-95% for the remainder of the period. Seed viability in the polypropylene bag declined from 100% on day 0 to 91% by day 45, after which it stabilized between 91–93% for the remainder of the storage period, with no further significant decline. The Purdue Improved Crop Storage bag maintained high seed viability throughout the 90-day period. Seed viability started at 100% on day 0 and remained consistently high, with minor fluctuations between 98% and 100%. Seed viability in plastic SILO started at 100% on day 0 and remained consistently high for the first 60 days. There was a slight decrease in seed viability from day 60 onwards, with percentages dropping to 99% by day 75 and

90. Plastic SILO maintained very high seed viability throughout the 90 days (Figure 7).

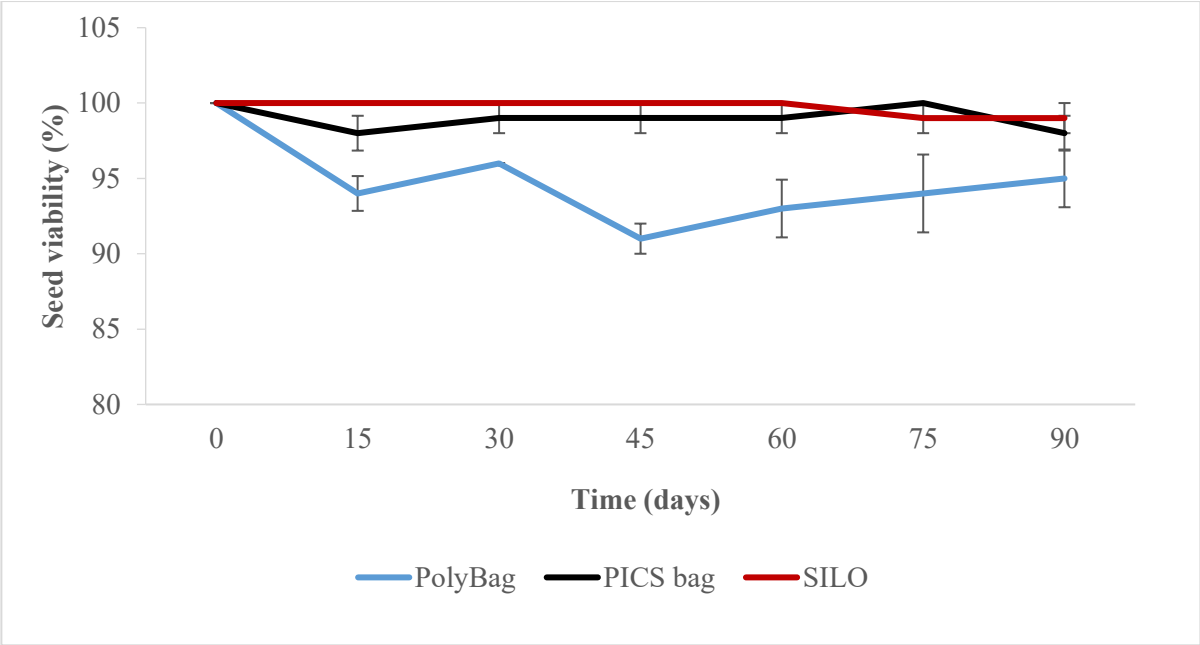


Figure 7. Mean seed viability of bean seed stored under different storage technologies over a 90-days period

CHAPTER FIVE: DISCUSSION OF RESULTS, CONCLUSIONS AND RECOMMENDATIONS

5.1. Discussion of results

5.1.1 Farmer Knowledge and Practices on Post-Harvest Storage Technologies for Optimum Bean Seed Quality in Iganga District

The findings showed that the main sources of seed for planting among farmers were informal seed systems, such as home-saved seed, seed obtained from fellow farmers, and agro-input dealers. This reliance on informal sources is common among smallholder farmers and is largely explained by limited affordability and accessibility of improved seed, as well as the preference for familiar varieties and the lack of alternative suppliers during planting seasons. These findings align with Agona and Muyinza (2002), who reported that 87.5% of farmers in Masindi and 69% in Lira relied on home-saved seed.

With respect to storage technologies, 63% of respondents indicated that they stored their bean seed in polypropylene bags, while others used jerricans, plastic silos, and PICS bags. These results are consistent with earlier reports by Agona and Muyinza (2002), who found that polypropylene bags were the dominant storage technology among farmers in Masindi (84.2%) and Lira (90%).

Despite using different storage methods, most farmers reported depending on traditional wisdom rather than standardized seed quality parameters when selecting seed. Awareness of recommended seed quality standards was generally low, and although there was some correlation between seed quality considerations and choice of storage method, the knowledge gap remains

substantial. This suggests that targeted outreach initiatives could help bridge the link between improved storage technologies and better seed quality outcomes.

The demographic characteristics of respondents provide context for these findings. The majority of farmers interviewed were female (60%), and prior studies have shown that women often play a central role in seed selection, preservation, and household food security in smallholder systems. Age distribution revealed that 92.2% of respondents were 30 years and above, indicating that most decision-makers in seed storage were older adults with accumulated experience, though possibly less exposure to new innovations compared to youth. Regarding education, most respondents had attained only primary education (58.5%), with very few reaching secondary (31.7% O-level; 4% A-level) or higher levels (1% university/tertiary). This low level of formal education partly explains why many farmers had limited knowledge of technical seed quality parameters, regardless of whether they had attended school. In fact, the study found no significant relationship between education level and awareness of seed quality standards ($p = 0.18$), showing that lack of information cuts across all categories of farmers

5.1.2 Influence of selected storage technologies on bean seed quality in Nambale Sub-county Iganga district

The findings showed that there were notable variations in the moisture content of the storage technologies ($P = 0.010$). Polypropylene bags exhibited the highest moisture content at 14.5%, whereas Plastic SILO storage demonstrated the lowest moisture content at 13.29%. This suggests that Plastic SILO storage is more effective in maintaining lower moisture levels compared to Polypropylene

bags. And this is due to the permeable nature of polypropylene bags, which allows moisture ingress, compared to the impermeable and controlled environment provided by Plastic SILOs. The results of this study contradict those of Abass et al. (2018), who noted that grain moisture content increased from 12.48% at the time of storage to between 12.95 and 13.54% at 30 weeks of storage in hermetic circumstances (silos, plastic barrels, and PICS). These moisture content values were substantially greater than the 12.36% moisture content of the maize held in the non-hermetic facilities (particularly the polypropylene bags) after 30 weeks of storage. The observed differences between the two studies are likely attributable to a combination of factors such as experimental conditions, sample variability, measurement techniques, storage environment, and, most importantly, the duration of storage and timing of measurements

Significant differences were observed in the percentage of bean bruchid-damaged seeds among the storage methods ($p = 0.003$). Plastic SILO storage resulted in the lowest percentage of damaged seeds at 0.01%, while polypropylene bags had the highest bean bruchid damage rate of 0.96%. This indicates that Plastic SILO storage offers better protection against bean bruchid infestation compared to Polypropylene bags. The lower percentage of bean bruchid-damaged seeds observed in Plastic SILO and Purdue Improved Crop Storage (PICS) bags can be attributed to their impermeable and controlled storage environment, which restricts pest access and minimizes the likelihood of infestation. In contrast, the porous nature of polypropylene bags facilitates bruchid entry and creates conditions more favorable for infestation and seed damage. The findings of this study are consistent with broader evidence showing

that hermetic storage technologies outperform conventional polypropylene bags in reducing postharvest losses. For example, Ngoma et al. (2024) conducted a meta-analysis comparing hermetic bags, such as PICS, with conventional storage methods and reported that grain damage averaged 4% in hermetic bags compared to 43% in polypropylene bags—a more than tenfold reduction. In addition, insect populations were approximately 42 times lower in hermetic bags, weight loss was significantly reduced (0.9% versus 20.8%), and seed viability loss was also lower (10% versus 36%). These findings reinforce the results of the present study, where lower bruchid damage was recorded in Plastic SILO and PICS bags relative to polypropylene bags, highlighting the effectiveness of hermetic storage technologies in maintaining grain quality (Ngoma et al., 2024). The percentage of shrivelled seeds also varied significantly across the storage methods ($P = 0.022$). Plastic SILO demonstrated the lowest percentage of shrivelled seeds at 0.61%, whereas polypropylene bags had the highest shrivelling rate of 1.55%. This implies that Plastic SILO storage helps prevent seed shrivelling more effectively than Polypropylene bags. The lower percentage of shrivelled seeds observed in Plastic SILO and the Purdue Improved Crop Storage bags compared to polypropylene bags can be attributed to the impermeable and controlled environment provided by Plastic SILOs, which effectively prevents moisture ingress and environmental fluctuations, while on the other hand polypropylene bags are not completely impermeable and can allow moisture and air to permeate the storage space. This can lead to fluctuations in environmental conditions within the bags, including temperature and humidity levels, which may contribute to seed deterioration and shrivelling over time.

Furthermore, there was a significant difference in seed viability among the storage methods ($p = 0.001$). Both Purdue Improved Crop Storage (PICS) bags and Plastic SILO storage resulted in significantly higher seed viability of 99.00 and 99.62%, respectively, compared to Polypropylene bags with 94.71% seed viability. This suggests that PICS bags and Plastic SILO storage are superior in maintaining seed viability over the storage period compared to Polypropylene bags. The superior seed viability observed in Purdue Improved Crop Storage bags and Plastic SILO compared to Polypropylene bags can be attributed to the controlled environment, protection from pests and pathogens, and environmental stability provided by these storage technologies. These factors collectively influence seed quality and contribute to higher viability over the storage period. These results concur with those of Abass et al. (2018), who reported that at 18 weeks of storage, the germination rate was over 80% in all treatments using hermetic and non-hermetic storage technologies and did not differ significantly from the rate of 92% obtained prior to storage (Abass et al., 2018).

The silo's airtight, hermetic design prevents oxygen and moisture ingress, creating an unfavourable environment for pest proliferation and fungal growth. Additionally, Tefera et al. (2017) emphasized that oxygen depletion in hermetic systems impairs bruchid survival, contributing to long-term seed viability and physical integrity. Compared to PICS bags and polypropylene sacks, the silo consistently preserved higher germination rates and minimized physical deterioration, justifying its recommendation for smallholder farmers seeking sustainable seed storage solutions.

5.2 Summary of Results

The study revealed that informal seed systems—including home-saved seed, farmer-to-farmer exchange, and agro-input dealers—were the main sources of bean seed in Nambale Sub-county, Iganga District. This reliance is attributed to affordability, accessibility, and preference for familiar varieties. Similar patterns have been documented by Agona and Muyinza (2002), who reported heavy dependence on home-saved seed in Lira and Masindi.

With respect to storage practices, 63% of farmers reported using polypropylene bags, while smaller proportions utilized jerricans, PICS bags, and plastic silos. These findings also align with Agona and Muyinza (2002), who observed that polypropylene bags dominated bean storage among farmers in northern Uganda. However, most farmers relied on traditional wisdom rather than formal seed quality standards when selecting and storing seed. Awareness of recommended quality parameters was generally low, with no significant association between educational attainment and knowledge of seed quality standards ($p = 0.18$). Demographic characteristics provided further context: the majority of respondents were female (60%), older than 30 years (92.2%), and had primary-level education (58.5%), reflecting the predominance of women and older adults with limited formal training in seed handling.

Experimental evaluation of storage technologies showed significant differences across seed quality parameters. Plastic silos and PICS bags consistently outperformed polypropylene bags. Moisture content was lowest in silos (13.29%) compared to polypropylene bags (14.5%), reflecting the silos' impermeable structure. Seed damage from bruchids was nearly eliminated in silos (0.01%) and PICS bags, but was highest in polypropylene bags (0.96%),

corroborating evidence from Ngoma et al. (2024) that hermetic technologies drastically reduce storage losses. Similarly, shrivelling was lowest in silos (0.61%) and highest in polypropylene bags (1.55%).

Seed viability was also significantly higher in hermetic systems, with silos (99.62%) and PICS bags (99.00%) maintaining near-perfect germination compared to polypropylene bags (94.71%). These results are consistent with Abass et al. (2018) and Tefera et al. (2017), who reported that hermetic storage prevents oxygen and moisture ingress, reduces pest survival, and safeguards seed physiological integrity. Overall, the study demonstrates that hermetic technologies, particularly plastic silos, provide superior protection for bean seed, justifying their recommendation for smallholder farmers seeking sustainable, pesticide-free storage solutions.

5.2 Conclusions

- Farmers in Iganga District predominantly rely on informal seed systems, including home-saved seeds and seeds obtained from fellow farmers or agro-input dealers.
- Indigenous knowledge plays a significant role in seed selection and storage techniques. However, overall knowledge regarding recommended seed quality parameters and improved storage technologies remains limited.
- The post-harvest technologies used by smallholder seed producers in Iganga District vary in effectiveness. Among the technologies assessed, Plastic SILO storage performed best, maintaining the lowest moisture

content, minimal bruchid damage, lowest percentage of shriveled seeds, and highest seed viability.

5.3 Recommendations

1. Targeted education and outreach programs

- Conduct workshops, demonstrations, and farmer field schools to enhance knowledge on recommended seed quality parameters and storage technologies.
- Use locally accessible communication channels such as radio programs, mobile SMS alerts, and agricultural extension bulletins to reach wider audiences.

2. Promotion of improved post-harvest handling technologies

- Encourage adoption of Plastic SILOs and PICS bags, as these technologies have shown superior performance in preserving bean seed quality. PICS bags are widely proven for their hermetic, chemical-free protection, while plastic silos have been scientifically shown to minimize storage losses to below 1%, preserve germination viability, and offer durable, reusable, and pesticide-free storage solutions.
- Provide hands-on training sessions and practical demonstrations at community and cooperative levels to familiarize farmers with setup, maintenance, and handling of these storage systems.

3. Knowledge Dissemination: Means and Key Strategies

To bridge the knowledge gap on improved post-harvest storage technologies and enhance adoption among smallholder farmers, targeted dissemination approaches are essential. Based on the livelihoods and accessibility of farmers in Nambale Sub-county, the following strategic pathways are recommended and ranked by effectiveness:

A. Farmer Field Schools and Cooperative Group Trainings (First Priority)

These are highly effective for smallholder farmers who operate collectively and rely on peer-to-peer learning. Demonstrations, practical sessions, and group discussions reinforce understanding and encourage adoption of improved storage technologies such as PICS bags and plastic silos.

B. Radio Programs and Mobile Messaging (Second Priority)

Mass media campaigns via local radio stations and mobile messaging provide wide coverage and are accessible even to farmers with limited mobility or literacy challenges. These platforms can deliver key messages on seed quality standards, storage techniques, and benefits of hermetic technologies.

C. Extension Officer Home Visits (Third Priority)

Personalized visits by trained extension officers allow for tailored guidance and direct troubleshooting. While resource-intensive, this strategy is particularly suitable for high-value seed producers or farmers requiring technical assistance to adopt new storage systems.

Implementation Consideration:

- Prioritizing group-based learning leverages existing social structures and enhances cost-effectiveness.
- Complementary radio/mobile communication ensures continuous reinforcement of messages.
- Home visits serve as a supplementary approach for targeted, high-impact adoption support.

Further research

- Evaluate the long-term effectiveness of storage technologies beyond the 90-day storage period studied.
- Assess the economic feasibility of adopting these technologies across different farm sizes and agro-ecological zones.
- Investigate the influence of agro-ecological diversity and local environmental conditions on the performance of storage methods.

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Appendices

Appendix 1: Research questionnaire for objective one

KYAMBOGO UNIVERSITY

Appendix I: Questionnaire for beans farmers

Dear respondents,

I am Ndyamuhaki Arthur a student at Kyambogo University pursuing a Master's Degree in crop science. The purpose of this questionnaire is to get your views on the effectiveness of post-harvest storage technologies on seed quality of beans and come up with practical strategies on how to ensure maintenance of seed quality during on farm storage in Iganga District. You have been chosen as one of the participants in this study so I am kindly requesting you to complete the questionnaire by writing in the spaces provided or ticking in the box provided. All information is specifically for academic purposes and shall be treated with utmost confidentiality.

SECTION 1 (HOUSE HOLD INFORMATION)

Date…….

District……...……

Sub- County…….

Parish……

Village…….

Name ……

Age ……

Members participating in bean farming …….

1. What is the highest level of your education?

Primary	
Secondary (O'level)	
Secondary (A'level)	
University	

Other (specify)	

SECTION 2 (FARM INFORMATION)

2. what is your farm size? (acres)

……
……

3. major crops at your farm

Crop	coffee	Bananas	Beans	Cereals	Root crops	Vegetables	Others, please specify
Area occupied in acres							

4. major seed sources

Seed sources	Seed companies	Home saved seed	Agro input dealers	Research activities	Seed loans	Others, please specify

5. what are the major indicators of ready to harvest beans.

Indicators	Yellowing of the leaves	Shading off of leaves	Pronounced seed color	Hardening of pods	Others, please specify

6. How do you transport your beans from the garden

Transport means	Polypropylene bags	Wheelbarrow	Bicycles	Vehicles	Others, please specify

7. How do you dry your beans

Drying methods	Bare ground	Raised ground	Concrete ground	Tarpaulins	Others, please specify

8. how long after harvesting do beans take to dry?

Drying period	Less than week	One week	Two weeks	Three weeks	One month	Others, please specify

11. how do you test moisture content before storage of bean seed

Testing method	Tooth bite	Using basin	Salt method	Others, please specify

SECTION 4 (STORAGE OF BEAN SEED)

12. How do you store your bean seeds for the next season?

Storage method	Polyproline bags	Silos	Pics bags	Jelycans	Pots	Others, please specify

16. For how long do you store your bean seed after drying?

storage period	Less than one month	One month	Two months	Three moths	I do not store seed	Others, please specify

19. What parameters do follow to determine seed quality; Mechanical damage

Parameter	Seed viability	Moisture content	Seed discoloration	Mouldy/ diseased	Pest damage	Mechanical damage	Others, please specify

End- Thank you