UNIVERSITY FOR DEVELOPMENT STUDIES



# EFFECTS OF SEED SOURCE, VARIETY, PACKAGING MATERIALS, STORAGE CONDITIONS AND STORAGE DURATION ON VIABILITY AND PROXIMATE COMPOSITION OF CERTIFIED SOYBEAN SEEDS FROM THREE REGIONS IN NORTHERN GHANA

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2026

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**BY**

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**(MPhil Crop Science)**

**(UDS/DHT/0001/21)**

**THESIS SUBMITTED TO THE DEPARTMENT OF HORTICULTURE, FACULTY OF AGRICULTURE, FOOD AND CONSUMER SCIENCES, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILLMENT OF THE REQUIRMENTS FOR THE AWARD OF DOCTOR OF PHYLOSOPHY IN HORTICULTURE**

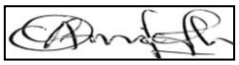
**MARCH, 2026**

## DECLARATION

**Student**

I hereby declare that this dissertation/thesis is the result of my original work and no part of it has been presented for another degree in this University or elsewhere:

**Candidate:**

Signature:  Date: 25/03/2026

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We hereby declare that the preparation and presentation of the thesis was supervised following the guidelines on supervision of thesis laid down by the University for Development Studies.

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## ABSTRACT

In Ghana, soybean is largely cultivated in the northern sector accounting for about 90% of the soybean produced in the country. Despite the crop's high potential to improve food and economic security, there is very little or insignificant growth in the rate of production of soybean in Ghana. Major factors contributing to the low level of production include poor seed quality and poor storage conditions. To date, there is limited information on the effect of long-term storage of soybean seed on quality, especially regarding seed viability and seedling vigour. This study was conducted to assess the effects of seed source, variety, packaging materials, storage room temperatures and storage durations on three popular certified soybean seed varieties. Three experiments were conducted from April, 2022 to December, 2023. Experiment 1 was a 4 x 3 x 2 factorial arranged in split-split plot design with three replications. The four sources of the seeds were three certified seed companies including Antika (Upper West Region), Heritage (Northern Region), Integrated Water and Agricultural Development (IWAD) (Upper East Region) and the Savana Agricultural Research Institute (Foundation seed) which served as a check. The three varieties evaluated were 'Afayak', 'Favour', and 'Jenguma' and the qualities of these seeds were measured at sampling (zero), and at five (5) and ten (10) months after storage under ambient temperature (zinc roofed room). Experiment 2 was a 5 x 3 factorial arranged in split plot design with three replications. The treatments were five storage conditions (cold room, air-conditioned room, warehouse, thatch house and zinc roofed room) and three storage durations (0, 5 and 10 months) after storage. For experiment 3, the treatments were three varieties ('Afayak', 'Favour', "Jenguma"), seven packaging materials (Ghana Seed Inspection Division (GSID) branded polypropylene bag, GSID Plastic bag, paper bag, jute bag, jute bags lined with plastic, polypropylene bag and

polypropylene bag lined with plastic) and three storage durations (0, 5 and 10 months) arranged in a split split plot design with three replications were used to evaluate treatments. In experiment one, 'Jenguma' in the control stored for 10 months maintained the highest number of normal seeds. Similarly, 'Jenguma' seed collected from UWR had the highest fat content, while that from UER had the highest ash content at end of the 10 months storage period. 'Favour' seeds obtained from UWR and stored for 10 months had the highest germination perectage and protein content. 'Afayak' seed sourced from UWR and stored for 10 months exhibited significant increase in the dry matter content, whereas, 'Jenguma' seeds from UER showed the highest moisture loss at the end of the 10 month storage period. Principal component analysis shows a strong positive correlation between moisture, protein, normal seeds and germination percent with strong correlation for germination and moisture percentages for seeds obtained from Upper East Region. Although Seed germination deteriorated with storage duration across all sources and varieties, the 'Favour' variety exhibited the highest germination percentage irrespective of the sources. Seeds from Upper West Region exhibited best performance in germination for all three varieties after ten months storage. For experiment two, there was a positive correlation between germination and normal seeds (r = 0.669). Cold room, thatch roofed rooms and commercial warehouses significantly preserved seed viability. 'Favour' seeds stored in GICS bag for 10 months had the highest normal seeds and germination percent. 'Jenguma' seeds stored in (PP) bags for 10 months showed the least decline in fat content. Germination % positively correlated with protein and normal seeds across all soybean varieties. Germination % showed a positive correlation with carbohydrate for the 'Favour' variety. For 'Afayak' and 'Jenguma', germination % was positively correlated with fat and moisture contents. For experiment three, hermetic storage and paper bags proved more effective in maintaining

seed viability and vigour compared to other conventional packaging options. The research has therefore demonstrated that, to maintain the viability of certified soybean seeds for longer period, the 'Favour' seed variety should be packaged in GICS (hermetic) or paper bags and stored in cold rooms, commercialized seed warehouses or thatch roofed rooms, depending on the availability of these facilities in the soybean growing areas in Ghana. This study suggests that breeders should pay more attention to the fat, carbohydrate and ash traits in breeding for high seed viability and seedling vigour for soybean.



## ACKNOWLEDGEMENTS

To Almighty God for granting us the enablement for this study. To my supervisors in the Department of Horticulture, Professor George Nyarko and Dr Hypolite Bayor, I am highly grateful for their immeasurable contribution and guidance towards the achievement of this work. Thank you and may God richly bless you.

Special thanks go to Dr. Isaac K. Amegbor of Savannah Agricultural Institute (SARI) for his technical support in shaping the work.

I also acknowledge the support and technical assistance given by Emmanuel Baako (SARI) during the laboratory work and Abdul Rashid Hudu

To my immediate office supervisors, especially Mrs. Augusta Nyamadi-Clottey (MD, Preciso Consult and General Services Ltd), Mr. Richard Etornam Nyahe and Mr. Evans Tuti Lawertey (Ghana Cocoa Board), I am grateful for their encouragements and support.

Finally, the support offered as prayers and words of encouragement by friends and family members, is acknowledged.

## DEDICATION

I dedicate this work to my dear wife (Mrs Philippine Dzorgbenyuie Aku Dogor) and lovely children (Daniel Setor Kwame Atsu Dogor, Deborah Senam Ama Atsufe Dogor and David Kwame Doe Sitsofe Dogor) for their encouragement, sacrifices and support during this study.

Also, to my parents (Rev. Sylvanus Worlanyo Kormla Dogor and Mrs. Christine Ama Dogor) and all my siblings for their support.



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# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 Background

Soybean (*Glycine max* L.) is an economical important crop known in the leguminous family and is globally traded for its high oil and protein value. The grain serves as essential plant-based protein for human and animals, and its oil is widely used in food processing and industrial applications (Mishra et al., 2024; Wrigley et al., 2004). Due to this nutritional profile, soybean production acreage driven by high demand has increased in recent years. In 2023, soybean was one of the most traded commodities in the agricultural sector worldwide and was ranked as the fourth most traded product after corn, wheat, and palm oil (Martignone et al., 2024). The global soybean seed market was estimated at USD 29.04 billion in 2024 and it has been projected to increase around 4.3% by 2032 (Martignone et al., 2024). This rapid increase in the expansion of soybean acreage requires high-quality seeds and improved storage facilities for effective commercialization of soybean.

Seed storage is an important aspect of seed quality management, as it impacts germination, viability, and overall seed composition (Nwaigwe, 2019). Several factors, including storage duration, seed variety, packaging materials, and storage conditions, impact soybean quality (Corbineau, 2024; Elsawy et al., 2024; Kebede et al., 2024). Variations in these factors can result in biochemical changes in the seed, affecting its germination potential and proximate composition such as protein, carbohydrate, and lipid contents. Effective storage methods are crucial to maintaining seed viability and nutritional quality over time, particularly in tropical climates where temperature and humidity fluctuations accelerate seed deterioration.

Soybean production is growing due to increasing demand from the food and livestock industries in Ghana. However, seed deterioration during storage remains a major constraint to productivity and economic returns particularly in developing countries including Ghana (Quarshie et al. 2021). Understanding the interactive impact of storage duration, packaging materials, and storage environments on different soybean varieties is essential to developing strategies for improving seed longevity and quality.

Despite the nutritional and economic importance of soybean, the germination percentage of stored soybean seeds is generally low (Mangena and Mokwala, 2019; Puozaa et al., 2023). This germination problem in Africa is largely due to seed producers and farmers' inability to preserve seeds properly for a long period. This study aims to investigate these factors and provide insights into optimizing storage practices to enhance seed germination and proximate composition.

### 1.2 Problem statement and justification

In Ghana, soybean is largely produced in the northern sector which is accounting for 90% of the soybean produced in the country (Martey et al., 2020). Despite the crop's potential to improve food and economic security, there is marginal significant, if at all in the production of soybeans in sub-Saharan African (SSA) countries including Ghana (Sedibe et al., 2016). For instance, soybean yields have not increased significantly despite the introduction of Planting for Food and Jobs (PFJ), a strategic flagship policy of the government of Ghana which was aimed at increasing crop yields (MoFA-IFPRI, 2020). Poor quality and poor handling of seeds have been identified as two major causes of low yield of soybean in Ghana (Adjei et al., 2022).

Mostly in SSA, where major season cultivation is done during the rainy season, harvested seeds need to be stored for longer periods (months) before they are used for

planting in the next major cropping season. This long storage duration coupled with limited access to improved storage facilities negatively affects seed viability (Raghunauth et al., 2025). Studies have demonstrated that the viability of seeds deteriorates rapidly with storage duration, and storage under poor conditions with high relative humidity, and high temperature (Corbineau, 2024; Sano et al., 2016). During storage, seed respires, utilizing stored fatty acids, fats, and glucose. This significantly decreases seed viability and invariably decreases the rates of germination and seed establishment, particularly in soybean (Munz et al., 2017; Toni et al., 2024).

Apart from storage, "seed genotype" which measures seeds' genetic makeup, is another quantitative property affecting the germination rate of stored seeds (Isaac et al., 2016; Kandil et al., 2013). Kumar et al. (2019) and Naflath et al. (2023) observed higher seed longevity in soybean cultivars with dark and hard seed coats. In other studies, it was indicated that smaller seed sizes have improved longevity of stored soybean seeds (Hosamani et al., 2013; Naflath et al., 2023). Similarly, less space between higher lignin and cotyledons and the seed coat content enhances seed longevity during storage (Kuchlan et al., 2010).

Other important factors affecting seed variability are preharvest conditions and seed sources (Lemes and Catão, 2024). It has been demonstrated that seed sources influence soybean germination rate and yield in north-western Ethiopia (Chaluma, 2023). In Ghana, the average yield of soybeans in the Upper West region (194 kg $ha^{-1}$), and the Northern region (348 kg $ha^{-1}$) have been relatively very low compared with 3.0(t/ha). Actual farmer yield average about 1.3t/ha (Avea et al., 2016). Thus, the output for soybeans in northern Ghana is generally low, despite the availability of improved soybean varieties. Among the major challenges underpinning this low yield is poor seed quality supplied by seed producers (Addae-Frimpomaah et al., 2022). To the best of

my knowledge, there is limited information available on the effect of storage periods on soybean seed in northern Ghana.

Similarly, poor seed storage affects seed viability and leads to unexpected losses, low seedling establishment and yields (Finch-Savage and Bassel, 2016). In SSA, most farmers store seeds using traditional structures, often rhombus systems, traditional cribs, underground pits, open stack storage, woven baskets, grain silos, farm store, and in communal warehouses (FAO, 2018; Kaur et al., 2022; Mobolade et al., 2019; Nwaigwe, 2019). Although it has being established that these storage structures negatively impact the duration and quality of stored seeds compared to warehouses and other advanced storage methods (Patel, 2024), few studies have scientifically evaluated their potential for short to long-term seed storage (Mobolade et al., 2019). Furthermore, research comparing indigenous storage structures and advanced methods is often not uniform or fair, as varying research methodologies and biases can skew results (Simonds and Christopher, 2013; Williams and Shipley, 2023). Nevertheless, these indigenous structures remain relatively affordable and readily accessible to local farmers for seed preservation (Mobolade et al., 2019).



In Ghana, seed quality losses are caused by inappropriate storage technology (Azumah et al., 2019). While most farmers and some seed producers store seeds using indigenous storage facilities, few studies have evaluated the impact of these facilities on quantitative losses of soybean seeds (Sugri et al., 2021). Mobolade et al. (2019) showed that the grains in straw bins remains viable for two growing seasons. The Food and Agriculture Organization has recommended the use of air-conditioned facilities to store early-generation seeds (FAO, 2018). As a result, some seed producers in Ghana install air conditions in their facilities to regulate high temperatures, particularly during the

warm season (mostly from January to March). However, the impact of these storage facilities on germination rate and seed quality has not been extensively documented.

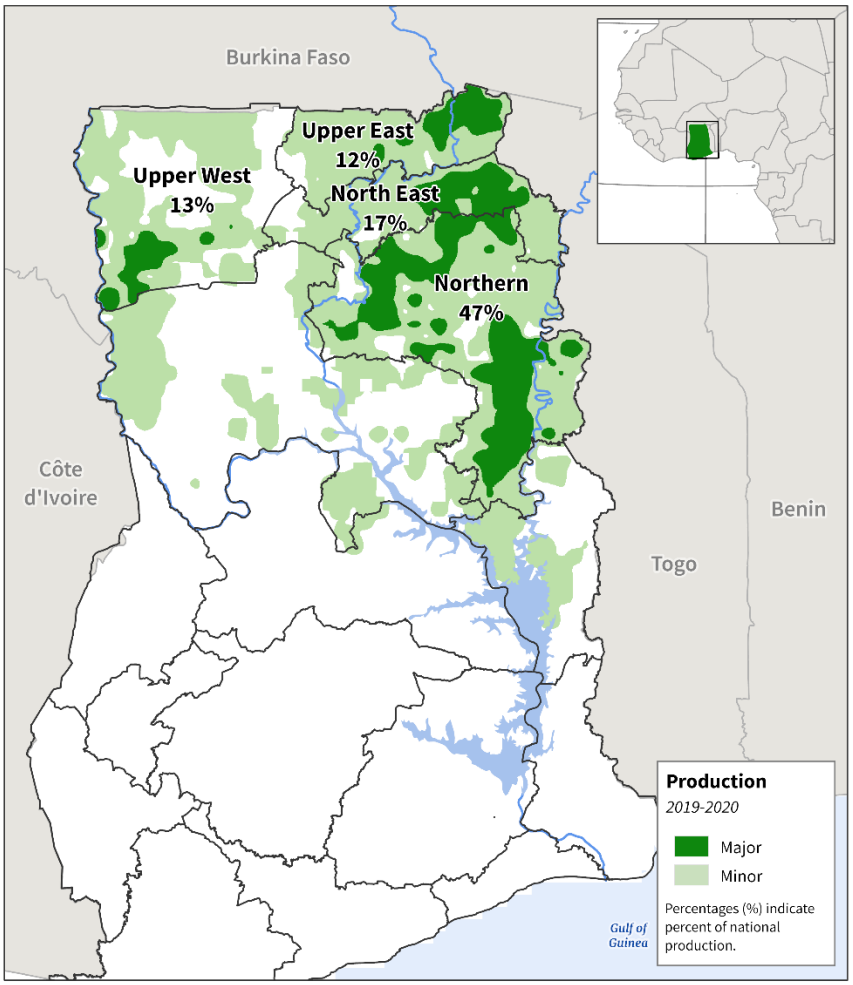



Figure 1.1: Areas of soybean production in Ghana

### 1.3 General Objective

To assess the effects of seed source, variety, storage duration, seed packaging materials, and storage room conditions on seed quality and proximate composition.

#### 1.3.1 Specific objectives

1. To assess the effects of seed source, variety (‘Favour’, ‘Afayak’ and ‘Jenguma’) and storage duration on soybean seed germination, vigour and proximate composition.

2. To assess the effects of Storage room conditions and duration on germination and proximate composition of "Favour" seeds from UWR.
3. To assess the effect of variety ('Favour', 'Afayak' and 'Jenguma' from UWR), storage bags and storage duration on the germination and proximate composition of soybean seeds.



# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Post-harvest factors affecting seed quality

Post-harvest management encompasses all activities involved in harvesting, processing, transporting agricultural produce from the farm gate to warehouse storage and moving the produce to consumption. Despite advancements in agricultural production technologies, post-harvest losses (PHL) continue to pose significant challenges globally, impacting food security, economic sustainability, and environmental resources (Sugri et al., 2021). This literature review examines key issues and challenges associated with post-harvest management, along with potential solutions proposed by researchers and practitioners. Despite its rich agricultural potential, inefficient post-harvest practices lead to significant losses, impacting food security, livelihoods, and the economy.

#### 2.1.1. Post-harvest losses and waste

Post-harvest challenges occur at different stages, starting from harvesting, through the farm gate to the final consumer. Many factors such as inappropriate handling, inefficient storage facilities, transportation inefficiencies, logistical challenges and market constraints (Anand and Barua, 2022). Globally, PHL amount to approximately one-third of total food production, equivalent to 1.3 billion tons of food annually (Stathers and Mvumi, 2020; Ali et al., 2021). This not only threatens food security but also exacerbates environmental degradation and economic losses. In Ghana, PHL range from 15% to 50% depending on the crop and region (Ridolfi et al., 2018; Sugri et al. 2021). Maize, tomatoes, and fruits are among the most affected commodities (Kitinoja et al., 2019). Factors contributing to PHL include inadequate post-harvest technologies,

lack of access to market information, and limited financial resources for investing in storage and processing facilities (Affognon et al., 2015; Gardas et al., 2018).

### 2.1.2. Infrastructure and technological constraints

In many developing countries, inadequate infrastructure, including storage facilities, transportation networks, and market access, contributes to post-harvest losses (Banjaw, 2017; Ali et al., 2021). Limited access to appropriate post-harvest technologies further exacerbates the problem, as smallholder farmers lack resources and technical knowledge to adopt effective preservation methods (Bishek and Rejikumar, 2023). Promising technologies such as hermetic storage bags, solar dryers, and modified atmosphere packaging offer potential solutions but require investment and capacity building to scale up implementation (Kitinoja and Tokala, 2018; Jarman et al., 2023). Inadequate storage facilities, transportation networks, and market access are primary infrastructure deficiencies affecting post-harvest management of crop produce (Dovlo et al., 2021). Limited cold storage facilities contribute to perishable food losses, especially in the fruit and vegetable sectors (Makule et al., 2022). Additionally, poor road networks and transportation systems result in delays and increased product deterioration during transit (Negi and Wood, 2022).

### 2.1.3. Market dynamics and value chain constraints

Complex market dynamics and fragmented value chains pose challenges to efficient post-harvest management. Small-scale farmers often face difficulties in accessing formal markets due to price volatility, lack of market information, and quality standards (Tomorri et al., 2022; Binge et al., 2023). Furthermore, power imbalances within value chains result in unequal distribution of benefits, with farmers bearing the brunt of post-harvest losses while downstream actors' profit from value-added activities (Mubaiwa, 2014). Strengthening market linkages, promoting collective action among stakeholders,

and enhancing farmers' bargaining power are essential for addressing these challenges (Ochieng et al., 2018). Limited market access and inefficient value chains exacerbate post-harvest challenges in Ghana. Smallholder farmers often face difficulties in accessing formal markets due to high transaction costs, lack of market information, and stringent quality standards (Kolavalli et al., 2020). Furthermore, fragmented value chains result in inefficiencies and reduced bargaining power for farmers (Dihel et al., 2018).



### 2.1.4. Policy and institutional frameworks

Effective policy and institutional support are critical for addressing post-harvest challenges and promoting sustainable food systems. However, policy frameworks often prioritize production over post-harvest activities, neglecting the need for comprehensive strategies to reduce losses and improve food quality (Magalhaes et al., 2021). Coordinated efforts among governments, research institutions, private sector actors, and civil society organizations are necessary to develop and implement policies that incentivize investments in post-harvest infrastructure, technology adoption, and market integration (Nyamulinda et al., 2011). Weak policy frameworks and institutional support further hinder effective post-harvest management in Ghana. There is a lack of coordinated efforts among government agencies, research institutions, and private sector stakeholders in addressing post-harvest challenges (Daum and Birner, (2017)). Moreover, existing policies often prioritize production over post-harvest activities, neglecting the crucial role of efficient handling and storage practices in enhancing food security and economic development (Sharma et al., 2021).

## 2.2 Quality Assurance

### 2.2.1. Post-harvest quality assurance

Post-harvest quality assurance is a critical aspect of agricultural production, particularly in the case of certified seeds. Certified seeds are crucial to ensure that reliable crop yields and quality foods are produced by farmers (Chauhan et al., 2016). However, the maintenance of seed quality during storage and distribution is a challenging task influenced by various factors such as storage conditions, packaging materials, and seed traceability (Olisa et al., 2022).

### 2.2.2. Effects of storage conditions on certified seeds

Storage conditions significantly impact the viability, vigour, and overall quality of certified seeds. Factors such as temperature, humidity, light exposure, and pest infestation can have detrimental effects on seed germination and longevity (Sudhakar et al., 2020). Optimal storage conditions involve maintaining a low temperature (typically between 5°C and 10°C) and low humidity (around 40-50%) to prevent moisture absorption and microbial growth, thereby preserving seed quality (Bakhtavar and Afzal, 2020). Proper ventilation and periodic monitoring of storage conditions are also essential to mitigate risks associated with fungal or bacterial infections (Masotti et al., 2019). The effects of storage conditions on certified seeds are multifaceted, encompassing various physiological, biochemical, and physical changes that can significantly impact seed quality and viability. Certified seeds, bred and produced to meet stringent quality standards, are susceptible to degradation when exposed to suboptimal storage conditions (Pagano et al., 2023; Corbineau, 2024). Temperature plays a crucial role in seed storage, with high temperatures accelerating seed deterioration and reducing viability. The optimal temperature range for seed storage typically falls between 10°C to 20°C, allowing seeds to maintain their germination

potential and vigour (Bakhtavar and Afzal, 2020). Humidity is another critical factor, as high humidity can lead to moisture absorption, causing seed degradation, mold growth, and insect infestations. Relative humidity should be maintained between 20% to 50% to prevent these adverse effects (Mohapatra et al., 2017; Chaudhary et al., 2025). Light exposure also affects seed quality during storage. Direct sunlight or high-intensity light can damage seeds, reducing germination rates and seedling vigour. Therefore, seeds should be stored in a dark or low-light environment to mitigate these effects. Pests and diseases can also compromise seed quality during storage. Insects, rodents, and fungal pathogens can damage seeds, reducing their viability and potentially introducing diseases into the seed stock. Effective pest management strategies and sanitation practices are essential to preventing these issues. Seed moisture content is another critical factor in seed storage. Seed moisture content (SMC) is the amount of water in a seed, expressed as the percentage of water contained in the seed relative to the total seed weight. It can be measured directly through the oven-drying method, described in the International Rules for Seed Testing (ISTA 2005. Seeds should be dried to a safe moisture level, typically between 8% to 12%, to prevent mold growth and insect infestations. Seeds with high moisture content are more susceptible to degradation and loss of viability. Suboptimal storage conditions can have far-reaching consequences for seed quality and viability. Reduced germination rates decreased seed vigour, and increased susceptibility to pests and diseases are all potential outcomes of poor storage conditions. Furthermore, prolonged exposure to suboptimal conditions can lead to genetic changes, potentially affecting seed performance and crop yields (Reed et al., 2022). To maintain the quality and viability of certified seeds, it is essential to store them in a cool, dry environment with controlled temperature and humidity. Airtight containers or bags can help maintain seed dryness and prevent moisture absorption.



Regular monitoring of stored seeds for signs of deterioration, pests, or diseases is also crucial, and seed stocks should be rotated regularly to ensure older seeds are used before they deteriorate.

### 2.2.3. Effects of packaging materials on certified seeds

Packaging materials play a crucial role in protecting certified seeds from physical damage, moisture, and environmental factors. The effects of packaging materials on certified seeds can be significant, impacting seed quality, viability, and longevity. The type of packaging material used can influence the storage environment, affecting factors such as moisture, temperature, and gas exchange. Studies have shown that appropriate packaging materials can enhance the longevity and quality of seeds during storage and transport (Bakhtavar and Afzal, 2020; Dadlani et al., 2023). Moisture-proof and durable packaging materials, such as laminated plastic bags or hermetic bags, are effective in preventing moisture ingress and maintaining seed viability (Toll, 1995). Additionally, specialized seed packaging technologies, such as modified atmosphere packaging (MAP), have shown promise in extending seed shelf life by controlling gas composition within the package (Bumbudsanpharoke and Ko, 2022). Packaging materials with low moisture permeability, such as foil pouches or airtight containers, can maintain a stable seed moisture content, reducing the risk of seed deterioration (Dadlani et al., 2023). In contrast, packaging materials with high moisture permeability, such as paper bags or breathable fabrics, may allow moisture to enter the package, potentially compromising seed quality (Bakhtavar et al., 2019). The oxygen transmission rate of packaging materials can also impact seed viability. Packaging materials with low oxygen transmission rates can reduce the rate of seed respiration, potentially prolonging seed longevity. Additionally, packaging materials that block or filter out light can reduce the risk of seed damage caused by exposure to direct sunlight

or high-intensity light (Groot et al., 2015). Some packaging materials, such as those with antimicrobial or insect-repellent properties, can provide additional protection against pests and diseases. The choice of packaging material should be carefully considered to ensure that it provides the necessary protection and storage conditions to maintain seed quality and viability.



### 2.2.4 Effects of seed traceability on certified seeds

Seed traceability refers to the ability to track and verify the origin and handling history of certified seeds. It plays a vital role in ensuring the integrity and quality of seed lots. Through traceability systems, it becomes possible to identify the seed source, production practices, and handling conditions, thus facilitating prompt recall and investigation in case of quality issues or contamination (Salah et al., 2019). Traceability also supports the establishment of trust among stakeholders and facilitates market access for certified seed producers (McEwan et al., 2021).

Improved post-harvest quality assurance for certified seeds requires careful consideration of storage conditions, packaging materials, and seed traceability. Maintaining optimal storage conditions, including temperature and humidity control, along with proper ventilation, helps preserve seed quality. The use of moisture-proof and durable packaging materials, such as laminated plastic bags or hermetic bags, prevents physical damage and moisture ingress. Furthermore, incorporating and implementing robust seed traceability systems utilizing technologies like barcodes, radio-frequency identification (RFID) tags, and blockchain enhances seed traceability by providing secured and transparent record keeping and accountability in the seed supply chain (Ellahi et al., 2023) By addressing these factors, stakeholders can work towards ensuring the availability of high-quality certified seeds and contributing to sustainable agriculture. Effective seed traceability systems enable the identification and

authentication of certified seeds, ensuring their quality, purity, and genetic integrity. By tracking seeds from production to distribution, traceability helps to prevent seed contamination, admixture, or substitution, which can compromise seed quality and performance (Kumar et al., 2023). Seed traceability also facilitates the implementation of quality control measures, such as seed testing and certification, and enables the rapid identification and recall of seeds in case of quality issues or regulatory non-compliance (Malabadi et al., 2025). Furthermore, traceability provides valuable information for seed breeding, research, and development, allowing breeders to track the performance of specific seed varieties and make informed decisions about future breeding programs. In addition, seed traceability can enhance transparency and trust in the seed supply chain, providing assurance to farmers, growers, and other stakeholders that certified seeds meet specific quality standards. By ensuring the authenticity and quality of certified seeds, traceability can contribute to improved crop yields, reduced seed-borne risks, and enhanced food security.

### 2.3 Soybean production and challenges

Despite the progress made in soybean production, Ghana still faces several challenges that hinder the sector's full potential. These challenges can be categorized into agronomic, market, and policy-related issues.

#### 2.3.1 Soybean production and challenges in Ghana

Soybean (*Glycine max*) is a legume crop that plays a significant role in global agriculture due to its nutritional value and versatile uses. In Ghana, soybean production has gained prominence 193,000 metric tons in 2020, a remarkable growth from 160,000 metric tons in 2015 (Asodina et al., 2021; Sedibe et al., 2023) as farmers recognize its potential for income generation and its contribution to food security. As of 2023, production was estimated at approximately 255,000 Metric Tonnes (MT), with a

forecast to reach 260,000 MT for the 2023/24 marketing year (TASAI 2022 Ghana Report). However, several challenges hinder the sustainable growth of soybean production in the country. This research aims to explore the current status of soybean production in Ghana and discuss the challenges faced by farmers in this sector.

### 2.3.2 Current status of soybean production in Ghana

Soybean production in Ghana has witnessed a steady increase in recent years, driven by growing demand for the crop both locally and internationally. According to statistics, soybean production in Ghana reached approximately 193,000 metric tons in 2020, a notable increase from 160,000 metric tons in 2015 (Asodina et al., 2021; Sedibe et al., 2023). This rise could be attributed to various factors, including government interventions, improved agronomic practices, and the availability of high-yielding soybean varieties.

Government interventions have played a pivotal role in promoting soybean production in Ghana. The Ministry of Food and Agriculture (MoFA) has implemented various programmes and initiatives to support soybean farmers. For instance, the Planting for Food and Jobs (PFJ) programme, launched in 2017, provided subsidized inputs such as improved seed varieties, fertilizers, and pesticides to farmers (Azumah, 2021; Pauw, 2022). These interventions helped increased soybean production by enabling farmers to adopt improved practices and technologies.

### 2.3.3 Storage pests and seedborne diseases

Storage pests and seedborne diseases, including fungi and insects cause significant losses in grain quality and viability during storage. Proper drying (<13% moisture), cleaning, sanitation, and hermetic storage are critical for control, while chemical, biological, and botanicals can be used.

Soybean is a vital crop globally, valued for its high protein content and versatility in food, feed, and industrial applications. However, the cultivation of soybean is often challenged by various pests and diseases, which can significantly impact yield and quality. Effective pest and disease management strategies are essential to mitigate these challenges and optimize soybean production. Inadequate knowledge and limited access to effective pest and disease control measures pose significant challenges to farmers, resulting in yield losses.

Pest management in soybean production is a critical aspect of maintaining crop health and maximizing yields. Soybeans are susceptible to a wide range of pests, including insects, diseases, and weeds, which can significantly impact crop productivity and quality. Pests such as aphids, pod borers, nematodes, and stink bugs pose significant threats to soybean crops, causing yield losses through feeding damage and transmission of diseases. Integrated Pest Management (IPM) practices, combining cultural, biological, and chemical control methods, have shown efficacy in reducing pest populations while minimizing environmental impact (Bansal et al., 2013). Promising advancements include the use of genetically modified (GM) soybean cultivars with enhanced resistance to specific pests, as well as the implementation of precision agriculture technologies for targeted pest control (Rahman et al., 2023). Weeds, such as Palmer amaranth and water hemp, can compete with soybeans for water, nutrients, and light, reducing yields and compromising crop quality. Effective weed management often involves a combination of cultural practices, such as row spacing and planting date, and chemical controls, such as herbicides (Monteiro and Santos, 2022). In addition to these strategies, soybean producers may also use precision agriculture techniques, such as precision planting and variable rate application, to optimize pest management and reduce the environmental impact of crop production.

Soybean is susceptible to a range of fungal, bacterial, and viral diseases, including soybean rust, stem rot, and bean pod mottle virus. Disease management strategies encompass cultural practices, such as crop rotation and sanitation, as well as the application of fungicides and biocontrol agents (Singh et al., 2020). Furthermore, the adoption of disease forecasting models facilitates timely interventions and reduces reliance on prophylactic treatments (Kamdi et al., 2020).



### 2.3.6 Integrated approaches to pest and disease management

Integrated pest and disease management strategies that synergistically combine preventive, cultural, and biological control measures offer a holistic approach to safeguarding soybean crops. Incorporating agroecological principles, such as enhancing biodiversity and soil health, can enhance the resilience of agroecosystems and reduce reliance on external inputs (Mahuku et al., 2017). Furthermore, stakeholder collaboration and knowledge sharing are vital for disseminating best practices and fostering sustainable agricultural practices among farmers.

### 2.3.8 Soil fertility assessment and management

A fundamental step in soil fertility management is the comprehensive assessment of soil properties and nutrient status. Soil testing techniques, including analysis of pH, organic matter content, and nutrient levels, provide valuable insights into soil health and nutrient availability (Bationo et al., 2018). This information forms the basis for tailored fertility management strategies, enabling farmers to address deficiencies and optimize nutrient balance for soybean growth and development.

Soybean has specific nutrient requirements at different growth stages, necessitating precise nutrient management strategies. Nitrogen (N), phosphorus (P), and potassium (K) are essential nutrients for soybean, with phosphorus being particularly critical for

root development and early growth (Drinkwater et al., 2017). Fertilization practices, including the application of organic amendments, synthetic fertilizers, and precision nutrient management techniques, play a pivotal role in meeting crop nutrient demands while minimizing environmental impacts (Wu and Ma, 2015).

Soybean's ability to form symbiotic relationships with nitrogen-fixing bacteria (*Rhizobium* spp.) presents a unique opportunity for biological nitrogen fixation (BNF) and sustainable soil fertility management (Sindhu et al., 2019). Effective inoculation of soybean seeds with compatible Rhizobium strains enhances BNF capacity, reducing the reliance on external nitrogen inputs and fostering soil health. Furthermore, crop rotations incorporating legumes promote soil fertility replenishment and break pest and disease cycles, contributing to sustainable soybean production systems (Janati et al., 2021).

Maintaining soil health and fostering beneficial microbial communities are integral to sustainable soil fertility management. Practices such as conservation tillage, cover cropping, and organic amendments promote soil structure, water retention, and nutrient cycling, enhancing the long-term productivity and resilience of soybean cropping systems (Farooq et al., 2020). Moreover, microbial inoculants and biofertilizers containing beneficial microorganisms augment nutrient availability and promote plant growth, offering environmentally friendly alternatives to conventional fertilization practices (Kour et al., 2020).

Despite the importance of soil fertility management in soybean production, challenges such as nutrient leaching, soil erosion, and nutrient imbalances persist (Hellal and Abdelhamid, 2013). Addressing these challenges requires interdisciplinary approaches that integrate agronomic, ecological, and socio-economic perspectives. The success of

soybean cultivation hinges significantly on soil fertility management practices. Therefore, maintaining soil fertility is crucial for sustainable soybean production. However, many soybean farmers in Ghana lack access to affordable and appropriate fertilizers, leading to poor soil fertility and suboptimal yields. Soil fertility management involves the strategic use of various practices and techniques to maintain and improve the fertility of soils, ensuring optimal crop production while minimizing environmental degradation (Shah and Wu, 2019). This encompasses a range of approaches, including the use of organic amendments, such as crop residues, manure, and compost, which enhance soil structure, increase nutrient content, and support beneficial microbial activity. Inorganic fertilizers can also play a role in soil fertility management, providing essential nutrients such as nitrogen, phosphorus, and potassium (Yahaya et al., 2023). However, their application should be judicious and based on soil testing to avoid over-fertilization, which can lead to environmental pollution and soil degradation. Crop rotation, intercropping, and cover cropping are additional strategies used in soil fertility management. These practices can help to improve soil physical properties, increase nutrient cycling, and reduce erosion. Leguminous crops, for example, can fix atmospheric nitrogen, reducing the need for synthetic fertilizers (Kakraliya et al., 2018). Soil pH management is also critical, as it affects nutrient availability and microbial activity. Regular soil testing and monitoring are essential components of effective soil fertility management, enabling farmers and land managers to make informed decisions about fertilizer applications, crop selection, and other management practices

### 2.5.2. Environmental conditions

Environmental factors play a significant role in seed storage, as they can influence seed germination, longevity, and overall quality. In Ghana, high temperature and humidity levels are common challenges. Seeds stored under such conditions are prone to reduced

viability, accelerated aging, and fungal or bacterial infections (Tutu, 2014). Temperature and relative humidity control are essential for maintaining seed quality during storage (Eliud et al., 2010). Proper ventilation and airflow are also critical to prevent the accumulation of moisture and heat, which can lead to seed deterioration (Sharma et al., 2023).



### 2.5.3. Seed quality

Seed quality could be viewed as a "standard of excellence in defined attributes that will determine the performance of the seed when sown or stored" (Hampton, 2002), This "standard of excellence" is defined by four key, interconnected attributes namely: Genetic Quality (the inherent potential of the variety for high yield, desirable grain quality, and tolerance to biotic/abiotic stresses), Physiological Quality (the potential for germination and vigor, which determines the speed and uniformity of seedling emergence and field establishment), Physical Quality (the cleanliness of the seed lot, including uniform size, weight, and freedom from contamination with weed seeds, inert matter, or mechanical damage) and Health Quality (the absence of infection or infestation by seed-borne pests, pathogens, fungi, bacteria, or viruses).

According to Rahman and Cho (2016), high-quality seeds are defined by several key attributes, such as True to Type (high genetic purity, ensuring the seeds produce plants that resemble the parent variety in all aspects), Free from Foreign Materials (cleanliness from inert matter (chaff, stones, dirt), weed seeds, and seeds of other crops), Free from Disease & Pest Infections (high health status, meaning the absence of pathogens (fungi, bacteria, viruses) and pest infestation (insects)), Acceptable Germination Percentage (high viability, ensuring a high ability to germinate and produce normal seedlings under favorable conditions), Vigour, (high physiological strength, enabling seeds to

germinate quickly and uniformly, establish a healthy stand, and survive under stressful field conditions), Appearance **(**uniformity in size, weight, and color, which indicates maturity and proper handling).

Based on the Plants and Fertilizer Act, 2010 (Act 803) and international standards, seeds and planting materials must be subjected to specific quality control mechanisms, namely Seed Certification or the Quality Declared Seed (QDS) system

The choice of quality seeds is the prerequisite for both high yield and good quality crops for both domestic and international markets (Thapa., 2024)

The quality of seeds stored in Ghana is another crucial factor affecting their storage. Seed quality refers to the genetic and physical characteristics of seeds, including purity, germination capacity, and freedom from diseases and pests (Sendeki, 2020). Low-quality seeds are more susceptible to damage during storage, reducing their viability and vigour. Proper seed selection, processing, and testing are necessary to ensure high-quality seeds before storage (Frischie et al., 2020). Seeds should be free from contaminants, diseases, and pests to maintain their quality and long-term viability during storage.



### 2.5.4. Pest and disease management

Pests and diseases pose significant threats to seed storage in Ghana. Insects, rodents, and microorganisms can damage stored seeds, leading to reduced quality and germination rates. Integrated pest management strategies, such as fumigation, hermetic storage, and the use of natural repellents, are employed to prevent infestations and control pests during storage (Sugri et al., 2013). Regular monitoring and preventive measures are crucial to minimize the risk of pest and disease outbreaks.

### 2.5.5. Storage facilities

The availability and quality of storage facilities are vital factors in ensuring successful seed storage in Ghana. Inadequate storage infrastructure, such as poorly constructed warehouses and lack of proper shelving and containers, can result in suboptimal conditions for seed preservation (Mutungi et al., 2012). Properly designed and well-maintained storage facilities, including temperature and humidity control mechanisms, are necessary to create favourable storage conditions and minimize seed deterioration (Zhang et al., 2021).

## 2.6. Seed viability under extreme and cold environments

Seed viability, defined as the ability of a seed to germinate and produce a normal seedling, is a crucial factor in plant propagation and conservation. Seeds are subjected to various environmental conditions during storage or natural dispersal, including extreme and cold environments. Understanding the effects of these conditions on seed viability is essential for successful seed preservation, crop production, and ecological restoration efforts (De et al., 2020).

### 2.6.1. Extreme environments conditions

Extreme environments, such as deserts, high altitudes, or arctic regions, are characterized by harsh climatic conditions, including high temperatures, limited water availability, and intense solar radiation (Kappen, 1973). These conditions can significantly affect seed viability. High temperatures can cause accelerated seed aging, leading to a decrease in germination rates and vigour (Adetunji et al., 2021). Water scarcity can also lead to seed dormancy or death, as seeds rely on proper hydration for metabolic activities (Ali and Elozeiri, 2017). Furthermore, solar radiation can induce DNA damage and affect cellular processes within seeds, further compromising their viability (Araujo et al., 2016).

Cold environments, such as polar regions or high-altitude areas, subject seeds to prolonged exposure to low temperatures. Cold stress can have both positive and negative effects on seed viability, depending on the species and their adaptive mechanisms. Some seeds are adapted to cold environments and require a period of cold stratification, a process that breaks seed dormancy and enhances subsequent germination (Klupczyńska and Pawłowski, 2021). However, prolonged exposure to extremely low temperatures can cause cellular damage, ice crystal formation, and membrane disruption, leading to decreased seed viability (Zahra et al., 2021).

### 2.6.3. Seed adaptations

Seeds have developed various adaptations to survive extreme and cold environments. These adaptations include specialized seed coats that provide protection against desiccation, mechanical damage, and temperature extremes (Perry and Moens, 2011). Some seeds produce protective compounds, such as antioxidants and cryoprotectants, which help mitigate the effects of extreme temperatures and oxidative stress (Bhandari and Nayyar, 2013). Additionally, certain seeds have the ability to enter a state of dormancy, which allows them to delay germination until favourable conditions occur (Kildisheva et al., 2020). These adaptations contribute to seed longevity and enhance viability under extreme and cold environments.

## 2.7 The effect of oil content on seed quality and germination

### 2.7.1 Effects of oil content on germination

Seed quality and germination are crucial factors in agricultural practices and crop production. Oil content is an important attribute of seeds, as it affects both the nutritional value and the germination potential. Numerous studies have investigated the impact of oil content on seed germination. For instance, a study by Sadeghi et al. (2011) examined the effect of oil content on germination rates in soybean seeds. The

researchers found that seeds with higher oil content exhibited delayed germination and reduced germination percentages compared to seeds with lower oil content. This observation suggests that high oil content can hinder the germination process in certain plant species.

Furthermore, the study conducted by Balešević-Tubi et al. (2010) explored the relationship between oil content and seed viability in sunflower seeds. The researchers discovered that seeds with lower oil content displayed higher germination rates and enhanced seedling vigour compared to seeds with higher oil content. This finding indicates that excessive oil content in seeds can impede the germination process, leading to reduced seedling establishment and overall crop productivity.

In contrast, other studies have reported varying results concerning the effect of oil content on germination. For example, a study by Afsahi et al. (2020) investigated the influence of oil content on germination rates in canola seeds. The researchers observed no significant difference in germination percentages between seeds with high and low oil content. However, they noted that the oil content influenced the time taken for germination to occur, with higher oil content causing delayed germination.

In addition to germination, oil content can also impact seed quality attributes. The study conducted by Gu et al. (2019) focused on rape seed and investigated the effects of oil content on seed vigour. The researchers found that seeds with higher oil content exhibited reduced vigour, as indicated by lower seedling growth, increased abnormal seedlings, and decreased shoot and root biomass. These findings suggest that excessive oil content negatively affects seed quality by impairing seedling development and overall plant performance.

Furthermore, a study by Konsoula and Liakopoulou-Kyriakides (2010) examined the impact of oil content on seed storage potential in sesame seeds. The researchers discovered that seeds with higher oil content had a shorter shelf life and were more susceptible to oxidative degradation during storage. Higher oil content in soybeans can lead to a shorter shelf life due to the potential for lipid oxidation and rancidity (Indiarto and Qonit, 2020). This process can damage cellular components, including cell membranes and DNA, ultimately disrupting cellular homeostasis and leading to cell death. As a result, soybeans with higher oil content may experience rapid loss of viability due to the degradation of essential cellular components and the inactivation of enzymes necessary for germination and seedling growth (Shelar et al., 2008). This finding emphasizes the importance of considering oil content in seeds to ensure their long-term viability and maintain seed quality during storage.

Overall, the available literature suggests that oil content significantly influences seed quality and germination. Higher oil content in seeds generally leads to reduced germination rates, delayed germination, decreased seedling vigour, and diminished storage potential. However, it is important to note that the specific effects of oil content can vary among different plant species.

### 2.7.2 Lipid content: oil crops including soybean, are rich in lipids

Lipid content significantly influences the shelf life of these crops, as lipids are susceptible to oxidative deterioration. Lipid oxidation can lead to off-flavours, rancidity, and loss of nutritional value. Factors such as processing methods and storage conditions can affect the rate of lipid oxidation, thereby impacting the shelf life of soybean and oil crops (Prabakaran et al., 2018).

## 2.8 Intrinsic factors affecting shelf life of seeds

The shelf life of soybean and oil crops is important for their commercial viability and nutritional value preservation. Extending the shelf life of these crops ensures their availability, minimizes post-harvest losses, and maintains product quality for consumers. Intrinsic factors play a significant role in determining the shelf life of seeds, including soybeans. One crucial factor is the seed's moisture content, as high moisture levels can lead to increased metabolic activity, promoting seed deterioration (Zhang et al., 2021). The seed's chemical composition, such as oil content and fatty acid profile, also influences its shelf life, with seeds high in polyunsaturated fatty acids being more prone to oxidation and rancidity. Additionally, the seed's genetic makeup and inherent biochemical processes can affect its longevity (Long et al., 2015). For instance, seeds with higher levels of antioxidants and other protective compounds may exhibit greater resistance to degradation. The seed's physical characteristics, such as seed coat integrity and permeability, can also impact its shelf life by regulating water uptake and gas exchange (Radchuk and Borisjuk, 2014). These intrinsic factors interact with environmental conditions, such as temperature, humidity, and light, to determine the overall shelf life of seeds. Understanding these factors is essential for developing effective strategies to maintain seed viability and quality over time.

### 2.8.1. Effects of moisture content on seed quality

Moisture content is a critical parameter affecting the shelf life of soybean and oil crops. High moisture content can lead to microbial growth, enzymatic reactions, and lipid oxidation, accelerating spoilage. Conversely, low moisture content can result in undesirable changes in texture and flavour. Controlling and maintaining optimal moisture levels during storage is essential for preserving the quality of soybean and oil crops (de Sousa et al., 2020).

## 2.9 Extrinsic factors affecting shelf life

### 2.9.1. Effects of Temperature on seed quality

Temperature is a critical environmental factor affecting the shelf life of soybean and oil crops. High temperatures can accelerate enzymatic reactions and microbial growth, leading to quality deterioration. Conversely, low temperatures can slow down these reactions and extend the shelf life. Storage at temperatures below 15°C is generally recommended for maintaining the quality of soybean and oil crops (Bisbis et al., 2018). The length of storage and the temperature can influence moisture content, germination rate, and biochemical composition of the seeds. Maintaining a controlled temperature and minimizing storage duration are key to preserving the quality of the seed (Haki and Hakki, 2025).

Seeds with low viability and vigour when stored using room temperature will experience a rapid decline in seed quality. Sandra, (2005), reported that seeds stored at room temperature will reduce the viability rapidly. Nasreen et al. (2000) and Schmidt (2002), both suggested that inappropriate storage facility such as storage under room temperature often results in low seed germination, seed deterioration, and the decline of viability during seed storage. Prolonged period of storage (18 months), purple maize indicated very low germination of 42% and seed growth rate of 19.42%. Engels et al. (2003) and Rao et al. (2006) noted that seeds storage periods could be prolonged, depending on the quality of the initial seed, moisture content, and temperature conditioned for long-term storage. Rahmawati and Muhammad Aqil (2020) reported that, low temperatures can extend the life time use of maize seeds, while high temperatures increase respiration and fastens changes in food reserves in the seeds that have an impact on the decrease in viability and vigour of the seeds. Low temperature

and air humidity will limit the increase of seed moisture content and the rate of respiration of the seeds during the storage period.

### 2.9.2. Effect of gases on seed quality

#### 2.9.2.1 Oxygen exposure

Exposure to oxygen can promote lipid oxidation and negatively impact the shelf life of soybean and oil crops. Oxidative reactions can lead to the development of off-flavours, loss of nutritional value, and decreased product stability. The use of oxygen barrier packaging materials, such as vacuum-sealed or modified atmosphere packaging, can minimize oxygen exposure and enhance the shelf life of soybean and oil crops (Nilsen-Nygaard et al., 2021). Groot et al. (2012) reported that the aging of dry seeds was accelerated by storing under high pressure oxygen.

#### 2.9.2.2 Carbon dioxide effects on seed quality

Carbon dioxide ($CO_2$) flushing in seed storage acts as a protective, modified atmosphere that enhances longevity. This is achieved by replacing oxygen ($O_2$) and by effect, reducing seed respiration, maintaining dormancy, and inhibiting pest activity. High concentrations of (10-40%) prevent insect damage while maintaining high seed viability and vigour, making it an effective, non-toxic alternative to traditional fumigants (Bera et al., 2024).

Similar treatments also checked the seed damage (2.36 per cent) and weight loss (1.97 per cent) up to six months of storage (Raghupathi et al, 2021). Seeds in different $CO_2$ concentrations (10, 20, 30 and 40 percent) maintained the seed quality (viability of seed) without any detrimental effect on germination (maintained above 90 per cent), seedling vigour and moisture content (8.63 percent) up to six months of storage (Raghupathi et al, 2021). Storage of maize seeds in the $CO_2$ rich atmosphere (60 and 80 percent) also maintained seed quality (viability of seed) without any detrimental

effect on germination (maintained above 90 percent), seedling vigour and moisture content (12 percent) up to six months of storage (Mada et al., 2018). Hampton et al., (2012) reported that $CO_2$ on seed storage educed respiration by replacing $O_2$ with $CO_2$. The process slows the metabolic rate of seeds, preventing premature germination and maintaining dormancy. Again, $CO_2$ - rich environments are effective in killing insect pests that require $O_2$ to survive, reducing seed damage from 14.57% (untreated) to below 2.4% in 6 months. Furthermore, studies show that $CO_2$ storage (e.g., 5-10% concentrations) keeps seeds in a stable, dormant state without adverse effects on germination potential. More so, $CO_2$ prevents damage caused by oxidation, further extending the shelf-life of the stored seeds and finally, unlike chemical pesticides, $CO_2$ flushing does not typically reduce the germination or vigour of the seeds, such as wheat or maize. While $CO_2$ is highly effective, it is important to note that very high concentrations of $CO_2$ combined with environmental stress, such as high temperature, can sometimes affect seed



### 2.9.3. Processing techniques

The extraction method used for obtaining oil from soybean and other oil crops can influence the shelf life of the extracted oil. Cold-pressed or solvent-free extraction methods are preferred over traditional solvent extraction, as they help preserve the natural antioxidants and minimize the chances of lipid oxidation. These methods contribute to a longer shelf life and improved quality of the extracted oil (Cakaloglu et al., 2018).

### 2.9.4. Refining processes

Refining processes, such as degumming, neutralization, bleaching, and deodorization, are commonly employed to enhance the stability and shelf life of edible oils. These processes remove impurities, oxidative components, and undesirable flavours, ensuring

a longer shelf life and improved sensory quality of soybean and oil crops (Lokuruka, 2011; Machado et al., 2023). Neutralization, also known as alkali refining, follows, where free fatty acids are removed through reaction with an alkaline substance, resulting in the formation of soap stock (Dijkstra and Dijkstra, 2013). This process not only improves the oil's flavour and odour but also reduces its acidity. Bleaching, the next step, utilizes adsorbents such as activated clay or carbon to remove pigments, residual soap, and other impurities that can impact oil colour and stability. Deodorization, a high-temperature vacuum process, eliminates volatile compounds responsible for undesirable flavours and odours. By removing these impurities and oxidative components, refining processes significantly enhance the oil's shelf life, flavour, and overall quality, making it more suitable for consumption and various industrial applications (Zio et al., 2020).



### 2.10.1. Seed packaging methods

Packaging plays a crucial role in preserving the quality, viability, and longevity of seeds. Proper packaging ensures protection against moisture, light, temperature fluctuations, mechanical damage, and microbial contamination.

### 2.10.2. Paper bags

Paper packets are widely used for seed packaging due to their low cost, ease of printing, and breathability. These bags are typically made of lightweight, porous paper that allows air exchange while protecting seeds from excessive moisture. They are often designed with moisture barriers or laminates to enhance seed preservation (Walters, 2007; Stejskal et al., 2021). Additionally, paper packets can be easily labelled with essential information such as seed variety, lot number, and expiration date.

### 2.10.3. Foil packets

Foil packets offer superior moisture and light barrier properties, making them ideal for storing sensitive seeds. Foil acts as a barrier against moisture, preventing seed deterioration caused by excessive humidity. The opaque nature of foil also protects seeds from light, which can induce premature germination or seed aging (Restrepo-Osorio et al., 2019). Foil packets are commonly used for long-term storage or for seeds that require specific environmental conditions.

### 2.10.4. Vacuum sealing

Vacuum sealing involves removing air from the packaging to create an oxygen-free environment. This method is particularly useful for seeds prone to oxidation, as it reduces the presence of oxygen, which can accelerate seed aging and reduce viability (Kurek et al., 2019). Vacuum-sealed bags or pouches are often made of durable materials such as nylon or polyethylene to prevent air leakage and maintain a low-oxygen environment.

### 2.10.5. Pelletized seeds

Pelletization is a technique where seeds are coated with an inert material, such as clay or vermiculite, to form uniform-sized pellets. These pellets are easier to handle, sow, and package compared to individual seeds. Pelletization enhances precision sowing, reduces seed wastage, and improves seed distribution (Reddy and Reddy, 2016.). The pellets can be packaged in various containers, including plastic bottles or bags.

## 2.11 Importance of effective seed packaging

### 2.11.1. Preservation of viability

Proper seed packaging protects seeds from external factors that can negatively impact their viability. Factors such as moisture, light, temperature, and mechanical damage can

lead to premature germination, reduced germination rates, or complete loss of viability (Bhattacharya, 2022). By creating an optimal storage environment, packaging ensures seed longevity and helps maintain high germination rates.

### 2.11.2. Maintaining seed quality

Seeds are living organisms that require specific conditions for optimal storage. Packaging materials and methods that control moisture levels, prevent mould growth, and protect against physical damage help maintain seed quality (Mohapatra et al., 2017). High-quality seeds are crucial for successful crop production, ensuring uniform germination and healthy plant growth.

### 2.11.3. Information and traceability

Seed packaging provides a platform for essential information such as seed variety, lot number, origin, and expiration date (Hu et al., 2013). This information enables traceability and facilitates quality control throughout the seed supply chain. Farmers, researchers, and seed companies rely on accurate labelling to make informed decisions regarding seed selection, planting, and purchasing. Effective packaging of seeds is vital for preserving their viability and quality. Various packaging methods, such as paper packets, foil packets, vacuum sealing, and pelletization, offer different benefits depending on the specific needs of the seeds. Proper packaging ensures protection against moisture, light, temperature fluctuations, mechanical damage, and microbial contamination.

## 2.12 Seeds and classes of seeds

Seeds are the product of ripened ovule, after the embryo sac is fertilized by sperm from pollen, forming a zygote. The embryo within a seed develops from the zygote and grows within the mother plant to a certain size before

growth is halted (Willan, 1987). According to (Erfatpour, et al., 2024), plant seed is a mature, fertilized ovule that is the reproductive unit of seed plants. It has an embryo, reserve nutrients, and a protective seed coat to ensure plant species survival and dispersal. The National Seed Policy of Ghana description of a Seed, as recognized in the context of agricultural policy as "a unit of plant propagation which forms the basic unit of life and carries heritable and genetic information from one generation to another". Seed according to the Plant Genetic Resources (PGRs) are defined as material of plant origin that contains functional units of heredity and possesses actual or potential value for food, agriculture, or research (Kotey, 2021). In summary, seed could be defined as source and continuity of life.



### 2.12.1. Monocotyledonous seeds

Seeds are reproductive structures produced by plants, serving as a means of propagation and dispersal. They contain an embryo, which develops into a new plant under suitable conditions. Seeds come in various shapes, sizes, and structures, and they play a crucial role in the life cycle of plants. Monocotyledonous seeds, also known as monocot seeds, belong to the class Monocotyledonae within the angiosperms (flowering plants) group. These seeds possess a single embryonic leaf, known as the cotyledon, which stores nutrients for the developing plant. Examples of monocot seeds include corn (*Zea mays*), wheat (*Triticum aestivum*), and rice (*Oryza sativa*) (Harada, 2001). Monocot seeds typically have a single furrow or slit called the hilum, from where the embryo emerges upon germination (Dahlgren et al., 2012).

### 2.12.2. Dicotyledonous seeds

Dicotyledonous seeds, or dicot seeds, belong to the class Dicotyledonae, another major group of angiosperms (Dahlgren, 1991). They have two embryonic leaves, or cotyledons, that provide nourishment to the developing plant. Dicot seeds exhibit a

wide range of morphological features and adaptations. Examples of dicot seeds include beans (*Phaseolus vulgaris),* Soybean (*Glycine max* L.) sunflowers (*Helianthus annuus),* and peas (*Pisum sativum*) (Sliwinska, Bewley, 2014). Dicot seeds typically have a distinct hilum, which is the point of attachment for the seed to the fruit or ovary (Dahlgren et al., 2012).



### 2.12.3. Gymnosperm seeds

Gymnosperms are a group of seed-producing plants that do not produce flowers. Their seeds are not enclosed within a protective ovary but are usually borne on the surface of specialized structures like cones (McLoughlin and Prevec, 2021). Gymnosperm seeds are classified into four main types based on their structure and development: Cycad seeds, Ginkgo seeds, Conifer seeds, and Gnetophyte seeds (McLoughlin and Prevec, 2021).

### 2.12.4. Seed technology classification

To ensure genetic purity, high yield, uniformity, seed technologists have classified sees into Breeder, foundation, certified and Farmer declared quality seeds which play a crucial role in ensuring sustainable agriculture and the production of high-quality crops. (Plants and Fertilizer Act, 2010)

#### 2.12.4.1 Breeder seeds

Breeder seeds are the initial stage of seed production and are developed by plant breeders or researchers. These seeds are typically produced through controlled crosses between different plant varieties or through other breeding techniques to incorporate desirable traits. Breeder seeds are primarily used for further seed multiplication and development. They are characterized by their genetic purity, high vigour, and distinct traits.

Breeder seeds are produced and controlled under strict regulations to maintain genetic purity and ensure the development of superior plant varieties (Afzal et al., 2019). These seeds undergo rigorous testing, evaluation, and selection processes to ensure their quality and suitability for subsequent stages of seed production.

### 2.12.4.2. Foundation seeds

Foundation seeds are the progeny of breeder seeds and are produced under controlled conditions to maintain genetic integrity and quality. These seeds serve as the basis for large-scale seed production and supply. Foundation seed production involves careful monitoring, field inspections, and adherence to specific guidelines and regulations. Foundation seeds are expected to exhibit genetic purity, uniformity, and high quality. They are produced in limited quantities and are distributed to certified seed producers or multiplicators for further multiplication and distribution to farmers. The International Seed Testing Association (ISTA) establishes guidelines and standards for foundation seed production to maintain consistency and quality (Pedrini and Dixon, 2020).

### 2.12.4.3. Certified seeds

Certified seeds are the final stage of the seed production chain and are made available to farmers for cultivation. These seeds are derived from foundation seeds through regulated multiplication and quality control processes. Certified seeds are characterized by their genetic purity, uniformity, and reliability in terms of yield potential and resistance to pests and diseases. Certification agencies, such as national seed associations or government authorities, are responsible for inspecting and certifying seed lots to ensure compliance with established standards. Certification involves field inspections, laboratory testing, and seed quality assessments (Misra et al., 2023). Certified seeds provide farmers with assurance regarding the quality and performance

of the seeds they purchase, which contributes to increased crop productivity and profitability.

#### 2.12.3.4 Farmer declared quality seed

In challenging situations such as prolonged draught, rains, severe bush fire and general bad weather situations where certified seed production falls below demand, GSID may fall of recognized commercial farmers who produced grains from known certified seeds for testing and acceptance for use as planting materials provided the test results meet minimum standards. Such seeds are referred to as farmer declared quality seeds.

### 2.13. Effect of storage duration and storage rooms on seed and nutritional qualities of soybean

The storage duration and conditions of storage rooms significantly impact the quality and nutritional value of soybean. Prolonged storage can lead to a decline in seed viability, vigour, and overall quality (Gebeyehu, 2020). Environmental factors such as temperature, humidity, and light exposure play a crucial role in soybean storage. High temperatures and humidity levels can accelerate lipid oxidation, leading to the formation of off-flavours, rancidity, and a decrease in nutritional value (Mbofung et al., 2013). Soybeans stored in environments with controlled temperature (typically between 10-20°C) and humidity (below 60%) can maintain their quality and nutritional content, including protein, oil, and isoflavones. Proper storage conditions can help preserve the nutritional value of soybeans, including their high protein content, polyunsaturated fatty acids, and isoflavones (Prabakaran et al., 2018). Storage rooms should be designed to minimize exposure to oxygen, moisture, and pests, which can compromise soybean quality. Effective storage strategies can help maintain the quality and nutritional value of soybeans, supporting their use in food products and animal feed.

# CHAPTER THREE

## 3.0 MATERIALS AND METHODS

### 3.1 Experiment 1: Effect of seed source, variety and storage duration on seed viability (germination linked parameters)

#### 3.1.1 Genetic material

Three soybean varieties 'Jenguma', 'Afayak', and 'Favour' (Table 3.1), were sourced from accredited soybean seed growers based in Upper West (UWR), Upper East (UER), and Northern (NR) regions of Ghana. At the same time, foundation seeds of the three soybean varieties were sourced from the Council for Scientific and Industrial Research (CSIR) - Savannah Agricultural Research Institute (SARI) and used as control. All the soybean seeds were certified by Ghana Seed Inspection Division (GSID) of the Plant Protection and Regulatory Services Directorate (PPRSD) of the Ministry of Food and Agriculture (MoFA), Ghana. 15kg (submitted sample) each of certified Soybean variety ('Jenguma', 'Afayak' and 'Favour') Sources: *ANTIKA SEED CO. LTD, Wa, Upper West Region, HERITAGE SEEDS CO. LTD., Tamale, Northern Region, and IWAD GHANA LTD., Yagaba, North-East* Region for experiment 1. Working sample of each variety (6kg)

Foundation seeds - 15kg (submitted sample) each of 'Jenguma', 'Afayak' and 'Favour' obtained from Savannah Agricultural Research Institute (SARI) (control for experiment 1). Working sample of each variety (6kg)

45Kg (submitted sample) of 'Favour' sourced from Antika Seed Company Ltd for experiment 2. Working sample (25kg)

15kg (submitted sample) each of certified varieties of 'Jenguma', 'Afayak' and 'Favour' obtained from Antika Seed Company Ltd *for experiment 3.* Working sample of each variety (6kg).

All specimen (harvested in January) were obtained by close of March, 2022 cropping season (Exp. 1) and 2023 cropping season (Exp. 2 & 3), assembled in Tamale for re-packaging, labelling and necessary documentations before the commencement of sampling

Further information on the varieties used in this study are presented in Table 3.1.



Table 3.1: Details of soybean varieties used for the study.

| S/N | Variety | Source | Key traits | Year of release/ Year of registry |
|---|---|---|---|---|
| 1 | 'Afayak' | CSIR-SARI/ IITA | Days to 50% flowering: 40-45; Days to maturity: 110-115; over 98% seed germination, yield potential: 2.0-2.4 t/ha; resistance to pod shattering: resistant up to 8%; Haulm yield:1100-1400 kg/ ha; Excellent seed quality; Good seed storability; High and stable yield across many environments; Above average tolerance to common soybean pests and diseases; Excellent trap-crop for *Striga hermonthica*; Protein content: 38%, Oil content: 18%; Carbohydrate content: 36%. | 2012/ 2015 |
| 2 | 'Favour' | CSIR-SARI/ IITA | Days to 50% flowering: 45-48; Days to maturity: 115-118; Yield potential: 2.0 -3.5 t/ha; Resistance to pod shattering: Resistant (up to 5% shattering); Excellent seed quality for soymilk; High and stable yield across many environments; Fairly tolerant to common soybean pests and diseases; Fixes up to 100 kg/ha of biological N with artificial inoculants; High leaf output to smoulder weeds and increase organic matter of soil; Contains up 43% protein; 18 % oil content; Carbohydrate: 39.9% | 2019/ 2019 |
| 3 | 'Jenguma' | CSIR-SARI/ IITA | Days to 50% flowering: 45-48; Days to maturity: 110-115; Yield potential: 2.5-2.8 t/ ha; Haulm yield: 1500-3000 kg/ha; Resistance to pod shattering: resistant; up to 3% shattering; Excellent seed quality; High and stable yield across many environments; tolerant to common soybean pests and diseases; relatively tolerant to low soil P; trap-crop for *Striga hermonthica*; Protein content: 38%, Oil content: 14%; Carbohydrate content: 37% | 2003/ 2015 |

Source: (Ministry of Food and Agriculture, 2019)

### 3.1.2 Experimental design and setup

A 4 × 3 × 3 factorial treatment arranged in split-split plot design with three replications was used for the experiment. The main plot was the seed source (Antika, Heritage, IWAD, SARI). The sub-plot consisted of varieties ('Jenguma', 'Afayak', 'Favour'), and the sub-sub plot), with two levels of storage (0 month, 5 and 10 months after storage). All seeds were placed in PPRSD approved and coded bags and placed on wooden pallets in the various storage rooms.



### 3.1.3 Seed storage

Polypropylene bags, approved for storing seeds were obtained from the Ghana Seed Inspection Division (GSID)-PPRSD. Soybean seeds were kept in polypropylene bags (55x100 cm to 60x100 cm) for 10 months under zinc-roofed room with ambient air temperature ($25.78^0$C – $41^0$C) and relative humidity (22.15% – 92.88%). The storage room's air temperature and relative humidity were daily monitored using a digital thermo-hygrometer (Temtop TemLog ST5). Each polypropylene bag contained approximately 15 kg of seeds (submitted sample) making it an experimental unit. Each unit was placed in rows on wooden pallets without overlapping. Stored seeds were randomized every 21 days to rearrange the position of the stored seeds.

### 3.1.4 Seed sampling

At each sampling point (0 month, 5 months and 10 months), the contents in the bags were poured out and manually mixed thoroughly before smaller samples were randomly drawn from several sections of mixed seeds to a weight of 2 kg. The sampled seeds were then divided into 1 kg each kept in plastic zip-lock bags. Each sampled bag was coded with 3-dig figure, one for seed proximate analysis (SARI Food science lab.) and the other for physical tests (PPRSD Lab). The remaining samples were sealed and

returned to the storage room and the sampling procedure described above was repeated at the selected month until the end of the study.

### 3.2 Experiment 2: Effect of storage room and storage duration on seed quality and proximate profile 'Favour' certified seeds

#### 3.2.1 Sources of soybean seeds used as test materials

Certified seeds of the soybean var. 'Favour' was obtained from Antika Seed Company Ltd; Wa was use in this study based on its best performance recorded in experiment 1. The variety is identified for it high protein and early maturity traits among other varieties as previously reported (Ministry of Food and Agriculture, 2019). A total of 15 kg seeds (submitted sample) of soybean was sourced but 6 kg working sample was used for the experiment.

#### 3.2.2 Experimental design and setup

A 5 × 3 factorial treatments arranged in split-plot experimental design replicated three times was used in the study. The main plot was the storage room condition (cold room, AC room, warehouse, thatch house and zinc roofed room) and the sub-plot was storage duration with three levels (0, 5 and 10 months after storage). All the seeds were measured on the selected indices the initial sample collection (zero month) before being packaged in PPRSD approved and coded bags, placed on wooden pallets in the five different storage rooms located in Tamale, Northern region.

#### 3.2.3 Description of storage rooms

In the study, five different storage conditions commonly used in Ghana to store seeds were investigated. The air-conditioning test room consisted of a room with fitted air-condition set at a constant temperature of 18$^{o}$C for 6 hours (12 noon to 5 pm) daily. The cold room ($5^{0}$C-$8^{0}$C) consisted of thermally insulated walls made of polyurethane

sandwich panels with a thickness of 0.10 m, and dimensions of 5 × 3 × 3 m for the length, width and height, respectively. In addition to these rooms, seed were also stored under zinc roofed conditions, thatch room and warehouse without any temperature and humidity adjustment. This was to provide a routine storage condition for smallholder farmers. The thatch room was built with mud to a height of 5 m and thatch roofed.



### 3.2.4 Sampling for test

At each sampling point (0 month, 5 months and 10 months), the contents in the bags were poured out and manually mixed thoroughly before smaller samples were randomly drawn from several sections of mixed seeds to a weight of 2 kg. The sampled seeds were then divided into 1 kg each kept in plastic zip-lock bags. Each sampled bag was coded with 3-dig figure, one for seed proximate analysis (SARI Food science lab.) and the other for physical tests (PPRSD Lab). The remaining samples were sealed and returned to the storage room and the sampling procedure described above was repeated at the selected month until the end of the study.

## 3.3 Experiment 3: Effect of variety, seed storage bag and storage duration on seed viability and proximate composition

### 3.3.1 Experimental design

A 3 × 7 × 3 factorial treatments arranged in split-split plot design with three replications was used for the experiment. The main plot treatments were the varieties, (‘Jenguma’, ‘Afayak’, and ‘Favour’). The sub-plot consisted of seven storage bags (Table 10) and the sub-sub-sub plots were assigned the storage duration at three levels (0, 5 and 10 months after storage).

### 3.3.2 Soybean variety and seed source

The soybeans varieties ('Favour', 'Afayak' and 'Jenguma') were all collected from Antika Seed Company (Upper West Region) based on the results of experiment 1.

### 3.3.3 Description of storage bags

Seven seed storage bags commonly used by seed producers and farmers in Ghana were selected to test our hypothesis (Table 3.2).

Table 3.2: Description of storage bags

| Storage bag | Description |
|---|---|
| Ghana Seed Inspection Division (GSID) branded polypropylene (PP) bags) | These are official storage/packaging materials produced and distributed by GSID and are used by registered seed producers for packaging of seed for distribution in Ghana.<br><br>The design allows limited air circulation which can keep seeds from atmospheric humidity/moisture absorption and entry of insects |
| GSID Plastic bags | These are mostly packaging materials not originally meant for storage but for seed distribution for sales in smaller units to smallholder farmers. However, they are abused by companies in storing mostly carry over seeds that were packaged but not sold within the season.<br><br>Some pack them directly in the warehouse, while others re-pack them into polypropylene or jute bags before storing for the next season. |
| Paper bags | These are made from bio-degradable paper materials designed for packaging seed both for storage and distribution. These are common in the East African countries, where the use of polythene is completely banned officially. In Ghana, it has been piloted for use in seed storage and distribution. Despite the fact that the paper is environmentally friendly, it has the potential of absorbing moisture if care is not taken |
| Jute bags | Jute sack are strong, biodegradable bag made from the fibres of the jute plant. They are common in our |

| | |
|---|---|
| | open markets and easily obtained by seed producers during harvesting seasons for storing, especially large quantities of seeds. |
| Jute bags lined with plastic | In Ghana, jute sacks are frequently modified by plastic lining to provide hermetic condition for seed storage. This is an improved technology from the seed companies to prevent contents from absorbing atmospheric humidity or accidental moisture that may enter the storage facility. This also prevents entry by insects and causes those already in to suffocate and die. |
| Polypropylene bags | PP bags in Ghana PP woven bags are moisture-resistant and are used by seed companies to store seeds. |
| Polypropylene lined with plastic | Some seed companies reinforced the permeability by lining the inside with plastic sheets. |



### 3.3.4 Storage duration and conditions

A total of 45 kg (15 kg per replicate) was kept in the various storage bags and stored for 10 months in a storage room.

Sampling for test: As in 3.2.4 above.

## 3.3 Data Measurement

### 3.4.1 Normal and abnormal seeds

A working sample of 100 seeds was taken from each replicate, and normal and abnormal seeds were counted. The percentage of normal seeds was calculated using the equation:

$$\text{Normal (\%)} = \frac{Number\ of\ normal\ seeds}{Total\ number\ of\ seeds} \times 100 \ldots\ldots\ldots\ldots \text{ Equation 1}$$

### 3.4.2 Seed germination

The method described in the official Methods of the International Seed Testing Association (ISTA) was used to evaluate the germination percentage of seed (ISTA,

1999) with slight modification to the storage temperature. The seeds (100 seeds replicated three times) were placed on seed trays filled with river sand. The seeds were germinated at room temperature, and distilled water was dispensed to the tray daily to keep the sand moist. After 12 days, the number of germinated seeds was counted and the percentage of germinated seeds was calculated using the formula:

$$\text{Seed germination (\%)} = \frac{Number\ of\ germinated\ seeds}{Total\ number\ of\ seeds} \times 100 \ldots\ldots\ldots\ldots \text{Equation 2}$$



### 3.4.3 Proximate profile

The amount of moisture, crude protein, crude fat and ash of the seeds was determined using the Official Methods of Analysis of the Association of Official Analytical Chemists (AOAC, 2005) as described below;

#### 3.4.3.1 Moisture

Five grams (5 g) of ground sample was weighed into a pre-weighed moisture dish and dried for 12 hours at 105$^{o}$C in an oven. The moisture content was then calculated using the formula below:

$$\text{Moisture content (\%)} = \frac{Weight\ of\ fresh\ sample - weight\ of\ dry\ sample}{Weight\ of\ fresh\ sample} \times 100 \ldots. \text{Equation (3)}$$

#### 3.4.3.2 Crude protein

Crude protein content was determined using the Official method of AOAC (2002) with slight modifications to the digestion time. Grinded samples (1 g) were moistened with 10 mL distilled water, digested with Kjeldahl catalyst, and 15 mL of concentrated $H_2SO_4$ for 4 hours at 420$^{o}$C. After cooling, the digested solution was decanted into a 100 mL volumetric flask and made up to the volume with distilled water. Ten millilitres (10 mL) of the diluted digest were dispensed in a 100 mL distillation flask containing

90 mL of distilled water. The solutions were distilled in the distillation unit with 20 mL of 40% NaOH. The distillates were collected into a 200 mL Erlenmeyer titration flask containing 25 mL $H_2BO_3$. Then 100 mL of the $H_2BO_3$ received solution was titrated with 0.10 M HCl to violet endpoint. The crude protein content was calculated using the formula below:

$$\% \text{ nitrogen} = \frac{(A-B) \times M \times 14.01}{10 \times W} \quad \text{..... Equation 4}$$

$$\text{Crude protein (\%)} = \% \text{ nitrogen} \times F \quad \text{..... Equation 5}$$

Where **A** = volume (mL) of standardized HCI used in the titration; **B** = volume (mL) of standardized acid used to titrate reagent blank; **M** = molarity of the standard HCl; **14.01** = atomic weight of nitrogen; **W** = weight of test portion; **10** = factor to convert mg/g to percentage; **F** = factor to convert N to protein (6.25).

### 3.4.3.3 Crude Fat

Eighty-five millilitres (85 mL) of petroleum ether were measured into a pre-weighed extraction thimble containing 2 g of the ground sample. The crude fat was then extracted for 65 minutes using a Soxhlet extraction fat extractor. Subsequently, the petroleum ether was evaporated slowly in water bath; then dried for 30 minutes at 105$^{o}$C, and cooled in a desiccator. Finally, the thimble with the extracted fat was reweighed. The percentage of crude fat was calculated using the formula:

$$\text{Crude fat (\% of DM)} = \frac{Weight\ of\ fat\ extracted}{Weight\ of\ sample} \times 100 \quad \text{..... Equation 6}$$

### 3.4.3.4 Ash content

For ash determination, 2 g the ground sample was weighed into a dry, tared porcelain dish and then placed in a muffle furnace at 550°C for 4 h. The dish was cooled in a desiccator and the ash content was calculated using the formula:

$$\text{Ash (\%)} = \frac{Weight\ of\ ash}{Weight\ of\ sample} \times 100 \ldots\ldots\ldots \text{Equation 7}$$

### 3.5 Statistical analysis

Three-factor analysis of variance (split split design) was performed to evaluate the combined effect of sample region, soybean variety, and storage duration on quality and proximate descriptors using RStudio (version 4.1.1). Fisher's Protected multiple comparison was used to compare differences between means at a significance of $p < 0.05$. Graphs were plotted using GraphPad Prism (version 8.4.0).

A Pearson correlation test and principal component analysis were used to check for relationship between the soybean varieties and germination percent as well as the proximate parameter using XLSTAT statistical software (2021.2.2.1141).

The Facto Analysis for Mixed Data (FAMD) was used to explore the clustering patterns of individual data points in the variance maximizing factor map space based upon the levels of qualitative variables. FAMD enables the analyse the similarity among individuals by incorporating both qualitative and quantitative variables. With this analysis, the mixed variables are normalized in order to balance the impact of each set of variables. The analysis was carried out using the *FactoMineR* package (version 1.41) and visualization were generated with *factoextra*. The R software (version 4.4.2) were used for FAMD analysis.

# CHAPTER FOUR

## 4.0 RESULTS

### 4.1 Experiment 1:

### 4.1 Source, variety and storage duration on seed quality and proximate profile

#### 4.1.1 Temperature variations in storage room

The ambient temperature and relative humidity within the soybean storage room exhibited gradual fluctuations over the 10-month period (Fig. 4.1). The experiment started in the peak of temperature ($31.9^0$C) in March but declined to the least ($25.0^0$C) in December. The gradual decrease in temperature was supportive in slowing down the rate of respiration and deterioration in the stored seeds. Relative humidity on the other hand increased from 50.0% in March through to 86.1% in September before gradually declining in December. This high relative humidity could be a course of rapid deterioration of stored soybean seeds by increasing seed moisture content, leading to accelerated aging and severe losses in seed viability. Optimal storage requires a relative humidity below 60% and a moisture content of 11%–13% to prevent rapid deterioration during the storage period.

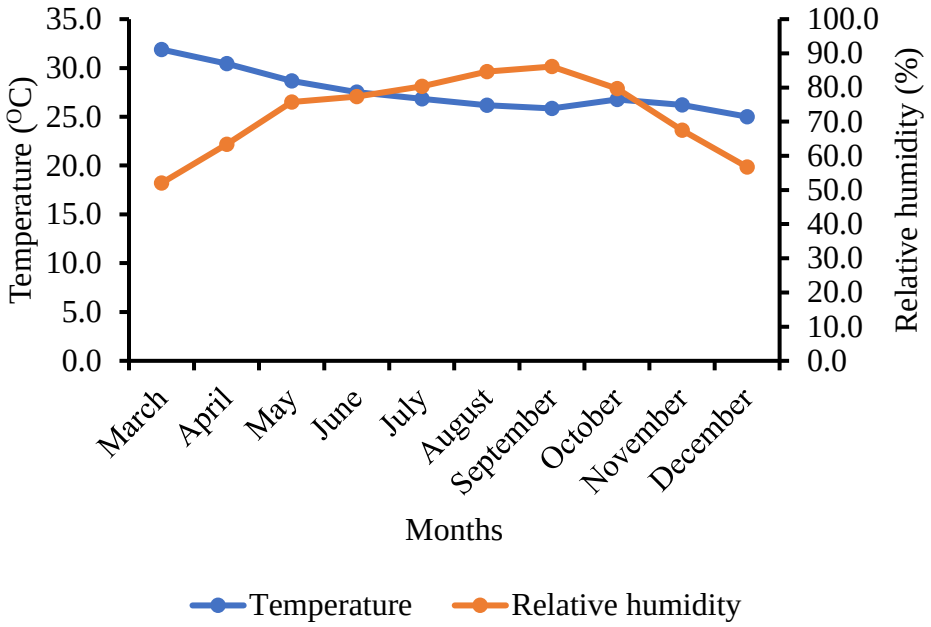



**Figure 4.1: Average monthly temperatures and relative humidity in the storage location**

### 4.1.2 Combined mean squares from analysis of variance for seed quality and proximate composition

The three way analysis (source × variety × storage duration) showed significant interaction ($p < 0.05$, $p < 0.01$, or $p < 0.001$) effects for all the indices measured except carbohydrate. Carbohydrate contents of the seeds was, however, significant ($P < 0.001$) variety × storage interaction (Table 4.1). The variations among the varieties and storage duration for the germination percent, number of normal seeds, dry matter, fat, moisture, ash, carbohydrate and protein contents for each region are presented the Figure below.

Table 4.1: Mean squares from analysis of variance for region, variety, and storage period on seed quality and proximate profile

| Source of Variation | df | Germination % | Normal seeds | Dry matter % | Fat % | Moisture % | Ash % | CHO % | Protein % |
|---|---|---|---|---|---|---|---|---|---|
| Main Plot (Region) | 3 | 6661*** | 1734.28*** | 20.78*** | 20.222*** | 20.11*** | 1.667*** | 15.239**ns** | 13.75*** |
| Error 1 (Main Plot Error) | 6 | 4 | 3.53 | 0.22 | 0.223 | 0.06 | 0.023 | 3.955 | 0.59 |
| Sub-Plot (Variety) | 2 | 402*** | 39.02*** | 11.01*** | 307.214*** | 8.77*** | 34.939*** | 155.796*** | 1070.9*** |
| Region: variety | 6 | 805*** | 249.63*** | 4.65*** | 6.426*** | 4.78*** | 8.474*** | 14.929* | 3.76*** |
| Error 2 (Sub-Plot Error) | 16 | 4 | 0.84 | 0.09 | 0.0880 | 0.10 | 0.105 | 4.241 | 0.48 |
| Sub-Sub Plot (Storage Condition) | 2 | 47164*** | 556.08*** | 407.98*** | 14.730*** | 334.53*** | 20.212*** | 51.344ns | 3.23*** |
| Storage × Region | 6 | 1130*** | 22.44*** | 3.66*** | 1.048*** | 3.14*** | 0.675*** | 3.005ns | 0.82*** |
| Variety × Storage | 4 | 484*** | 6.93*** | 2.11*** | 1.408*** | 2.11*** | 0.990*** | 26.863*** | 0.40* |
| Location × Variety × Storage | 12 | 41*** | 1.95*** | 0.67*** | 1.06*** | 0.95*** | 0.918*** | 5.307ns | 0.87*** |
| Error 3 (Sub-Sub Plot Error) | 48 | 2 | 1.04 | 0.08 | 0.066 | 0.06 | 0.058 | 4.277 | 0.14 |

df; degree of freedom. *, **, *** and ns represent significant differences at $p < 0.05$, $p < 0.01$, $p < 0.001$ and not significant, respectively, CHO; Carbohydrat

### 4.1.3 Effect of seed source, variety and storage duration on normal seeds count

Generally, normal seed count declined progressively over the storage period across all seed sources and among the three varieties (Fig. 4.2). The results shows that the percentage of normal seeds was highest in 'Favour' seeds obtained from the UWR and UER (93% and 84.7%) regions against the same variety obtained from Northern region (70.5%). Though the same variety, regional effects resulted in 8.3%, 9.7% and 11.5% decreases in percentage normal seeds from the baseline figures for UWR, UER and the Northern regions, respectively. Though the interations resulted in seed detrioration across all regions and varieties with prolonged storage periods, the statistic showed the least seed detriorations for UER at 5 months (1% and 1%) for 'Afayak' and 'Favour' followed by UWR (2.5% and 2.5%) for 'Afayak'and 'Favour' respectively. The highest deterioration was, however, observed in seeds from the north (6%, 3.5% and 4%) for 'Afayak', 'Favour' and 'Jenguma', respectively.



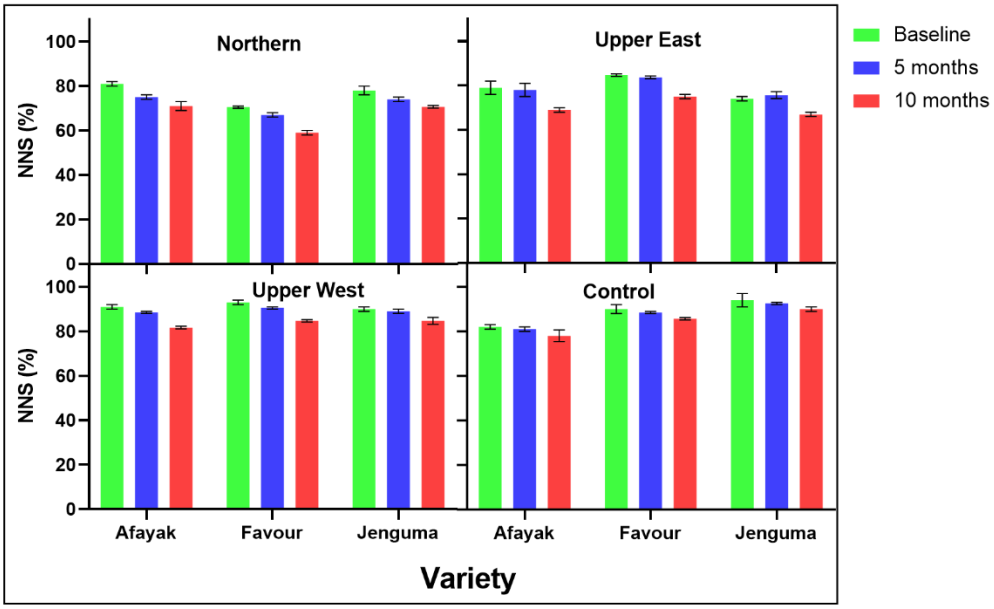



Figure 4.2**:** Effect of seed source, variety and storage duration on the number of normal seeds.
Error bars represent mean ± standard deviation of triplication determination. Control – Samples of foundation seeds obtained from SARI to serve as a check in this experiment. NNS- Number of normal seeds

### 4.1.4 Effect of seed source, variety and storage duration on germination percentage

The germination percentage of soybean seeds decreased significantly over the 10-month storage period across all varieties and region. However, the variation in deterioration rates could be linked to combined effects of region, variey and period of storage (Fig. 4.3). The results shows that the highest germination for all three varities were recorded from seeds obtained from the UWR (‘Favour’95.5%, ‘Afayak’ 94.5%, ‘Jenguma’-86%) whiles the least germination percentages were obtained from seeds obtained from the NR (‘Favour’,74.7%,’Afayak’,33.7%,’Jenguma’, 49%).. Although the seeds obtained from NR relatively had poor viability, ‘Favour’ maintained an appreciable level of germination of 74.7% which could be utilied by farmers for planting. The three way interaction effect

(region × variety × storage duration)“ shows that ‘Favour’ seeds obtained from UWR and stored for five months suffered only 2% decrease in their germination perectage compared with the initial but deteriorated by as high as 64% when kept in storage for 10 months. Similarly, observations in ‘Afayak’ from UWR deteriorated by 2.5% and 46.5% at 5 and 10 months, whiles ‘Jenguma’ from UWR recorded 3,5% and 40.5% deterioration at 5 and 10 months respectively



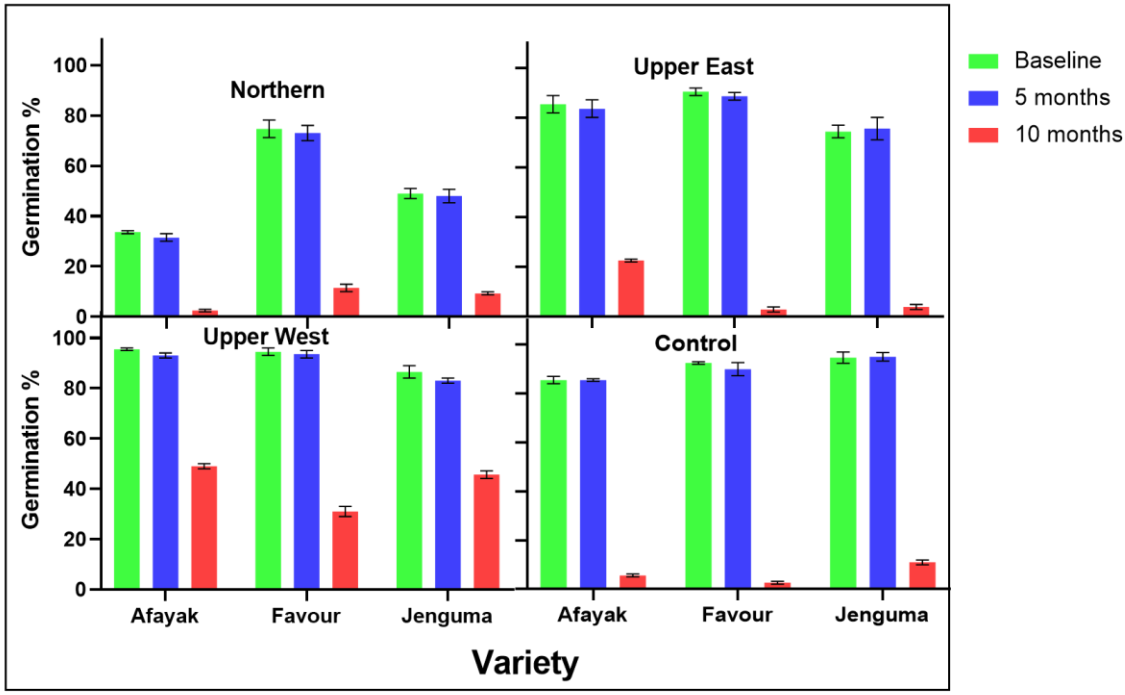



Figure 4.3**:** Effect of source, variety and storage duration on the germination percentage Error bars represent mean ± standard deviation of each treatment. Control – Samples of foundation seeds obtained from SARI to serve as a check in this experiment.

### 4.1.5 Effect of seed source, variety and storage duration on moisture content

Moisture contents in the soybean varieties from the study locations are presented in Figure 4.4. Moisture percentage in all varities at the baseline were above 15% with some as high

as 17.8%.Although the observed moisture contents were above the 12% generally recommended for storage, they were used at those high levels for the experiments as part of the seed characteristics associated with their sources at the time of the experiment. Results however recorded moisture loss in all seed varieties from all source in storage. At 5 monhts, moisture loss was 3.2%, 1.5% and 3.2% for 'Afayak', 'Favour'and 'Jenguma from North, 4.5%, 2.9% and 2.4% for 'Afayak', 'Favour'and 'Jenguma' from UE, 2.9%, 2.7% and 1.9% for 'Afayak', 'Favour' and 'Jenguma' from UW respectively. By the 10$^{th}$ month, all varieties across all regions had lost moisture to below 12 %. Moisture loss for regions from the baseline to 10 month were 7%. 5% and 7% for 'Afayak', 'Favour' and 'Jenguma' from the north. Those from UER recorded 9%, 8% and 7% for 'Afayak', 'Favour' and 'Jenguma' and finally, UWR recrded 5%, 8% and 4% for %) for 'Afayak', 'Favour' and 'Jenguma' respectively.

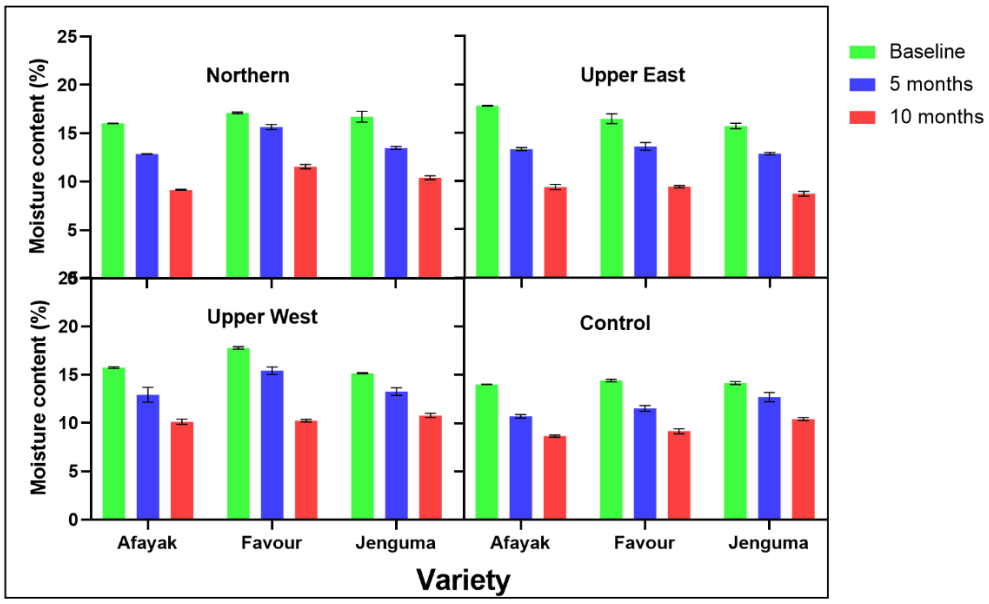



Figure 4.4**:** Effect of seed source/region, variety and storage duration on the moisture content.
Error bars represent mean ± standard deviation of each treatment. Control – Samples of foundation seeds obtained from SARI to serve as a check in this experiment.

### 4.1.6 Effect of seed source, variety and storage duration on dry matter content

The combined effect of the interaction increased the dry matter contents of all the certified soybean varieties over the storage period across all three regions over the ten months storage duration (Fig. 4.5).

In the Northern Region, 'Afayak' showed a notable increase from 83.45% at baseline to 90.84% at 10 months representing 7.39% increase. 'Favour' and 'Jenguma' followed in similar pattern, increasing from 82.14% and 83.07% to 88.44% and 89.58%, representing 6.3% and 6.51% increment, respectively. The UER gave comparable results, with all varieties, increasing by an average of 5% between 5 and 10 months, recording above 90% dry matter by the 10 month. Observations however indicates that, the interaction supported almost equal dry matter accumulation among and within all factors with very marginal differnces.

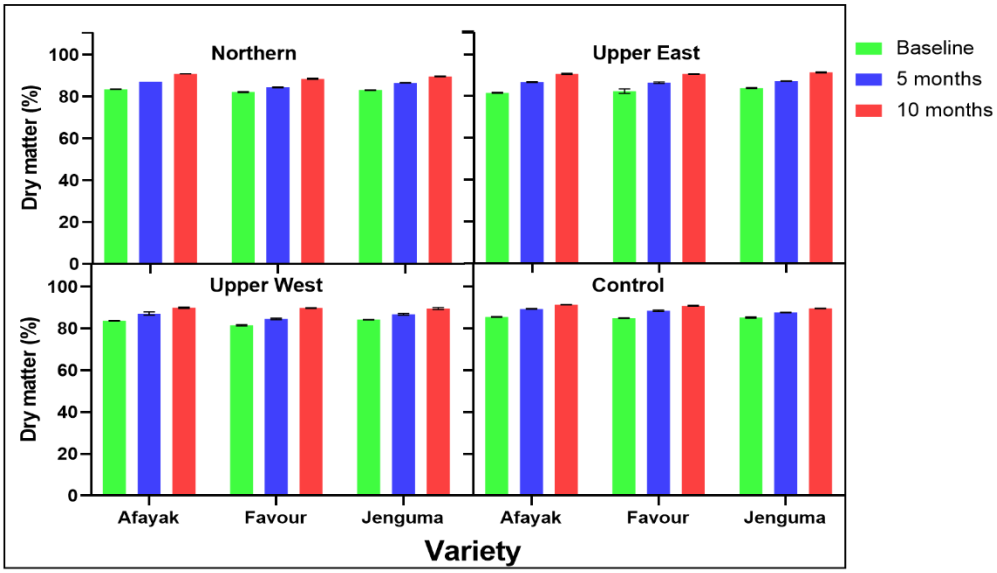



Figure 4.5**:** Effect of seed source/region, variety and storage duration on dry matter content.
Error bars represent mean ± standard deviation of triplication determination. Control – Samples of foundation seeds obtained from SARI to serve as a check in this experiment.

### 4.1.7 Effect of seed source, variety and storage duration on protein content

The three-way interaction effect on protein was significant at $P < 0.05$ (Fig. 4.6). The highest protein content was found in the 'Favour' seeds from all sources and over all storage durations. The protein % was largely maintained across all data points (0, 5 and 10 months) in seeds obtained from NR (56%) and UWR (57%) but decreased by 2% from the baseline in UER at 5 months from the baseline. Although the three-way interaction did not show marked differences in protein content between 'Favour' and 'Afayak' seeds from NR, UER and UWR (0.2%, 0.6% and 1%), a relatively greater differences were observed between 'Favour' and 'Jenguma' seeds from NR North, UER and UWR (9.1%, 9.6% and 10%). The least protein contents were observed at all stages in the 'Jenguma' seeds.

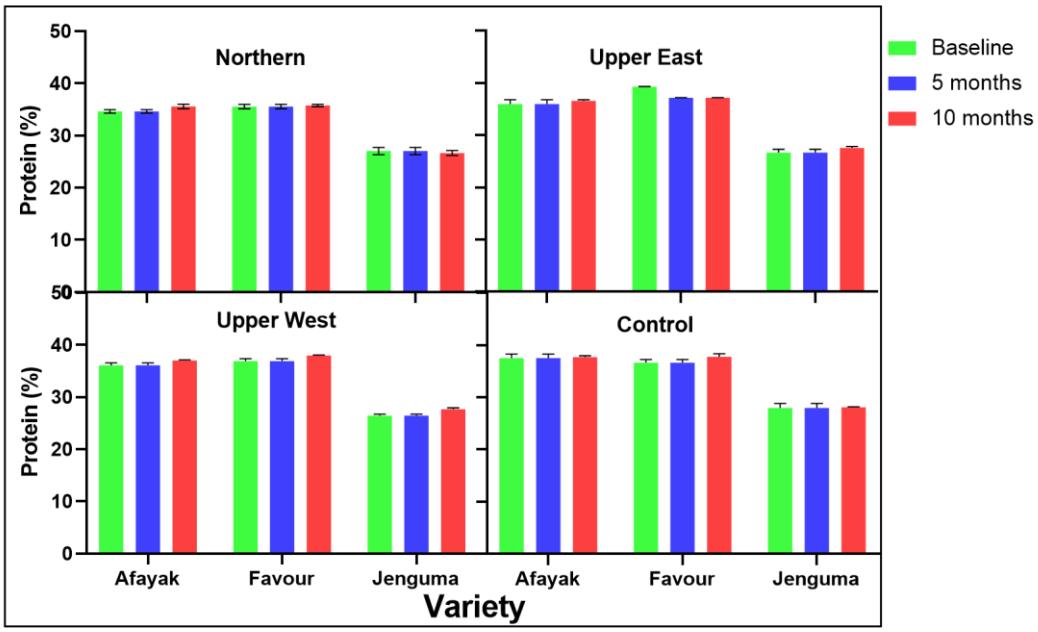



Figure 4.6**:** Effect of seed source, variety and storage duration on protein content in seeds.
Error bars represent mean ± standard deviation of each treatment. Control – Samples of foundation seeds obtained from SARI to serve as a check in this experiment.

### 4.1.8 Effect of seed source, variety and storage duration on fat content

The fat contents were significantly high in soybeans from the North (16%, 13% and 20%) as against 14%, 12% and 18% in 'Afayak', 'Favour' and 'Jenguma' from UWR. The highest fat content was measured in 'Jenguma' regardless of seed source and storage duration (Fig. 4.7). All the soybean varieties showed a decrease in fat contents over the 10-mouth storage period. Even though general deterioration across all varieties, regions and durations were observed, the rates were very marginal in UWR for 'Afayak' (0.5% and 1.35%) at 5 and 10-months storage, for 'Favour' (0.44% and 0.83%), at 5- and 10-months storage and in 'Jenguma' (0.17% and 1.65%) at 5- and 10-months storage. The decrease in fat level was substantially high within the first five months of storage ($P < 0.05$) but less pronounced after the five months in storage ($P > 0.05$), particularly, for 'Afayak' and 'Flavour' seeds from all the sources.

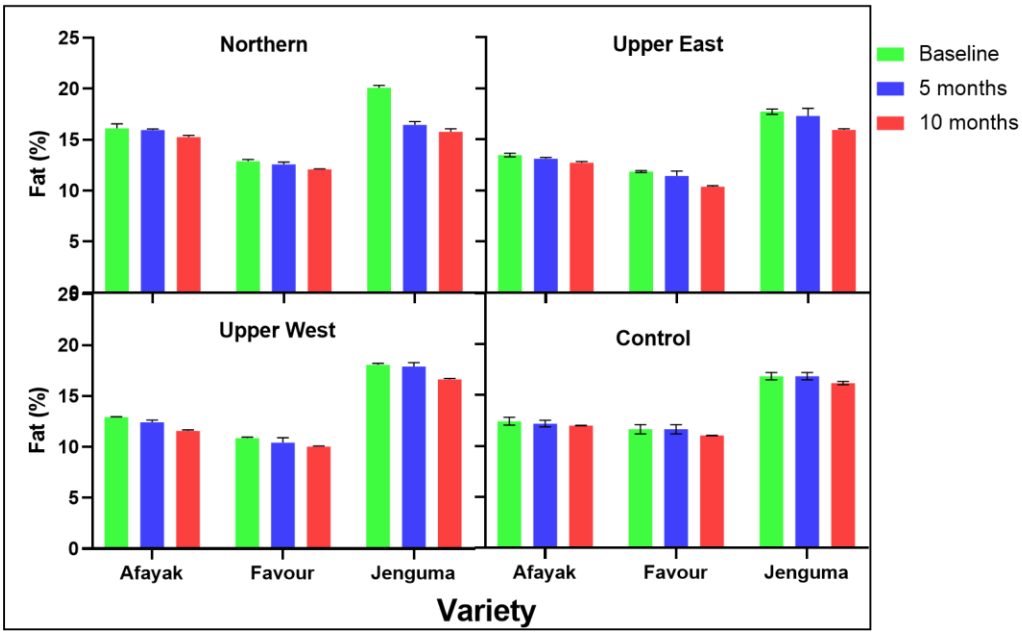



Figure 4.7**:** Effect of seed source, variety and storage duration on fat content.
Error bars represent mean ± standard deviation of each treatment. Control – Samples of foundation seeds obtained from SARI to serve as a check in this experiment.

### 4.1.9 Effect of seed source, variety and storage duration on ash content

There was significant three-way interaction effect ($P < 0.001$) on ash contents of the certified seeds (Fig. 4.8). The average increase in the ash content was least in seed samples from Upper West region at 5 and 10 months (0.6% and 1%, 0.2% and 0.7%, 0.3% and 0.2%), for 'Afayak', 'Favour' and 'Jenguma' while the highest were noted in seeds from the UER at 5 and 10 months (0.2% and 1%, 1% and 2%, 1% and 4%) for 'Afayak', 'Favour' and 'Jenguma' respectively. The greatest increment in ash content occurred in "Jenguma" obtained from UWR with 4% difference between the baseline and the 10-month measurement whiles the least was observed in 'Favour' (0.7%) from UWR for the same period.

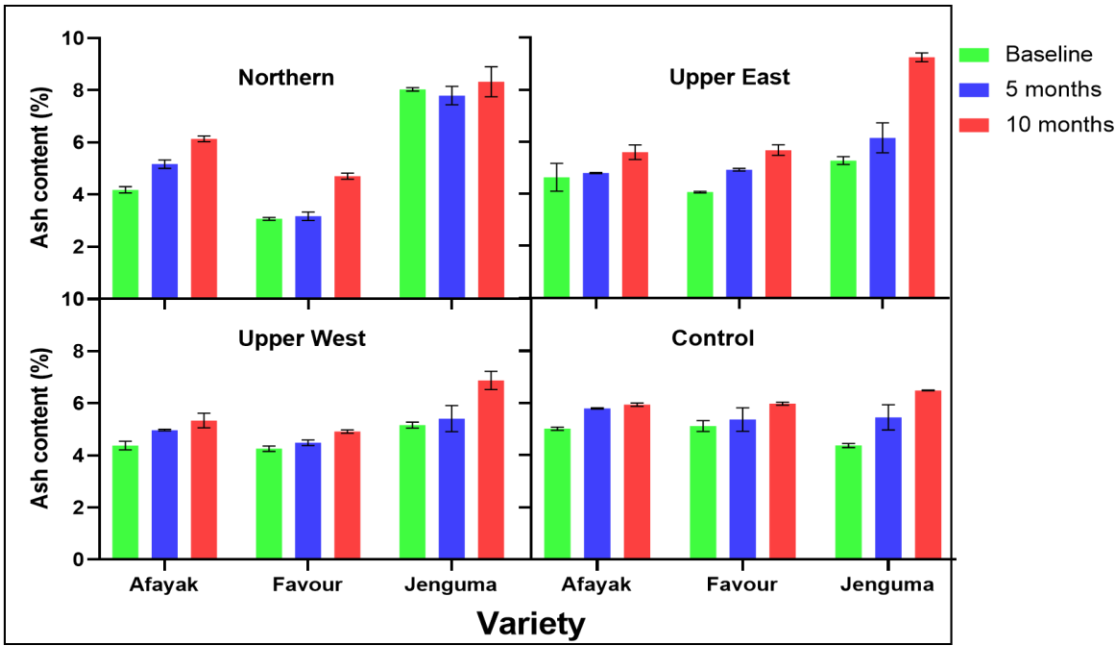



Figure 4.8**:** Effect of seed source, variety and storage duration on ash content.
Error bars represent mean ± standard deviation of triplication determination. Control – Samples of foundation seeds obtained from SARI to serve as a check in this experiment.

### 4.1.10 Effect of seed source, variety and storage duration on carbohydrate contents

The three-way interaction showed no significant source × storage × variety effect on carbohydrate content. However, the variety × storage interaction significantly ($P < 0.001$) affected contents of carbohydrates in the seeds (Fig. 4.9). 'Jenguma' had the highest carbohydrate levels among all the varieties stored at 5 months while 'Favour' and Jenguma recorded similar figures at 10 months, 'Afayak' had the lowest carbohydrate content when these were stored for both 5 and 10 months.

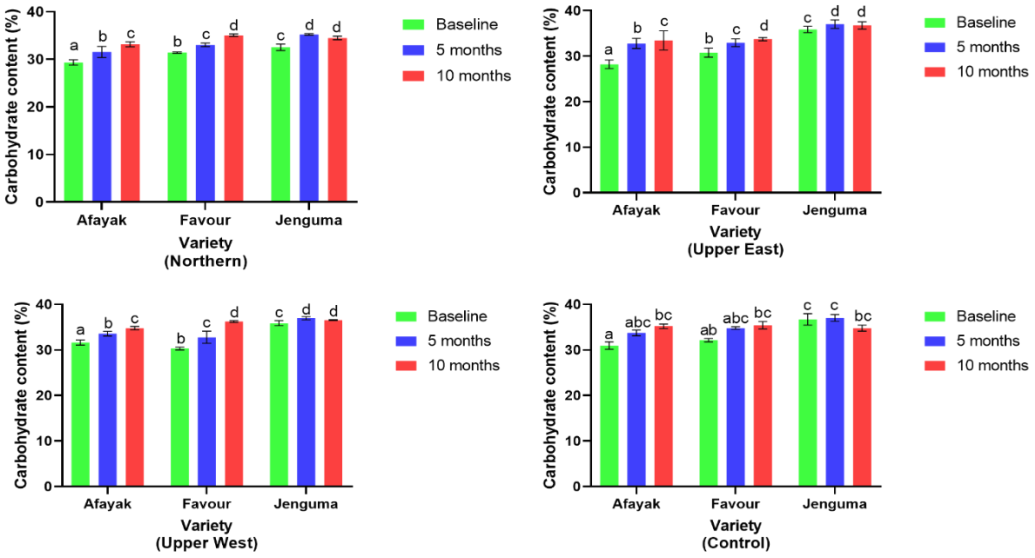
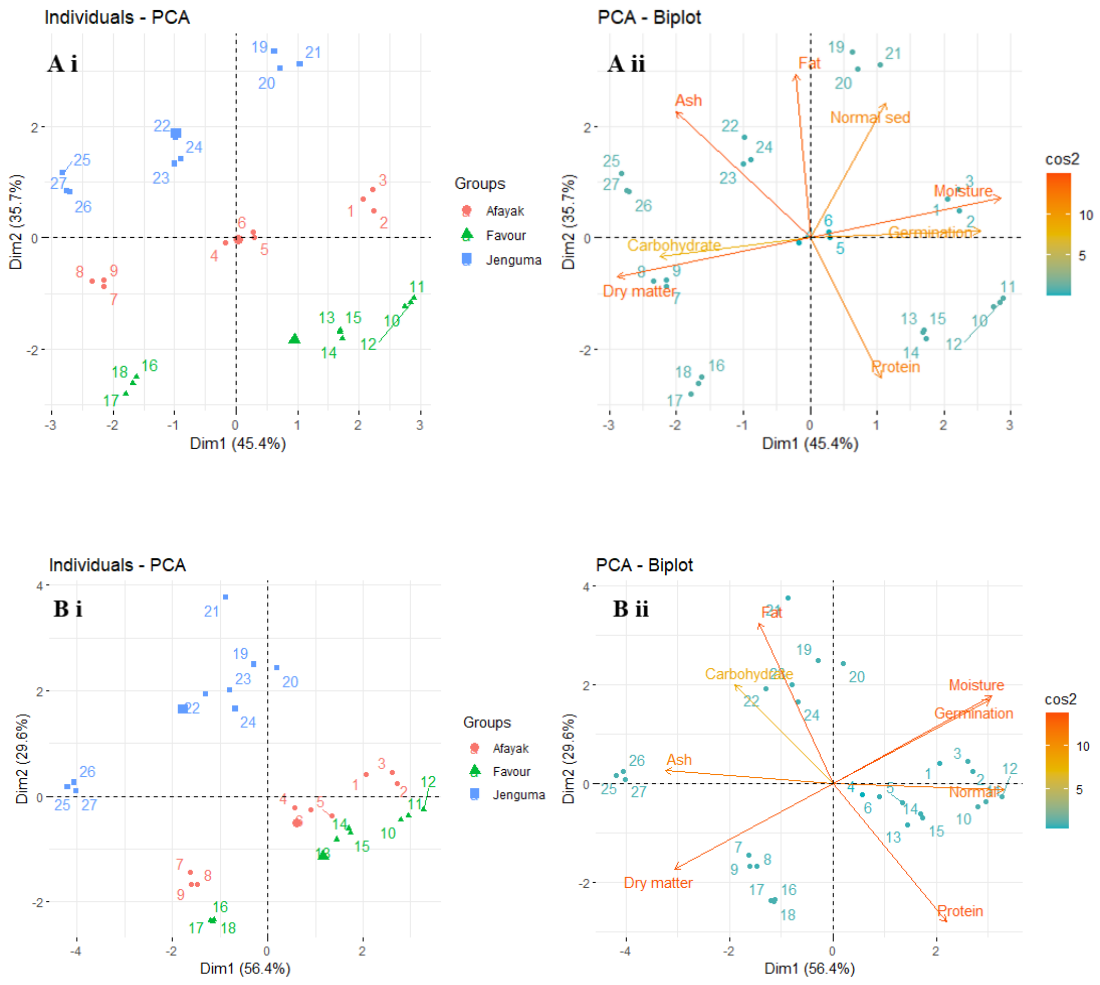



Figure 4.9**:** Effect of variety and storage duration on carbohydrate content.
Error Bars represent mean ± standard deviation of triplication determination. Bars with different letters for each region and control are significantly different at $P < 0.05$. Control – Samples of foundation seeds obtained from SARI to serve as a check in this experiment.

### 4.1.11 Principal component and correlation analysis

There was a strong positive correlation between moisture content, protein content, normal seeds and germination percent with perfect correlation for germination and moisture percentages for in UER. Thus, these indices contribute to germination percentage and any

decreament will result otherwise. For a perfect correlation as in UER, any change in moisture percentage will result in an equal change in germination percentage. Except for Northern region samples, the dry matter content was negatively correlated with the number of normal seeds, the germination percentage, moisture content, protein content, and fat content as indicated by the active variable angles. Similarly, protein content correlated negatively with all the other parameters at all the sampling regions (Fig. 4.10). For parameter that are negetively correlated with germination, any increase in their percentage will lead to reduction in germination and *vice versa.*



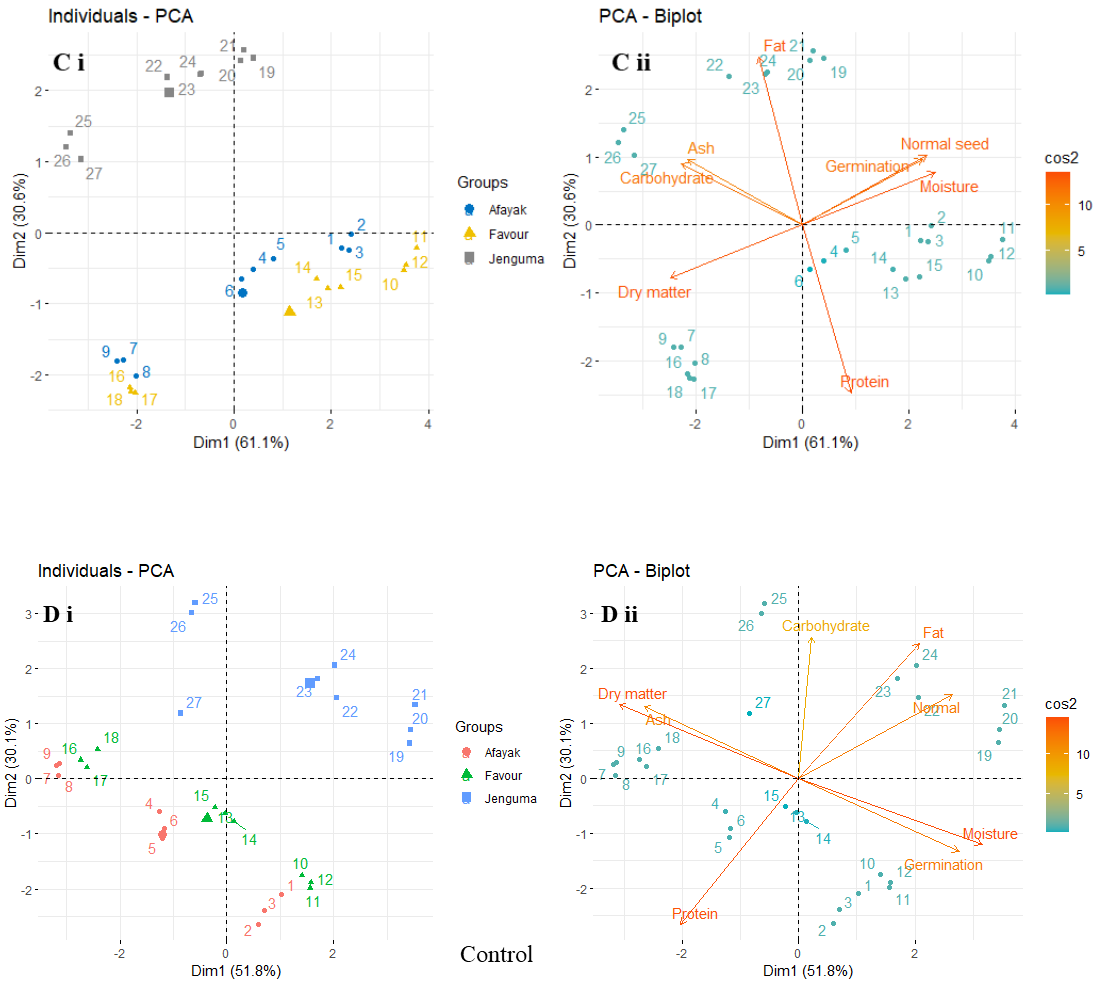



Figure 4.10**:** Biplots PCA variance explained by the first two components
**a;** Northern region, (b); Upper East region, (c); Upper West region and **d;** Control (Fundation seeds).

The principal components analysis identifies five components with eigenvalues greater than 1 for three components in the Northern region (Table 4.2). The UER and UWR as well as the control had two component each having eigenvalues greater than 1 (Tables 4.2 and 4.3). The first two component accounted for 81.05%, 85.98%, 91.73% and 81.92% for NR, UER, UWR and the control, respectively (Fig. 9)

Table 4.2: Principal component analysis showing the contributions of each trait to the variation in the Northern and Upper East regions

| | Northern | | | | | Upper East | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Traits** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** |
| Normal | -0.368 | 0.785 | -0.433 | 0.217 | -0.018 | 0.908 | -0.035 | 0.129 | 0.374 | 0.072 |
| Germination | -0.826 | 0.042 | 0.495 | 0.228 | 0.102 | 0.831 | 0.465 | 0.015 | 0.183 | -0.190 |
| Moist | -0.926 | 0.234 | 0.255 | -0.145 | -0.015 | 0.845 | 0.487 | -0.114 | -0.125 | 0.137 |
| Pro | -0.345 | -0.819 | -0.415 | -0.033 | 0.188 | 0.602 | -0.766 | 0.122 | -0.077 | 0.058 |
| Fat | 0.068 | 0.953 | -0.170 | -0.123 | 0.204 | -0.395 | 0.893 | -0.152 | -0.017 | -0.108 |
| Ash | -0.653 | 0.736 | 0.139 | -0.030 | -0.007 | -0.887 | 0.072 | -0.291 | 0.249 | 0.225 |
| CHO | 0.729 | -0.108 | 0.653 | 0.029 | 0.106 | -0.518 | 0.550 | 0.644 | -0.003 | 0.111 |
| DM | -0.935 | -0.224 | -0.227 | 0.138 | 0.046 | -0.841 | -0.472 | 0.108 | 0.151 | -0.186 |
| Eigenvalue | 3.629 | 2.855 | 1.197 | 0.157 | 0.101 | 4.509 | 2.369 | 0.579 | 0.280 | 0.172 |
| Variability (%) | 45.359 | 35.686 | 14.958 | 1.964 | 1.265 | 56.363 | 29.614 | 7.239 | 3.497 | 2.152 |
| Cumulative % | 45.359 | 81.046 | 96.004 | 97.968 | 99.233 | 56.363 | 85.976 | 93.215 | 96.712 | 98.864 |

Table 4.3: Principal component analysis showing the contributions of each trait to the variation in the Upper West region and control

| | Upper West | | | | | Control | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Traits** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** | **PC1** | **PC2** | **PC3** | **PC4** | **PC5** |
| Normal | 0.882 | -0.386 | -0.037 | -0.096 | -0.236 | 0.762 | -0.440 | -0.084 | -0.437 | -0.071 |
| Germination | 0.852 | -0.367 | -0.005 | 0.367 | -0.042 | 0.798 | 0.386 | 0.179 | 0.040 | 0.406 |
| Moist | 0.943 | -0.293 | 0.040 | -0.126 | 0.043 | 0.912 | 0.347 | -0.082 | -0.042 | 0.010 |
| Pro | 0.344 | 0.934 | 0.032 | 0.061 | -0.028 | -0.587 | 0.771 | 0.215 | -0.089 | -0.015 |
| Fat | -0.311 | -0.934 | -0.011 | 0.057 | 0.133 | 0.600 | -0.711 | -0.192 | 0.305 | 0.012 |
| Ash | -0.815 | -0.365 | 0.432 | -0.008 | -0.114 | -0.767 | -0.380 | -0.345 | -0.175 | 0.298 |
| CHO | -0.858 | -0.341 | -0.360 | -0.027 | -0.108 | 0.065 | -0.743 | 0.646 | -0.051 | 0.038 |
| DM | -0.938 | 0.291 | -0.030 | 0.152 | -0.074 | -0.893 | -0.388 | 0.078 | 0.030 | 0.077 |
| Eigenvalue | 4.888 | 2.450 | 0.322 | 0.191 | 0.108 | 4.144 | 2.410 | 0.671 | 0.330 | 0.266 |
| Variability (%) | 61.104 | 30.622 | 4.019 | 2.385 | 1.350 | 51.798 | 30.127 | 8.392 | 4.120 | 3.325 |
| Cumulative % | 61.104 | 91.727 | 95.746 | 98.131 | 99.481 | 51.798 | 81.924 | 90.316 | 94.435 | 97.761 |

## 4.2 Experiment 2: Effect of Storage room and storage duration on 'Favour' variety from Upper West Region (UWR)

### 4.2.1 Average weekly temperature in storage room

The initial temperature at the start of the experiment was high (above $20^0$C) for almost all the storage rooms, except for cold storage (below $10^0$C), but declined to around $20^0$C as the rains sets in within all the storage rooms (Fig. 4.11). The average weekly temperatures were relatively higher in the warehouse and zinc roofed rooms (close to $40^0$C) initially but also declined to about $22^0$C between the $19^{th}$ – $29^{th}$ weeks. Temperatures within these two store houses however rose to above $40^0$C by the $35^{th}$ week towards the end of the study. The least was recorded in the Cold rooms ($5^0$C – $8^0$C). The temperature observed in the storage location apart from the cold room were far above recommended temperature for soybean short term storage ($15^0$C) or below for long term and stands the potential to hasten deterioration.

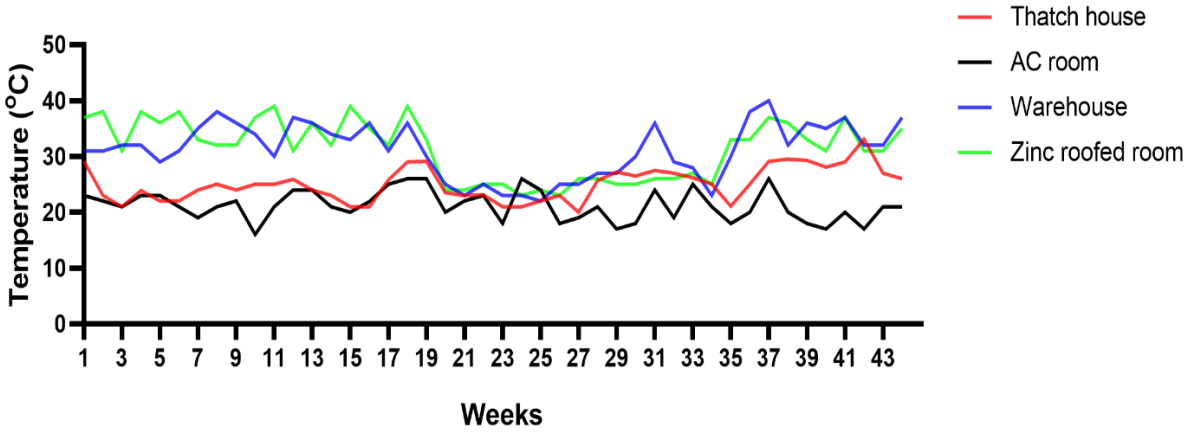



Figure 4.11:Average weekly temperatures in storage rooms

### 4.2.2 Analysis of variance

All the general linear models were statistically significant ($P < 0.01$; Table 4.5). The storage duration accounted for majority of the variations for number of normal seeds (57.31%), dry mater (71.96%), protein (75.58%), ash (43.43%), moisture (73.87%) and carbohydrate (70.58%) Interaction effect of storage room and storage duration accounted for fat (53.09%) and germination percentage (40.88%), respectively.



Table 4.4: Combined mean squares from analysis of variance for storage room type and storage period

| Indices | Source | MS | Contribution | P-Value |
|---|---|---|---|---|
| Normal seed | Room type | 5 | 13.60% | 0.002 |
| | Duration | 42.1556 | 57.31% | 0.000 |
| | Room type*Duration | 2.0167 | 10.97% | 0.050 |
| | Error | 0.8889 | 18.13% | |
| Germination percent | Room type | 558.08 | 23.71% | 0.000 |
| | Duration | 1620.27 | 34.43% | 0.000 |
| | Room type*Duration | 480.96 | 40.88% | 0.000 |
| | Error | 3.09 | 0.98% | |
| Dry matter | Room type | 2.4507 | 13.23% | 0.000 |
| | Duration | 26.6598 | 71.96% | 0.000 |
| | Room type*Duration | 1.2015 | 12.97% | 0.000 |
| | Error | 0.0453 | 1.83% | |
| Protein | Room type | 0.41059 | 10.11% | 0.000 |
| | Duration | 6.13675 | 75.58% | 0.000 |
| | Room type*Duration | 0.28564 | 14.07% | 0.000 |
| | Error | 0.00126 | 0.23% | |
| Fat | Room type | 0.162528 | 53.09% | 0.000 |
| | Duration | 0.122829 | 20.06% | 0.000 |
| | Room type*Duration | 0.040709 | 26.60% | 0.000 |
| | Error | 0.000102 | 0.25% | |
| Ash | Room type | 0.07068 | 15.85% | 0.000 |
| | Duration | 0.38726 | 43.43% | 0.000 |
| | Room type*Duration | 0.088527 | 39.71% | 0.000 |
| | Error | 0.000596 | 1.00% | |
| Moisture | Room type | 2.5275 | 13.49% | 0.000 |
| | Duration | 27.685 | 73.87% | 0.000 |
| | Room type*Duration | 1.1801 | 12.60% | 0.000 |
| | Error | 0.0012 | 0.05% | |
| Carbohydrate | Room type | 0.49468 | 18.10% | 0.000 |
| | Duration | 3.85854 | 70.58% | 0.000 |
| | Room type*Duration | 0.15153 | 11.09% | 0.000 |
| | Error | 0.00088 | 0.24% | |



### 4.2.3 Effect of storage room and duration on the number of normal seeds of soybean

The two-way interaction of storage room and storage durations was significant (P = 0.05) on normal seed count (Fig. 4.12). The interactions resulted in pairs of similar behaviours

between cold room and thatch room at 5 and 10 months (1.7% and 2% for both) and another very close and similar outcome for warehouse (2.7% and 2%) and AC room (2.3% and 2.3%) respectively. Results from the zinc roofed room completely deviated from all others (4% and 5.7%) in 5 and 10 months, making it the worse storage condition in the study. The percentage difference between the best performed treatment (AC room) and the least (zinc roof room) was 3.7% for normal seeds.



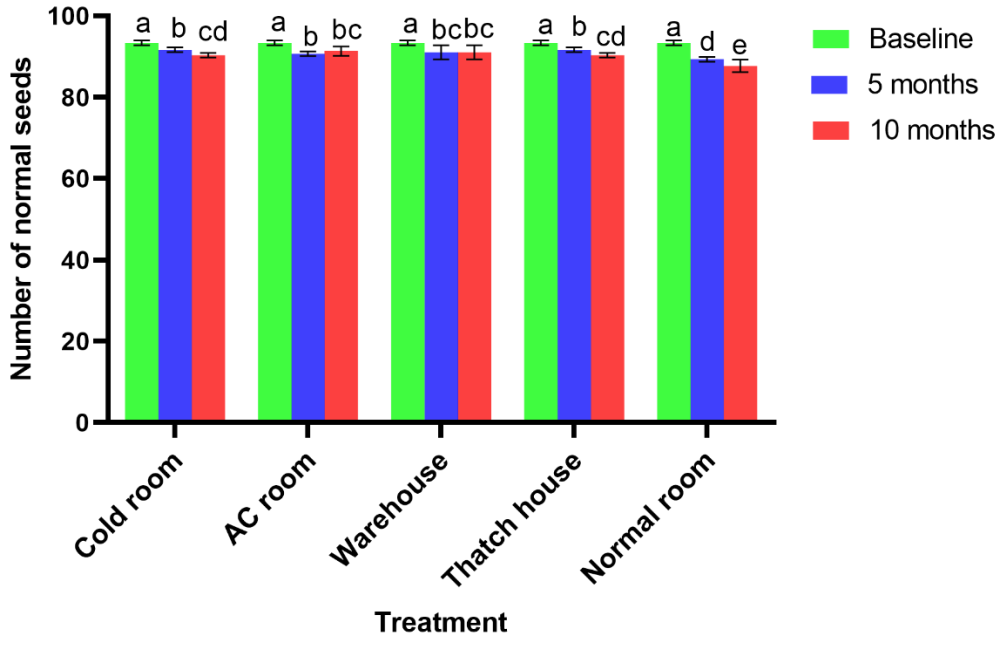



Figure 4.12: Effect of storage rooms and storage durations on number of normal seeds.

Bars represent means ± standard deviation of triplicate determination. Bars with the same alphabet are significantly not different at $P < 0.05$.

### 4.2.3 Effect of storage room and duration on the germination percentage of soybean seeds

There were decreases in the germination percentage of the seeds regardless the storage room used, but to varying degrees (Fig. 4.13). Cold room recorded the least seed

deterioration at both 5 and 10 months (2.7% and 3.7%), followed by thatch house (2.3% and 7%) and warehouse (7.3% and 7.3%) respectively. The highest decline in germination percentage in this study was recorded in zinc roofed room (5% and 56%) followed by AC room (13.3% and 37.3%) respectively for 5$^{th}$ and 10$^{th}$ month data points. The other three storage rooms (cold room, thatch room and warehouse) maintained higher germination percentages85% (90%,87% and 86%, respectively), while the least was recorded in zinc roofed room (56%).



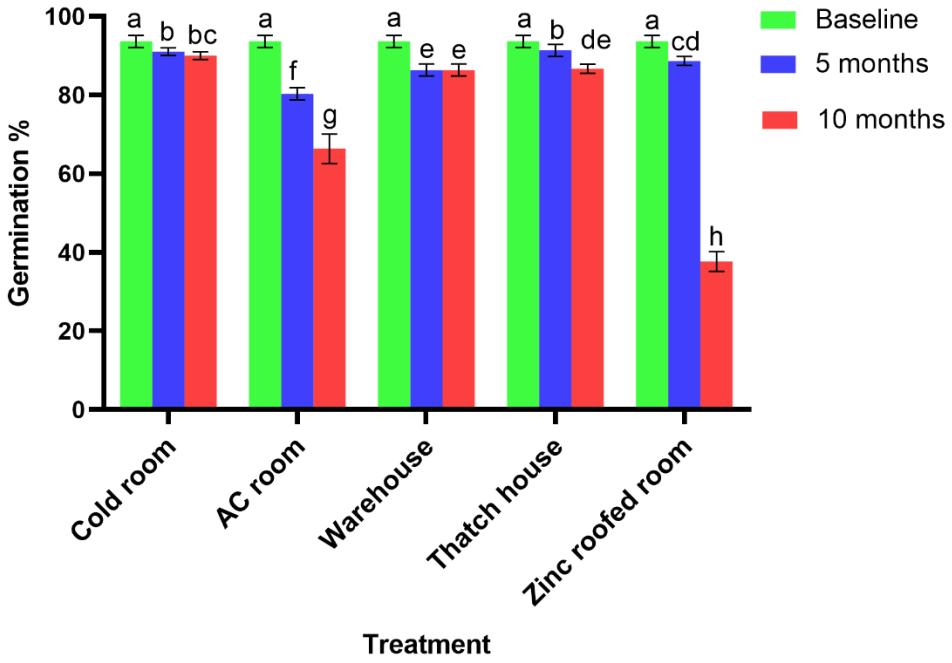



Figure 4.13: Effect of storage rooms and storage durations on germination percentage.

Bars represent means ± standard deviation of triplicate determination. Bars with the same alphabet are significantly not different at $P < 0.05$.

### 4.2.4 Proximate composition

#### 4.2.4.1 Fat content

The storage room and storage duration significantly affected the fat content (Fig. 4.14). The warehouse and zinc roofed rooms had initial higher fat content (14.8%) while the least

was observed in cold and thatch rooms (14.5%) respectively. Zero deterioration was recorded for fat in both AC room and warehouse in the 5th month, but very marginal reduction (0.27%) took place for both at the 10th month. 0.14% deterioration was observed in thatch room at the 5th month which remained same at 10 months. The results recorded the highest deterioration if fat under zinc roofed room (0.36%) by the 10th month to end the study.



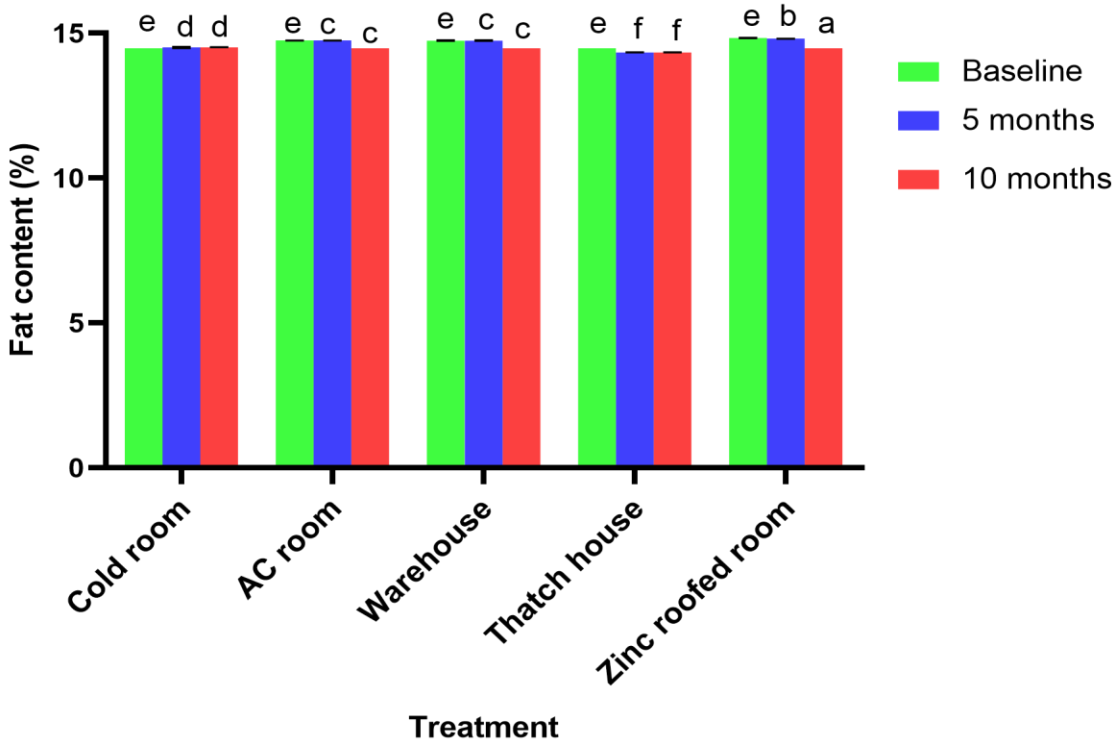



Figure 4.14: Effect of storage rooms and storage durations on fat content.

Bars represent means ± standard deviation of triplicate determination. Bars with the same alphabet are significantly not different at $P < 0.05$.

**4.2.4.2 Protein content**

The protein content of the soybean ranged from 37.52% to 39.24% (Fig. 4.15), demonstrating significant variation among the varieties during storage ($P < 0.001$). Initially, the protein content was low (37.5%) but increased significantly by the 10th month

of storage. Thatch house promoted protein increment at both 5 and 10 months (0.43% and 1.72%) while warehouse recorded 0.27% and 1.73% representing the first two best performances over the period. Cold room promoted a good protein rise in the 5th month (0.47%) but the percentage remained unchanged at the 10th month. AC room maintained the least among protein figures at 5 months (0.03%) but rose to 0.91% by the end of the study.



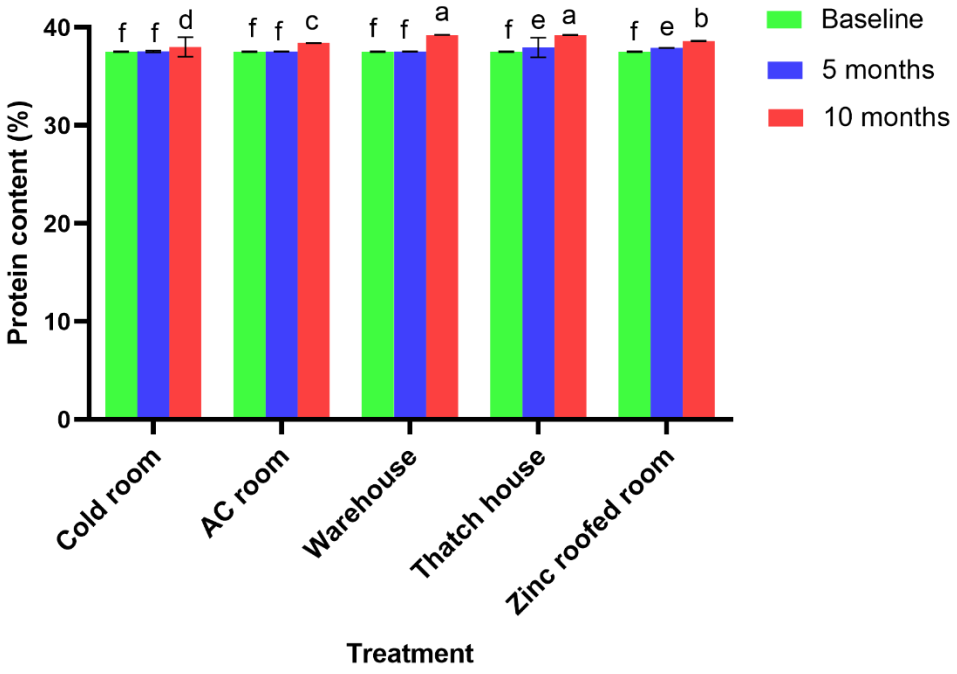



Figure 4.15: Effect of storage rooms and storage durations on protein content.

Bars represent means ± standard deviation of triplicate determination. Bars with the same alphabet are significantly not different at $P < 0.05$.

### 4.2.4.3 Moisture content

Moisture content for baseline measurement was below 10%, indicating thorough drying seed. The percentage however decreased for all treatments and with prolonged storage (Fig. 4.16). Results indicate the highest moisture loss in warehouse (1% and 4%) for 5 and 10

months, followed by zinc roofed house (1.6% and 3.2%) and thatch house (1.06% and 2.9%) for 5 and 10 months respectively. The least moisture loss occurred in cold room (0.29%) for both 5 and 10 months.

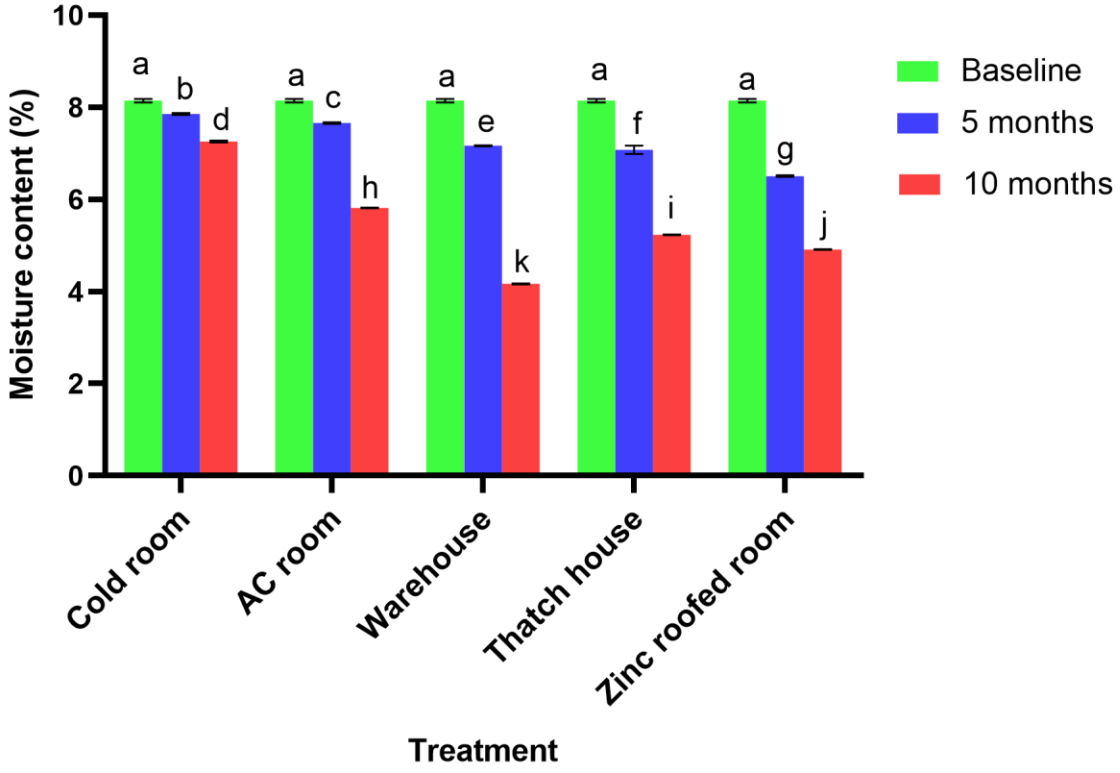





Figure 4.16: Effect of storage rooms and storage durations on moisture content.

Bars represent means ± standard deviation of triplicate determination. Bars with the same alphabet are significantly not different at $P < 0.05$.

#### 4.2.4.4 Ash content

The combine effect of storage room and storage duration significantly increased the ash content (Fig. 4.17). Relative to the initial ash content (4,61%), the ash content increases marginally in both zinc roofed room and cold room (0.07%) at 5 months, 0.05% in the warehouse with the least in AC room (0.03%) at 5 months. Again at 10-month period, both

warehouse and zinc roofed room recorded a higher increment of 0.05%, followed by AC room (0.4%) and the least in cold room (0.09%) respectively.

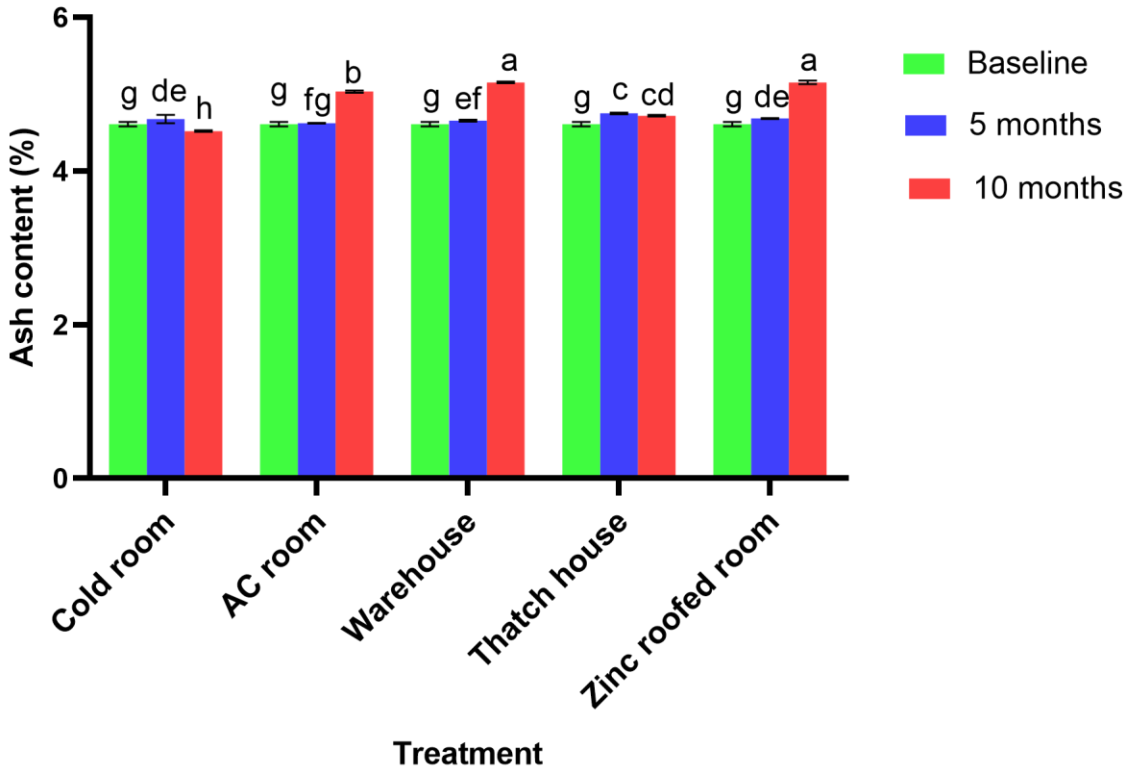



Figure 4.17: Effect of storage rooms and storage durations on ash content.

Bars represent means ± standard deviation of triplicate determination. Bars with the same alphabet are significantly not different at $P < 0.05$.



### 4.2.4.5 Carbohydrate content

The carbohydrate content of the soybean ranged from 35.24% to 36.7% (Fig. 4.18). Initially, gains in carbohydrate content were low (014%, 0.18%, 0.64%, 0.63% and 0.66%) for cold room, AC room, warehouse, thatch house and zinc roofed room at 5 months. The results again showed more increment at 10 months for all treatments (0.44%, 0.17%, 1.44%, 1,22% and 1.23%) for cold room, AC room, warehouse, thatch house and zinc roofed rooms respectively.

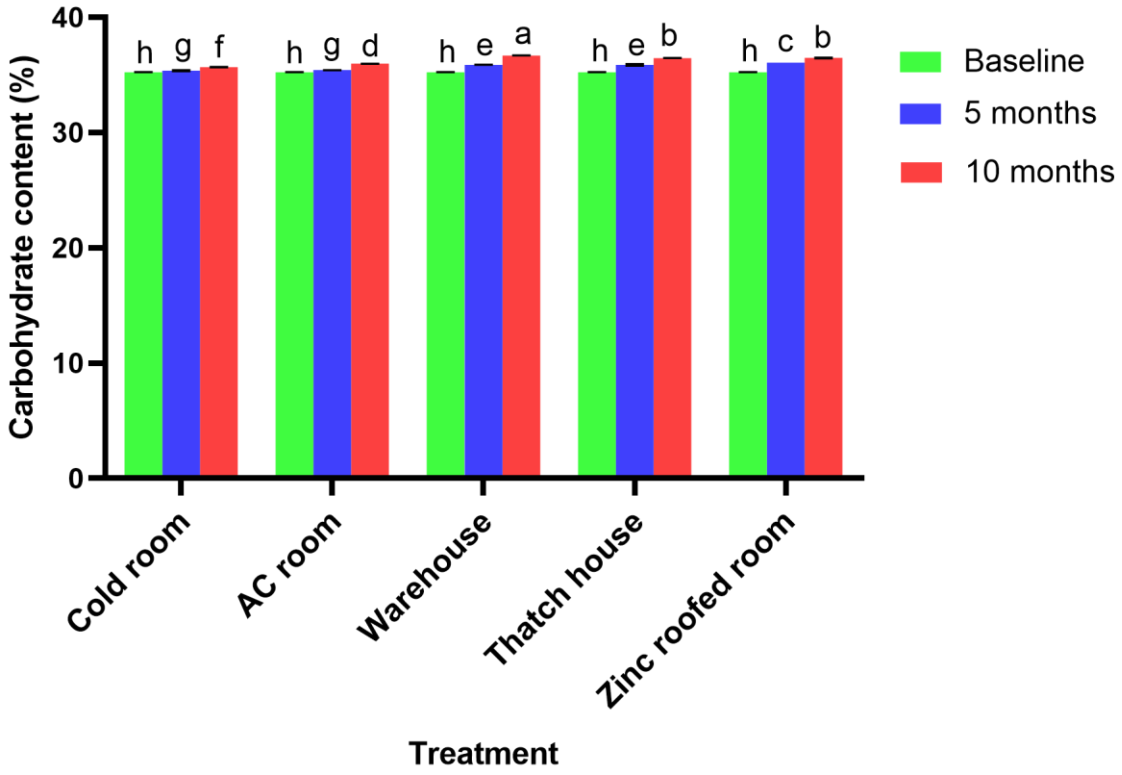



Figure 4.18: Effect of storage rooms and storage durations on carbohydrate content.

Bars represent means ± standard deviation of triplicate determination. Bars with the same alphabet are significantly not different at $P < 0.05$.



### 4.2.5 Pearson correlation and Principal Component Analysis

#### 4.2.5.1 Pearson correlation

There was a positive correlation between germination percentage and the number of normal seeds (r = 0.669). Thus, a greater number of normal seeds contribute to higher germination in soybean seeds. A significant negative correlation between germination percentage and both moisture (r = -0.724) and ash content (r = -0.530). Similarly, moisture content had strong negative correlation with carbohydrate content (r = -0.973) reflecting the interplay between moisture reduction and nutrient concentration, a critical factor for seed quality (Fig. 4.19).

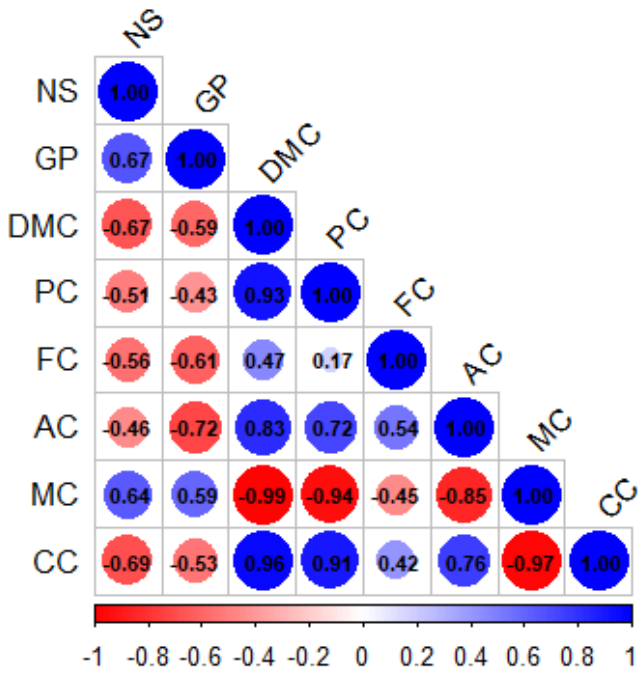



Figure 4.19**:** Pearson correlation analysis between germination linked traits and proximate indices.

**NS**; Normal seeds, **GP**; Germination percentage, **DMC**; Dry matter content, **PC**; Protein content, **FC**; Fat content, **AC**; Ash content, **MC**; Moisture content and **CC**; Carbohydrate content.



### 4.2.5.2 Biplot analysis

Biplot was used to establish the association between proximate composition and germination of the studied soybean. The first and second PCA accounted for 71.9% and 14.7% of the total variance, respectively (Fig. 4.20). Three proximate component (dry matter, carbohydrate and protein) were positively correlated and grouped on axis 2, while fat and ash were grouped in axis 1 and moisture on the negative region.

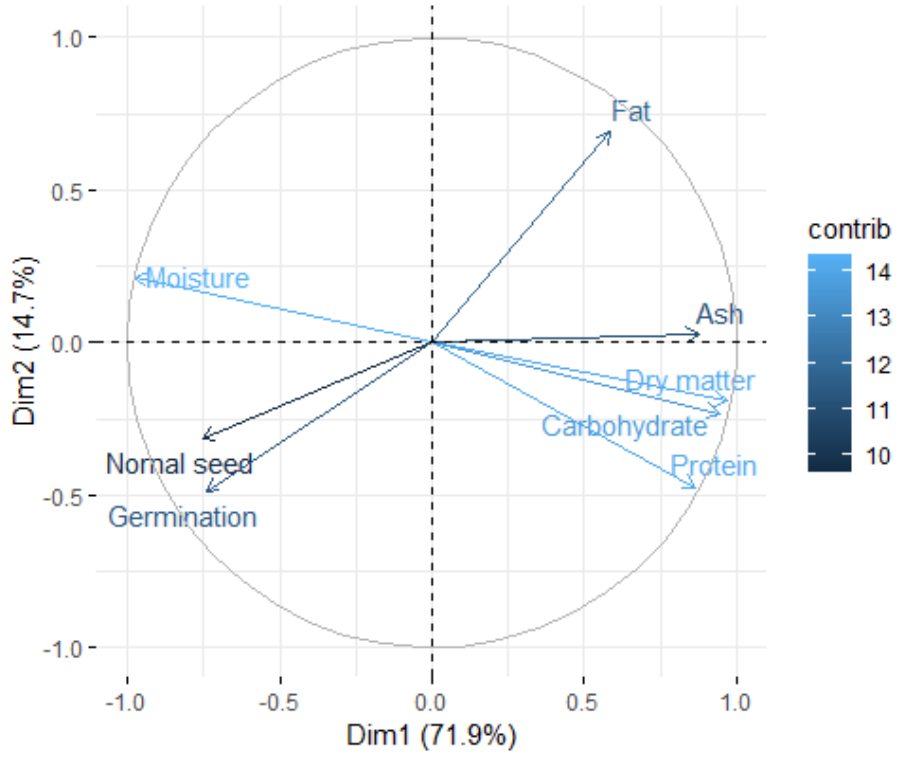



Figure 4.20: Biplot analysis of PC1 and PC2 showing germination and biochemical traits

### 4.2.5.3 Principal component analysis

The traits were partitioned into five PCs with the first three component having eigenvalue above one. These five PCs accounted for a total of 99.2% of the total variability with eigenvalues ranging from 5.751 for PC1 through to 0.078 for PC5 (Table 4.6). Whiles PC1 contributed more than half (0.719) of the total variation observed, PC2 accounted for 14.7%. PC3, PC4 and PC5 also explained 6.8%, 4.8% and 1.0% of the variation, respectively (Table 4.6).

Table 4.5: Principal component analysis showing the contributions of each trait to the variation in the germplasm

| Variable | PC1 | PC2 | PC3 | PC4 | PC5 |
|---|---|---|---|---|---|
| Normal seed | -0.314 | 0.29 | 0.756 | -0.154 | 0.384 |
| Germination | -0.309 | 0.449 | -0.168 | -0.692 | -0.392 |

| | | | | | |
|---|---|---|---|---|---|
| Dry matter | 0.405 | 0.177 | -0.016 | -0.13 | 0.093 |
| Protein | 0.361 | 0.437 | -0.022 | 0.05 | 0.418 |
| Fat | 0.244 | -0.637 | 0.138 | -0.654 | 0.233 |
| Ash | 0.365 | -0.026 | 0.594 | 0.111 | -0.667 |
| Moisture | -0.406 | -0.2 | -0.036 | 0.107 | -0.086 |
| Carbohydrate | 0.393 | 0.214 | -0.165 | -0.166 | -0.093 |
| **Eigenvalue** | **5.751** | **1.177** | **0.541** | **0.388** | **0.078** |
| **Proportion** | **0.719** | **0.147** | **0.068** | **0.048** | **0.010** |
| **Cumulative** | **0.719** | **0.866** | **0.934** | **0.982** | **0.992** |



### 4.3 Experiment 3: Effect of soybean variety, storage bags and storage duration

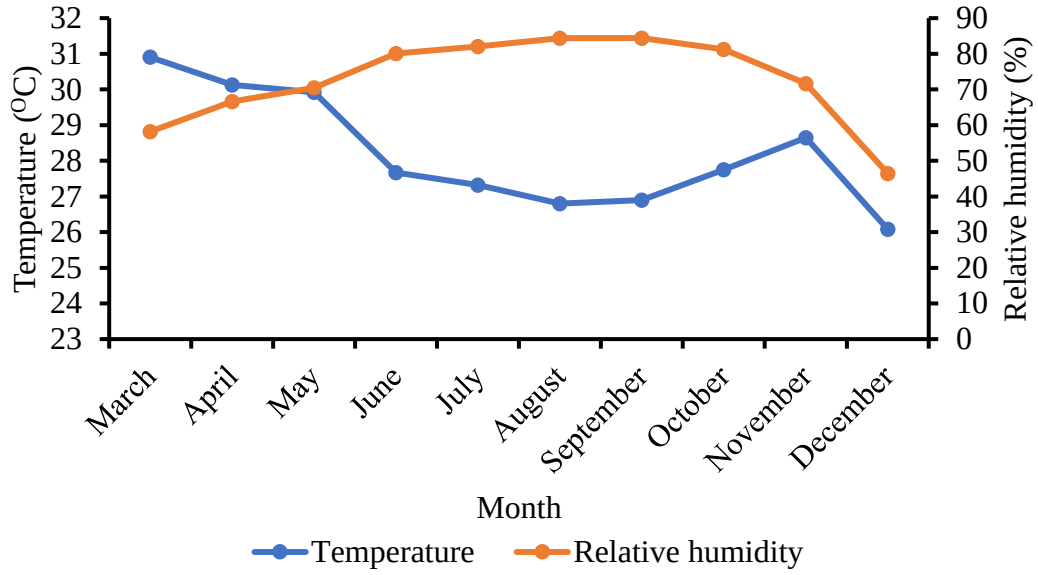



**Figure 4.21: Average monthly temperatures and relative humidity of the study location**

There was significant three-way interaction on all the indices measured except for fat content (Table 4.7). However, there was significant ($P < 0.001$) variety x storage duration

effect on germination percent, number of normal seeds, dry matter, fat, moisture, ash, carbohydrate and protein contents for each region.



Table 4.6: Mean squares from analysis of variance for variety, storage bag and storage period on seed quality and proximate profile

| Source of Variation | df | Germination % | Normal seeds | Dry matter % | Fat % | Moisture % | Ash% | CHO% | Protein % |
|---|---|---|---|---|---|---|---|---|---|
| Main Plot (Variety) | 2 | 59.83*** | 6.02ns | 0.00083*** | 0.05ns | 0.001*** | 0.00001*** | 0.0001*** | 0.001*** |
| Error 1 (Main Plot Error) | 4 | 3.53 | 0.8889 | 0.43 | 1.01 | 0.005 | 0.19 | 0.43 | 0.06 |
| Storage bag | 6 | 157.25*** | 54.57*** | 2.61*** | 0.27*** | 0.87*** | 2.05*** | 0.22*** | 0.09** |
| Variety × Storage bag | 12 | 5.94*** | 8.64*** | 0.90*** | 0.08*** | 2.43*** | 0.85*** | 1.45*** | 0.08** |
| Error 2 (Sub-Plot Error) | 36 | 0.4691 | 0.2654 | 0.03 | 0.01 | 0.007 | 0.01 | 0.02 | 0.02 |
| Storage duration | 2 | 43671.62*** | 1167.73*** | 0.021*** | 2.83*** | 0.59*** | 0.81*** | 81.48*** | 82.49*** |
| Variety × Storage duration | 4 | 13.87*** | 5.69*** | 6.84*** | 6.33*** | 0.57*** | 0.16*** | 120.05*** | 1.25*** |
| Storage bag × Storage duration | 12 | 84.20*** | 17.39*** | 0.95*** | 0.13ns | 0.42*** | 0.65*** | 0.16ns | 0.06** |
| Variety × storage bag × Storage duration | 24 | 5.01*** | 4.27*** | 0.33*** | 0.11ns | 0.80*** | 0.28*** | 0.45*** | 0.09*** |
| Error 3 (Sub-Sub Plot Error) | 84 | 0.7381 | 0.60 | 0.13 | 0.19 | 0.006 | 0.03 | 0.18 | 0.02 |

df; degree of freedom. CHO; Carbohydrate. *, **, *** and ns represent significant differences at $p < 0.05$, $p < 0.01$, $p < 0.001$ and not significant, respectively.

#### 4.3.1.1 Variety, storage bags and storage duration effect on germination percentages

A significant reduction in germination percentage was observed after 10 months across all storage bags (Fig. 4.22). At the start of storage, germination was highest in 'Favour' (95.00%), followed by 'Afayak' (93.67%) and 'Jenguma' (93.67%). By the end of the storage period, seeds stored in jute sacks experienced the greatest reduction in germination: 57.19% for 'Favour', 58.72% for 'Afayak', and 57.55% for 'Jenguma'. In contrast, the lowest reductions were observed in seeds stored in GICS bags, with decreases of 36.84% for 'Favour', 41.09% for 'Afayak', and 41.37% for 'Jenguma'.

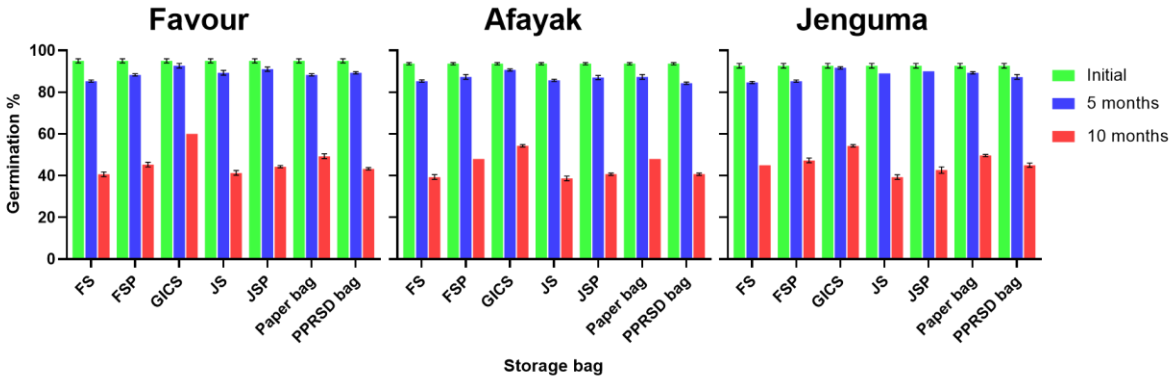



Figure 4.22: Effect of variety, storage bags and storage duration on germination percent

Error bar represents mean (Standard deviation) of three replication. FS- Polypropylene bags without lining, FSP- Polypropylene bags lined with polyethylene sheets, JS- Jute sack without lining, JSP- Jute sack lined with polyethylene sheets, PPRSD bag- Plant Protection and Regulatory Services Department bag recommed for use in storing seeds in Ghana.

#### 4.3.1.2 Variety, storage bags and storage duration effect on number of normal seeds

Significant decline in number of normal seeds was observed after 10 months, regardless of the variety and type of storage bag (Fig. 4.23). Seeds stored in jute and GICS bags gave

the highest and least number of abnormal seeds during the storage period, respectively (Fig. 4.23).

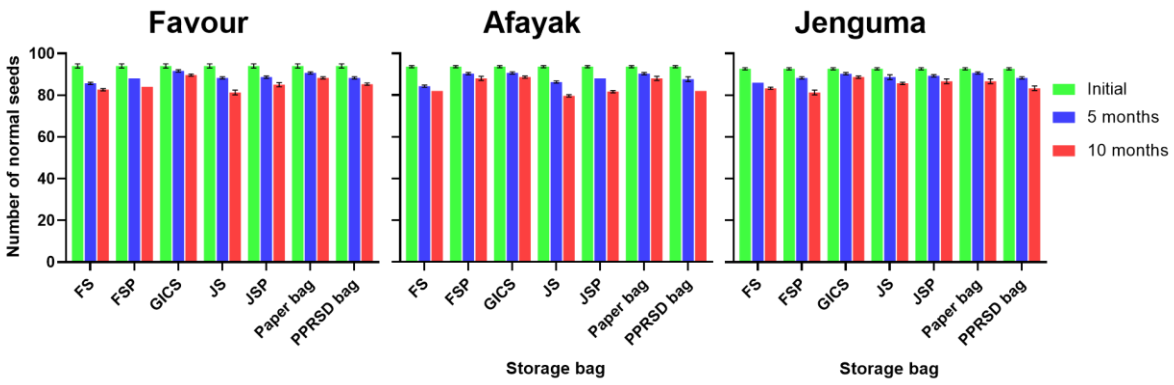



Figure 4.23: Effect of variety, storage bags and storage duration on the number of normal seeds

Error bar represents mean (Standard deviation) of three replication. FS- Polypropylene bags without lining, FSP- Polypropylene bags lined with polyethylene sheets, JS- Jute sack without lining, JSP- Jute sack lined with polyethylene sheets, PPRSD bag- Plant Protection and Regulatory Services Department bag recommed for use in storing seeds in Ghana.

### 4.3.1.3 Variety, storage bags and storage duration effect on dry matter content

The dry matter level of all the three soybean varieties increased during the storage period (Fig.4.24). The initial dry matter content was relatively lower in 'Jenguma' (85.07%) as compared to 'Favour' (91.84%). After the storage period, the average dry matter content increased by 5.33%, 3.59%, and 3.06 % for 'Afayak', 'Favour' and 'Jenguma', respectively. However, among the storage bags, seeds packaged in the paper bag had the highest increase in dry matter content for 'Afayak' (6.51%) and 'Jenguma' (4.46%), whiles the jute sack showed high dry matter content for 'Favour' (4.49%). Th GICS bag had the lowest dry matter content increase for 'Favour' and 'Afayak', whereas seeds kept in the PPRSD bags had the least dry matter in 'Jenguma'.

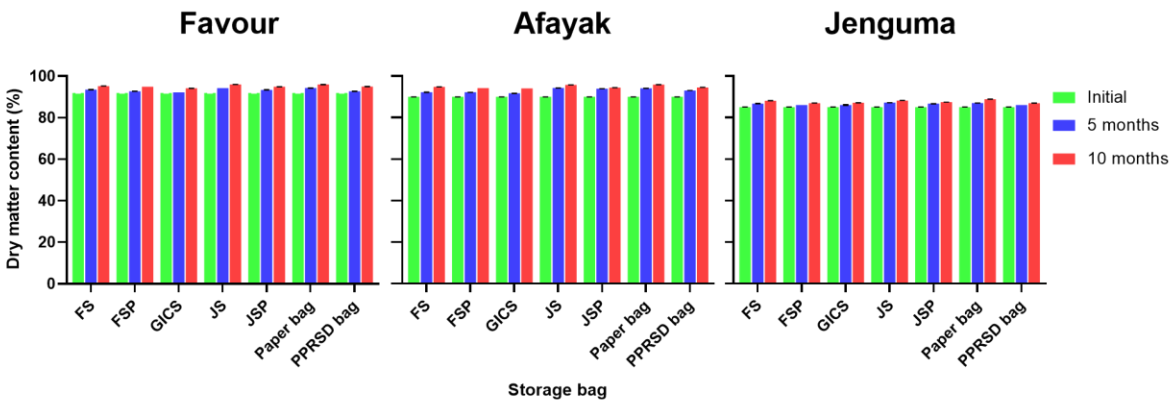



Figure 4.24: Effect of variety, storage bags and storage duration on dry matter content

Error bar represents mean (Standard deviation) of three replication. FS- Polypropylene bags without lining, FSP- Polypropylene bags lined with polyethylene sheets, JS- Jute sack without lining, JSP- Jute sack lined with polyethylene sheets, PPRSD bag- Plant Protection and Regulatory Services Department bag recommed for use in storing seeds in Ghana.

#### 4.3.1.4 Variety, storage bags and storage duration effect on protein content

The initial protein levels were 27.38%, 35.91% and 37.52% in 'Jenguma', 'Afayak' and 'Favour', respectively, and these levels decreased over the storage period (Fig. 4.25). Although 'Favour' had the highest initial protein content, the decrease was highest (7.32%) and least in 'Afayak' (6.10%). The protein content did not differ significantly *(P > 0.05)* among the various storage bags for 'Favour' and 'Jenguma' at the end of the storage period. For 'Afayak', jute sack lined with poly bag had the greatest decline in protein content over the storage duration.

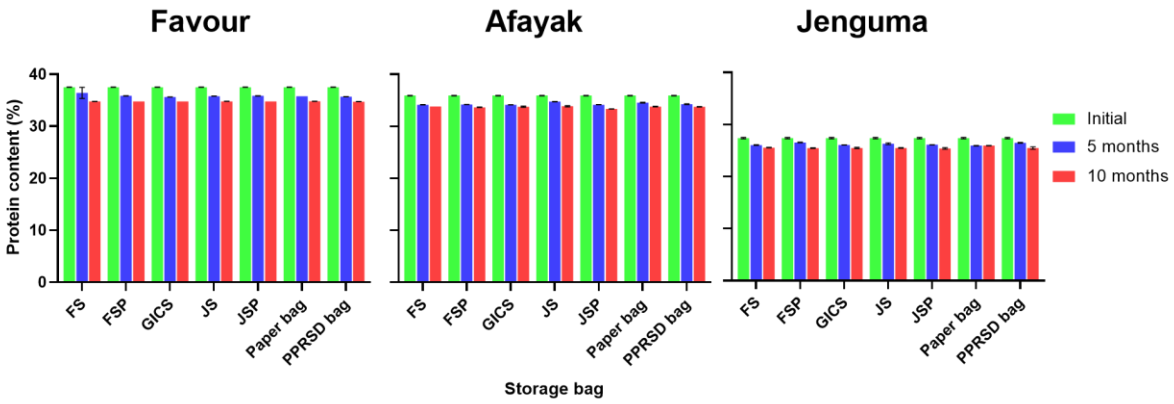



Figure 4.25: Effect of variety, storage bags and storage duration on protein content

Error bar represents mean (Standard deviation) of three replication. FS- Polypropylene bags without lining, FSP- Polypropylene bags lined with polyethylene sheets, JS- Jute sack without lining, JSP- Jute sack lined with polyethylene sheets, PPRSD bag- Plant Protection and Regulatory Services Department bag recommed for use in storing seeds in Ghana.

#### 4.3.1.5 Variety, storage bags and storage duration effect on percent fat content

The three-way (variety × storage duration × storage bag) did not show any significant (P = 0.918) effect on the fat content of the seeds. However, the two-way interactions significantly (P < 0.001) affected fat content in the seeds (Fig. 4.26)

The interaction effect between storage bags and storage duration on fat content was significant for 'Afayak' (P < 0.001) but not for 'Favour' (P = 0.986) or 'Jenguma' (P = 0.479) (Fig. 4.25a and 4.25c). three packaging materials (Jute sacks, Jute sacks lined with polyethene and paper bags) give a similarly higher fat content (21%) 5 months for 'Jenguma', 16% for 'Afayak' and 15% for 'Favour'. 'Jenguma' and 'Afayak' both lost 1% fat at 10 months under Jute sacks, Jute sacks lined with polyethene and paper bag storages but the fat content in 'Afayak' remained unchanged (15%). However, storage duration alone had a significant effect on both 'Favour' and 'Jenguma'. The initial fat content in

'Jenguma' was high (2.14%) but it decreased by about 19.12% at the end of the 10 months storage period. Although seeds kept in the PPRSD bag had the highest fat loss (9.10%) in 'Afayak', this loss was comparable to those observed in JSP, JS, GICS, FSP, and FS bags.

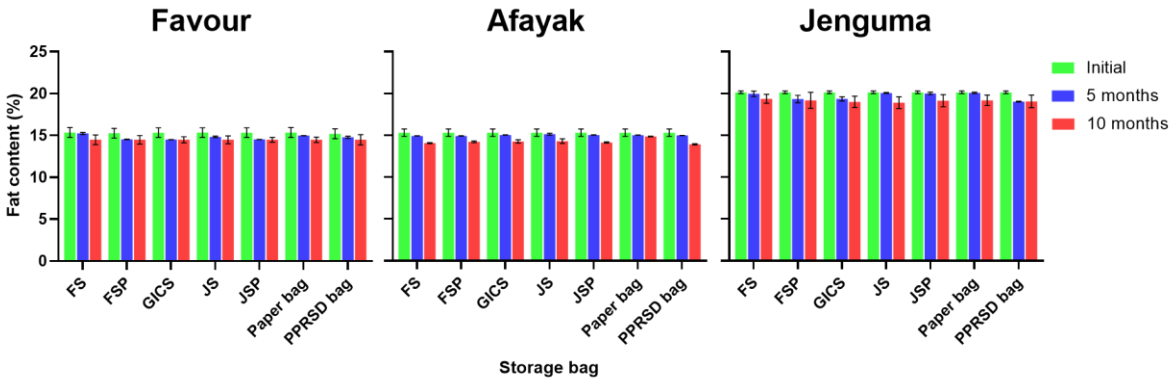



Figure 4.26: Effect of variety, storage bags and storage duration on fat content

Error bar represents mean (Standard deviation) of three replication. FS- Polypropylene bags without lining, FSP- Polypropylene bags lined with polyethylene sheets, JS- Jute sack without lining, JSP- Jute sack lined with polyethylene sheets, PPRSD bag- Plant Protection and Regulatory Services Department bag recommed for use in storing seeds in Ghana.



#### 4.3.1.6 Variety, storage bags and storage duration effect on ash content

The ash content increased over the storage duration, with the increase significantly influenced by both storage bags and storage duration for 'Favour' and 'Afayak' (Fig. 4.27). The rate of increase was highest in the paper bag, reaching 51.34% for Favour and 75.14% for 'Afayak' at the 10$^{th}$ month of storage.

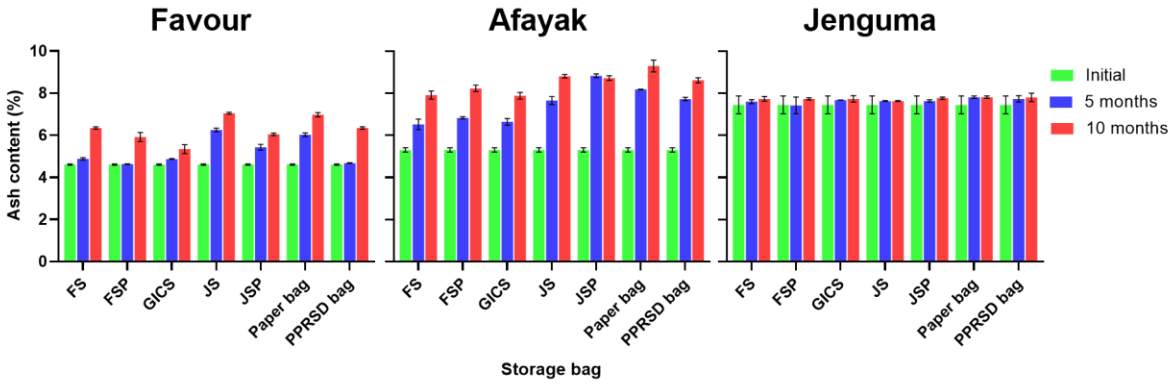



Figure 4.27: Effect of variety, storage bags and storage duration on ash content

Error bar represents mean (Standard deviation) of three replication. FS- Polypropylene bags without lining, FSP- Polypropylene bags lined with polyethylene sheets, JS- Jute sack without lining, JSP- Jute sack lined with polyethylene sheets, PPRSD bag- Plant Protection and Regulatory Services Department bag recommed for use in storing seeds in Ghana.

### 4.3.1.7 Variety, storage bags and storage duration effect on moisture content

There was a significant ($P < 0.001$) three-way interaction effect on seed moisture content. significant interaction effect ($P < 0.001$) was observed between storage bags and storage duration (Fig. 4.28). The initial seed moisture content at the start of the experiment was 8.14% for 'Favour', 9.99% for 'Afayak', and 14.93% for 'Jenguma'. By the end of the storage period, seeds kept in the jute sack had the highest moisture loss in 'Afayak' (58.62%) and 'Favour' (50.08%) whereas seeds kept in the paper bag recorded the highest loss for 'Jenguma' (25.43%). Across all soybean varieties, the highest increase in moisture was recorded in seeds stored in paper bags: 50.08% for 'Favour', 58.62% for 'Afayak'', and 25.43% for 'Jenguma'.

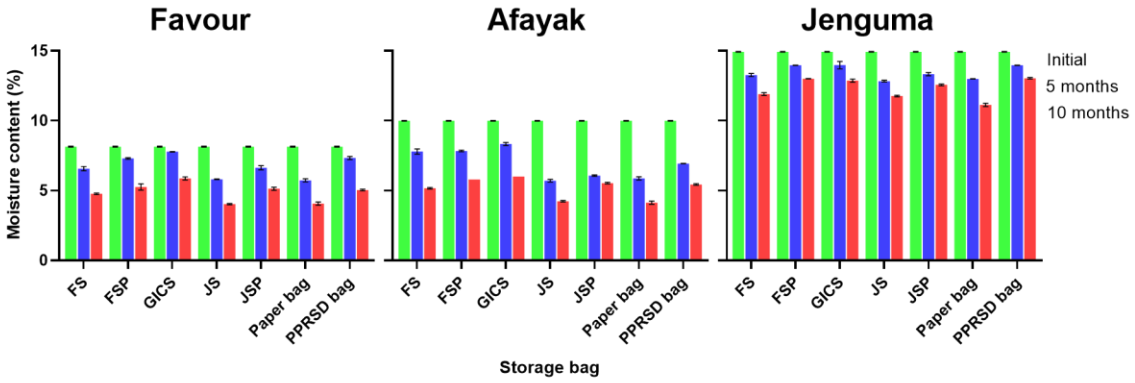



Figure 4.28: Effect of variety, storage bags and storage duration effect on moisture content

Error bar represents mean (Standard deviation) of three replication. FS- Polypropylene bags without lining, FSP- Polypropylene bags lined with polyethylene sheets, JS- Jute sack without lining, JSP- Jute sack lined with polyethylene sheets, PPRSD bag- Plant Protection and Regulatory Services Department bag recommed for use in storing seeds in Ghana.

### 4.3.1.8 Variety, storage bags and storage duration effect on carbohydrate content

There was a significant ($P < 0.01$) interaction between storage bags and storage duration on carbohydrate content. At the start of the experiment, the carbohydrate contents were 35.24 %, 33.49 % and 30.11 % for 'Favour', 'Afayak' and 'Jenguma', respectively. The carbohydrate content of the seeds stored in FS, FSP, GICS, JS, JSP, paper bag and PPRSD bag did not demonstrate a significant increase after the 10 months storage duration for 'Favour' (Fig. 4.29). For 'Afayak', seeds stored in FSP, GICS, JS, JSP, paper bag and PPRSD bag had similar ($P > 0.50$) carbohydrate contents (Fig. 4.29).

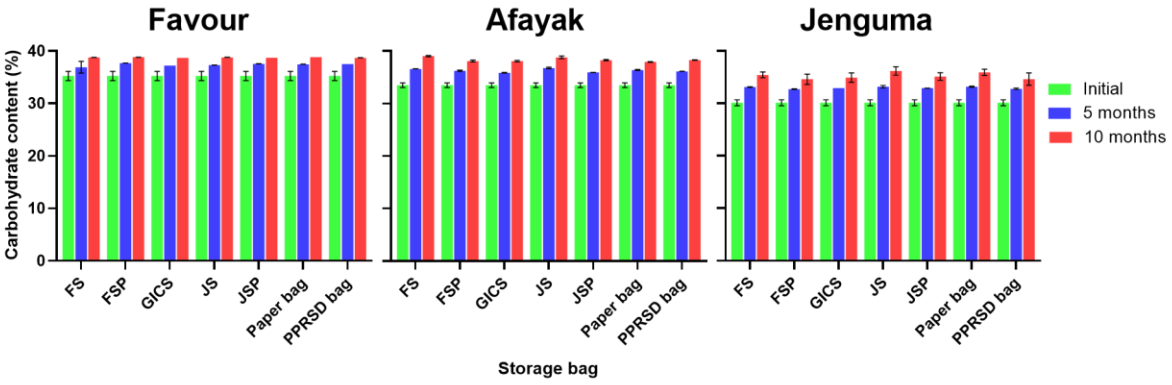


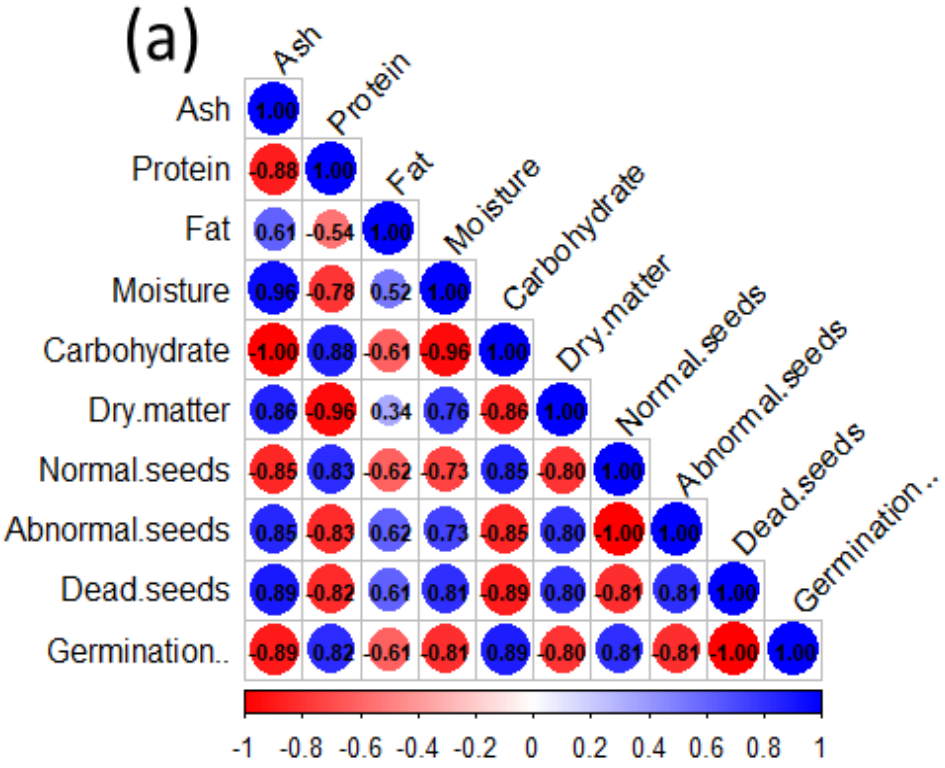

Figure 4.29: Effect of variety, storage bags and storage duration on carbohydrate content

Error bar represents mean (Standard deviation) of three replication. FS- Polypropylene bags without lining, FSP- Polypropylene bags lined with polyethylene sheets, JS- Jute sack without lining, JSP- Jute sack lined with polyethylene sheets, PPRSD bag- Plant Protection and Regulatory Services Department bag recommed for use in storing seeds in Ghana.

### 4.3.2 Pearson correlation

Figure 4.29 shows that germination % significantly and negatively correlated with ash content, dry matter content, the number of abnormal seeds, and dead seeds. Thus, higher levels of these indices have the tendency to suppress seed germination in soybean. In contrast, germination % positively correlated with protein content and the number of normal seeds across all soybean varieties (Fig. 4.30a, Fig. 4.30b, and Fig. 4.30c). Thus, higher contents of protein and greater normal seed count will enhance seed germination in soybean. Interestingly, germination % showed a positive correlation with carbohydrate content (0.89) for the 'Favour' variety but a negative correlation for 'Afayak'' (-0.88) and 'Jenguma' (-0.85). Similarly, for 'Favour', germination % was negatively correlated with fat (-0.61) and moisture (-0.81). However, for 'Afayak' and 'Jenguma', germination % was positively correlated with fat and moisture contents (Fig. 4.29b and c). These results

demonstrate the influence of the genetic variability of the different certified seeds which will require closer attention by the breeders for improvement purpose.



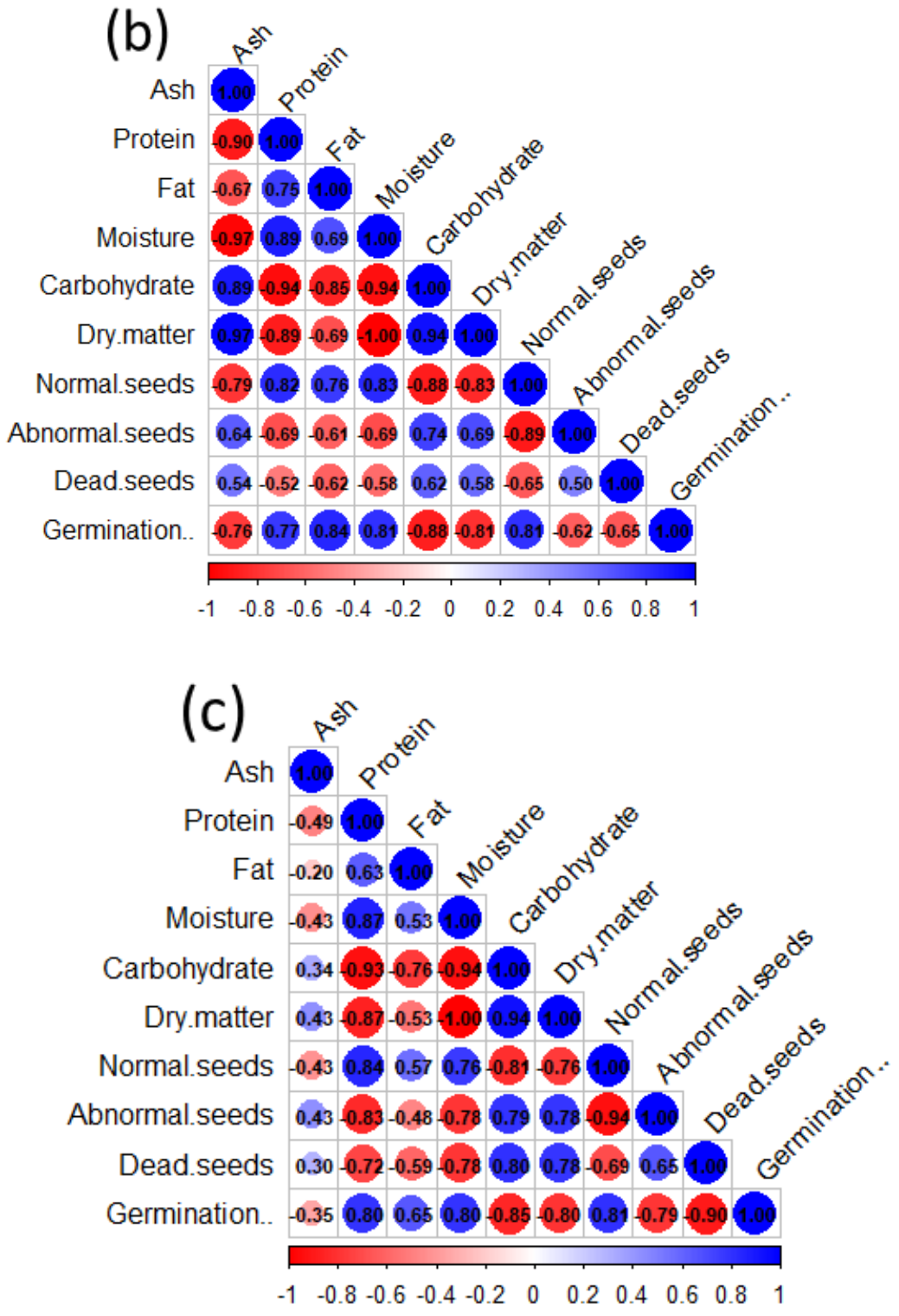


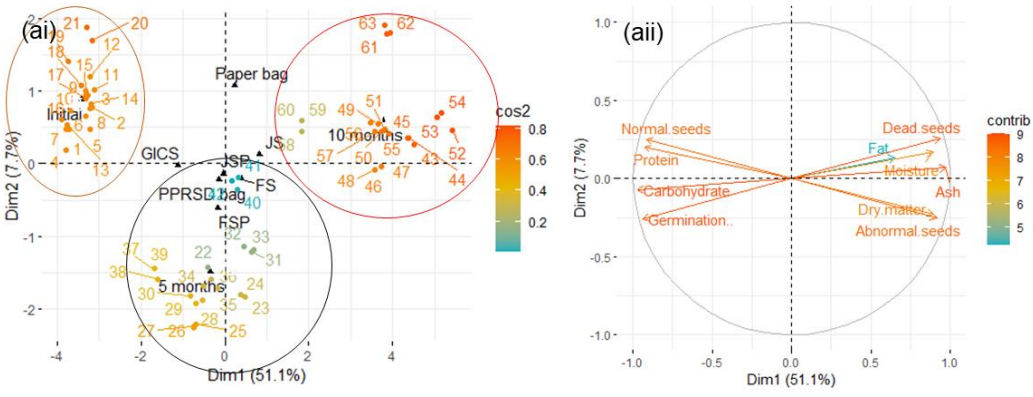

Figure 4.30: Pearson's correlation matrix among proximate and germination linked traits. a; Favour, (b); Afayak and (c); Jenguma.

### 4.3.3 Principal Component Analysis (PCA)

To explore the relationships between different storage bags and storage duration in relation to proximate components and germination-linked traits, we projected individual values onto the first two dimensions (Dim1 and Dim2) using Factor Analysis for Mixed Data (FAMD). The first two dimensions explained 59.6% of the total variability for 'Favour', 58.4% for 'Afayak', and 54.8% for 'Jenguma'. Additionally, the biplot showed clear and distinct groups among the three storage periods (initial, 5 months, and 10 months). The 10-month storage group exhibited greater dispersion of datapoints compared to the 5-month storage, suggesting that prolonged storage significantly alters seed composition.

### 3.3.4 Factor Analysis of Mixed Data (FAMD)

The variance maximizing data point distribution in the factor map showed a clear clustering pattern based on the storage duration (initial, 5-month, and 10-month) (Fig. 4.31ai, Fig.4.31bi and Fig. 4.31ci). Additionally, the widest spread in data points suggests increased heterogeneity in seed deterioration over the storage period.



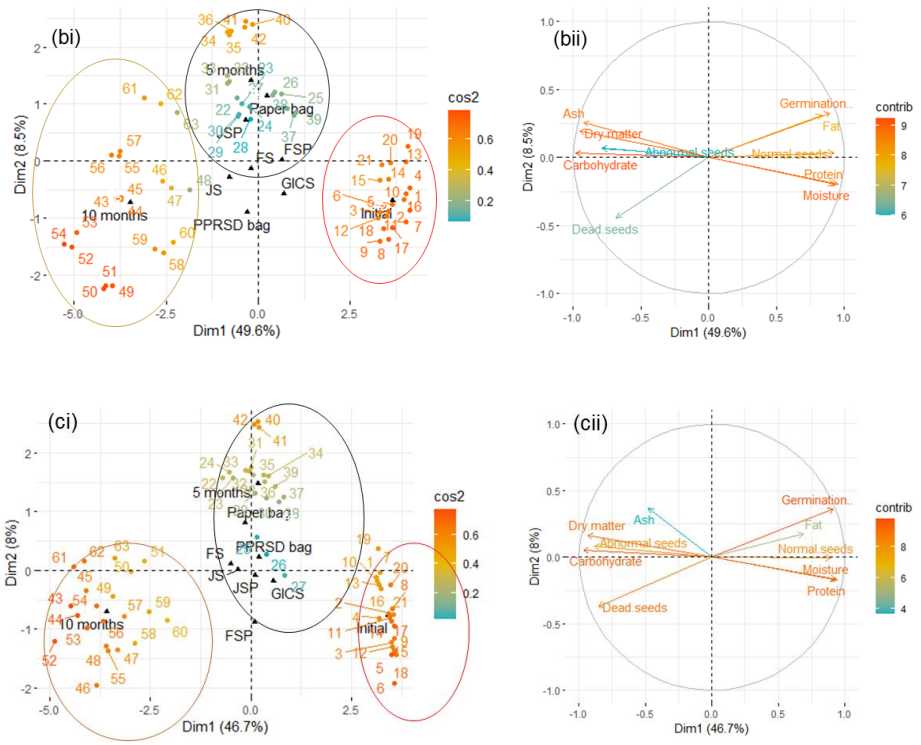



Figure 4.31: Factor maps obtained from the FAMD showing variance maximizing distribution pattern of data points

a; Favour, (b); Afayak and (c); Jenguma. FS; Fertilizer sack without lining, FSP; Fertilizer sack lined with polyethylene sheets, JS; Jute sack without lining, JSP; Jute sack lined with polyethylene sheets, PPRSD bag; Plant Protection and Regulatory Services Department bag recommed for use in storing seeds in Ghana.

For 'Favour', the ash, carbohydrates, protein, germination %, moisture contents as well as the number of normal seeds significantly contributed to the formation of Dim1, while the Dim5 was mainly influenced by the fat content (Table 4.7 and Figure 4.28aii). Similarly, Carbohydrate content, moisture content, dry matter, ash, protein content, germination %, fat content contributed substantially to Dim1 whereas, abnormal seeds was positively correlated with Dim3 for 'Afayak' (Table 4.8 and Figure 4.30bii). In 'Jenguma', the dead seeds, fat and ash contents correlated positively with Dim2, Dim4 and Dim5, respectively (Table 4.7 and Figure 4.28cii).

Table 4.7: Contributions of the first five dimensions by FAMD

| | Favour | | | | | Afayak | | | | | Jenguma | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Dim. 1** | **Dim. 2** | **Dim. 3** | **Dim. 4** | **Dim. 5** | **Dim. 1** | **Dim. 2** | **Dim. 3** | **Dim. 4** | **Dim. 5** | **Dim. 1** | **Dim. 2** | **Dim. 3** | **Dim. 4** | **Dim.5** |
| AC | 10.32 | 0.34 | 2.01 | 0.26 | 0.00 | 9.56 | 4.30 | 1.91 | 0.74 | 0.12 | 2.70 | 9.35 | 0.00 | 1.89 | 11.20 |
| PC | 9.37 | 2.95 | 0.50 | 4.86 | 0.04 | 9.67 | 2.46 | 0.63 | 1.25 | 4.19 | 10.53 | 2.04 | 0.24 | 0.69 | 0.78 |
| FC | 4.65 | 1.31 | 1.20 | 1.24 | 7.09 | 7.86 | 6.42 | 0.42 | 3.64 | 0.46 | 5.67 | 2.19 | 4.62 | 11.59 | 0.89 |
| MC | 8.70 | 2.05 | 7.14 | 1.22 | 0.36 | 10.18 | 2.51 | 0.68 | 0.93 | 0.63 | 10.41 | 1.87 | 4.24 | 0.22 | 0.04 |
| Car C | 10.29 | 0.36 | 2.17 | 0.29 | 0.01 | 10.81 | 0.06 | 0.17 | 0.39 | 0.30 | 11.10 | 0.21 | 0.11 | 0.67 | 1.19 |
| DM | 8.68 | 3.77 | 0.73 | 4.72 | 0.15 | 10.18 | 2.51 | 0.68 | 0.95 | 0.62 | 10.41 | 1.87 | 4.24 | 0.22 | 0.04 |
| NS | 9.13 | 4.55 | 2.16 | 2.54 | 0.03 | 9.60 | 0.07 | 6.66 | 0.05 | 0.11 | 9.55 | 0.00 | 6.07 | 3.56 | 0.00 |
| ANS | 9.13 | 4.55 | 2.16 | 2.54 | 0.03 | 6.96 | 0.30 | 17.37 | 0.22 | 0.06 | 9.26 | 0.46 | 4.48 | 4.49 | 0.25 |
| DS | 9.54 | 4.77 | 2.99 | 0.64 | 0.18 | 5.24 | 12.81 | 0.11 | 11.05 | 1.47 | 8.68 | 9.57 | 3.40 | 0.05 | 0.08 |
| G% | 9.54 | 4.77 | 2.99 | 0.64 | 0.18 | 9.00 | 7.04 | 1.68 | 1.34 | 2.73 | 9.94 | 9.05 | 0.08 | 0.02 | 1.48 |

**AC**; Ash content, **PC**; Protein content, **FC**; Fat content, **MC**; Moisture content, **Car C**; Carbohydrate content, **DM**; Dry matter, **NS**; Normal seeds, **ANS**; Abnormal seeds, **DS**; Dead seeds and **G%**; Germination percent.

# CHAPTER FIVE

## 5.0 DISCUSSION

### 5.1 Experiment 1: Seed source, variety and storage duration on seed quality and proximate profile

The quality of seed during storage is greatly influenced by the proximate composition of the initial seed (quality) before storage, moisture content, temperature, relative humidity of the storage environment and storage duration. Within the study area (northern Ghana), soybean seeds for planting a cropping season are typically produced during the preceding cropping seasons. Due to low investment in storage infrastructure, temperature range of $25^0$C – $35^0$C recorded over this storage period was far above the recommended $15^0$C or lower. This contributed towards a quick decline in viability, poor germination and low dry matter accumulation. This observation corresponds with (Coradi et al, 2020), who reported that, ambient temperature and storage time were main factors reducing the quality of soybean seeds in storage. Relative humidity for the storage location ranged from 28% - 45%, over the period. This however fell within recommendation of below 60% (Mbofung et al., 2013). The low RH surported nornaml physiological activites of the seed with no negetive influence on the seed within the storage period. Thus, the low RH with high temperature allowed for moisture loss, reduced respiration and supressed fungal growth. Similar observations were made by Pratiwi et al. (2015) in their study on effects of temperature and RH for Aspergillus flavus BIO 2237 growth and aflatoxin production on soybeans.

However, this study focused on investigating the effect of seed source, variety and storage duration on seed quality in three commercials in soybean varieties.

The results shows significant difference between the three way interaction (source × variety × storage durartion) for both normal seeds and germination percentages. Again the correlation figures from all regions indicated strong posive bonds of correlation between normal seeds and germination (north – 0.83, UER – 0.83, UWR – 0.85, Control – 0.8). these are clear indications that, higher percentage of normal seeds would promote an equally higher germination percentage among the seeds. The expectation played out in UWR where high percentages of normal seeds ('Afayak' – 91%. 'Favour' – 93% and 'Jenguma' – 90%) resulted in similarly higher percentage of germinatio ('Afayak' – 94.5%. 'Favour' – 95.5% and 'Jenguma' – 86.5%). Similar obervetions were reported by Mangena and Mokwala, (2019) that high germination rates and efficient in vitro shoot induction depended largely on seed viability and storage duration. Selecting quality seeds for planting improve seed germination speed and success (Reed et al., 2022). High percentage normal seeds alone may not be the ultimate and automatic parameter in determining germination. Other factors such as genetics, environment (moisture, temperature, RH, dormancy and inherent disease conditions) and proximate compositions may all play part. Such observations were made in seeds from the north where 'Afayak' recorded highest percent of normal seeds (81%), followed by 'Jenguma' (78%) and 'Favour – the least (70.5%). Results from germination on the other hand placed 'Favour' first (74.5%), 'Jenguma' second (49%) and 'Afayak' third (33.6%). This finding corresponds with similar works reported by Mai-Hong et al., (2003) who reported on seed dormancy and moisture variations as sources of variation in seed germination. It also corresponds with Wang et al.

(2016) who reported that, seed germination is a response to temperature, osmotic potential, salinity and depth of seed burial.

The percentage of normal seeds and germination rate of the soybean seeds decreased over the storage duration. In particular, the decreasing trend was high in the tenth month of storage. This can be attributed to the high temperature, deterioration of seed components and the loss of seed viability. This decrease is likely due to the accumulation of damages from various cellular and biochemical processes that occur over time as reported by Corbineau, (2024). It is well-established that storage conditions have an adverse impact on seed quality (Koskosidis et al., 2022). This has been demonstrated in several varieties of soybean with a more than 37% reduction in germination rate after six months of storage (Isaac et al., 2016). In the present study, more than 80% reduction after 10 months of storage was observed while more than 90% reduction after 12 months of storage was reported by Kandil et al. (2013) under ambient temperature and relative humidity. Within this changing profile, significant germination differences were found between the soybean genotypes and their respective control samples. These differences varied in magnitude depending on the seed source, with seeds from the Upper West and Upper East regions showing distinct differences compared to those from the Northern region, suggesting an impact of preharvest practices, seed source, or microenvironment on seed quality. These results support the previous finding of Chaluma (2023), who reported that prolonged storage decreases soybean seed germination irrespective of the seed source.

Again, the results shows significant difference between the three way interaction (source × variety × storage durartion) for protein and germination percentages. This indicates that protein contents in soybean seeds promoted germination, The higher germination

performance in 'Favour' could be linked to its higher protein content than the other two varieties (north - 36%, UE – 39% and UW – 37%) as compared to 'Afayak' (north - 34%, UE – 35% and UW – 36%) and 'Jenguma' (north - 26%, UE – 26% and UW – 27%). This agrees with Wen et al., (2018) who reported that Nitrogen mobilization from storage protein is required to meet the amino acid demands at the early stage of germination. It also corresponds with Lopez (1973) who noted that, the higher protein seed had a faster speed of germination, good water absorption and oxygen consumption and better performance in stressed conditions. Karak and Hazra (2018) also reported higher germination in onion varieties with high protein content. Thus, their finding agrees with this current study. Previous studies have reported a significant reduction in the protein levels in soybean seeds during storage (Narayan et al., 1988; Sharma et al., 2013). In this current study, however, the protein content of all three soybean varieties remained fairly the same ($P > 0.05$) over the same period. This dynamic in protein levels suggests that the proteins in our soybean varieties may have some resistance to storage heat stress. Protein structural changes are less prominent in the tolerant soybean genotype (Krishnan et al., 2020). Seed protein content has been reported to increase with increasing growing temperature and a negative correlation exists between protein and oil across a range of rising temperatures (Wolf et al., 1982; Xu et al., 2016). The principal component analysis (PCA) demonstrated that protein negatively correlated with fat across the storage period. Consistent with the finding of Bakhtiar et al. (2024), the PCA suggested that fat, ash, and carbohydrate contents had a significant positive correlation.

Moisture percent recorded for all seeds at the onset of the study (14%-18%) was generally high as compared to recommended range of 10% to 12% (IOWA State University, 2006)

for soybean storage. Though no physical observations were seen in form of mold, fungal growth, discoloration, or rapid spoilage that were attributed to this high moisture content, that could result in high respiration, increased chemical degradation and reduced viability. This agrees with IOWA State University, (2006), that, storing soybean seeds with high moisture content over 10% for long periods could result in fungal growth and mold, rapid spoilage, reduced germination, increased chemical degradation, physical damage and discoloration and shortened storage Life. Moisture content for all seed varieties from all sources however decreased with prolonged storage period, high temperature, low humidity recorded in the storage environment and good aeration to between 11.5% 8.5% by the 10$^{th}$ month. The reduction in moisture content contributed to slowing down the rate of deterioration. This agrees with Adjei et al., (2022) who reported similar moisture loss in beans in Ghana as economical for seed growers instead of artificially drying the seed to lower moisture levels before storage. On the other hand, loss of seed moisture during storage can cause cellular dehydration, leading to the disruption of metabolic processes and the loss of seed viability. The combination of these factors contributes to the observed decrease in normal seed count and germination rate during the tenth month of storage. The observation highlights the importance of optimizing storage conditions to maintain seed quality. For germination however, moisture correlated highly and positively with gemination (north - 0.93%, UER - 0.85%, UWR - 0.94% and control 0.91%). This is an indication that moisture is most relevant for germination. As moisture supply increase, germination is enhanced. This agrees with Cheong and Lim (2023) who reported that seed water uptake is the first process in germination. The germination efficiency increased with increasing seed moisture content.

Fat content was highest in the 'Jenguma' variety from all sources followed by 'Afayak' and 'Favour'. Fat content decreased gradually from the basal point through to 5$^{th}$ and 10$^{th}$ months. The lower germination percentages recorded in 'Jenguma' variety particular and seeds from north and UER were clear indications that high soybean fat content during storage is detrimental to germination. 'Favour' variety which recorded the least fat performed best throughout the study. This agrees with earlier literature that, the lipid related changes of seeds during storage revealed decline in phospholipids and polyunsaturated fatty acids leading to marked decline in seed germination and vigour (Priestley and Leopold 1983). Auto-oxidation of lipids and increase in the content of free fatty acids during storage period are the main reasons for rapid deterioration of oil seeds (Balesevic-Tubic et al. 2005). Previous studies have reported a significant reduction in the fat levels in soybean seeds during storage (Narayan et al., 1988; Sharma et al., 2013) a phenomenon that matches with the current study. The presence of high-fat content makes soybean seeds susceptible to rapid deterioration due to lipid hydrolysis, lipid oxidation, and the resulting rancidity (Ludwig et al., (2021)

Though carbohydrate was not significant in the three-way interaction, it shows significance in two-way interaction (variety × storage durartion). Carbohydrate in this study did not influence germination. Thus 'Jenguma' which showed the highes carbohydrate content throughout the study period did not translate into highest germination, but germination was best I 'Favour' which recoded the least carbohydrate content. Results from this study however, contradicts earlier reports from Hirsche et al., (2017) and Ologhobo and Fetuga, (1986) in Arabidopsis Pollen Germination and germinating cowpea seeds. Carbohydrate contents increased marginally across all varieties and study period probably due varietal

composition and moisture loss. This finding contradicts Ramtekey et al., (2022) who noted that, prolonged storage leads to the breakdown of seed carbohydrates, compromising seed integrity and functionality. Soluble carbohydrates generally decline with seed ageing (Petruzelli and Taranto 1989) and this decline might result in limited availability of respiratory substrates for germination (Sharma et al. 2005)

Ash content was more pronounced in 'Jenguma' variety across all three regions and increased with prolonged storage period across all regions and varieties. This finding contradicts earlier studies Narayan et al., (1988) which reported that ash content first increased and thereafter decreased with increasing storage period. Principal component analysis shows ash content highly correlated negatively with germination which suggests that, the higher the ash content, the less the gemination percentage of the seed. These were evidence in the results where 'Jenguma' with the highest ash contents translated into the least germination percentage in both UW, UE and in the control. This finding consolidated earlier work reported by Onwugbuta-Enyi and Offor, (2020) that higher ash content inhibited germination in oil palm

Dry matter seed dry matter (DM) content represents the solid, non-water constituents (starch, protein, oil) remaining after all moisture is removed. Seed dry matter content in this study increased from the baseline through to 5 and 10 months. This was attributed to moisture loss due to high temperature and low RH in the storage environment. The principal component analysis shows high negative correlation between dry matter and germination, implying that the higher the dry matter accumulation in storage, the lower the germination percentage, and *vice versa*. Rapid moisture loss in stored seeds as a result of high temperature could lead to potential physiological damage and breaking of the seed

cotyledon. The ultimate effect is loss of viability when the seed is planted as observed. This agrees with earlier reports by Long and Bonilla (2019) and Filho et al. (2016) that increase in the temperature of drying air affects the physiological quality of soybean seeds, and this effect is increased over time.



### 5.2 Experiment 2: Storage room and storage duration

The viability of a seed is primed on seed germination percentage, and is influenced by several endogenous and exogenous factors including energy reserves in seed, storage conditions and the duration of seed storage. Generally, soybean seeds have low vitality due to their high fat content, susceptibility to oxidation, and tendency to sustain mechanical damage (Koskosidis et al., 2022; Muhammad et al., 2020).

Results from the current study established the cold room storage as the best option for preserving soybean seed viability in storage. Its results were best for all the germination indices which highly and positively correlated with germination (normal seed and moisture) as shown in the principal component analysis. This agrees with earlier findings that ambient temperature and storage time are the main factors reducing the quality of soybean seeds (Caradi et al., 2020). Optimal storage practices, particularly maintaining controlled temperatures and minimizing storage duration, are essential for preserving the seeds' nutritional and germination properties (Kibar and Soydemir, 2025). Patel et al. (2017) also reported that Cold room storage is essential for maintaining soybean seed quality and viability. Corn seeds when stored under controlled conditions remain for long periods without causing decreases in physiological quality (Dubal et sl., 2021). Contrary

to this finding, Nyo et al. (2019) found that, the seed moisture content percent was not significantly affected by storage environments.

Although indigenous storage structures are not suitable for storing seeds for very long periods, many famers still store seeds using these methods. Therefore, it is imperative to consistently evaluate these storage structures for informed decision marking. In Sub Saharan Africa (SSA), most seeds are stored in structures build from local raw materials including thatch houses with fluctuation temperatures. In this study however, the local thatch house storage proved to be the second best among the five storage conditions studied. Seed germination which started from 93.7% only deteriorated by 2.3% at 5 month and 7% at 10 months as against 2.7% at 5 months and 3.7% at 10 months for cold room. Such a high germination percent from thatch house (86.7%) at 10 months against 90% from the cold room for the same period is very economical should cost – benefit analysis is conducted. This placed thatch house storage over warehouse, AC room and zinc roofed house, a strong indication that the local thatch house has a very great potential for soybean storage if given basic improvement with features of the standard warehouse. The conditions provided and maintain consistently dry and cool for the stored seeds. This falls in line with earlier reports by Motis, (2019) that earthbag houses stabilize storage temperature in comparison to outside air. In the warm tropics, temperature and humidity tend to be high and can fluctuate widely. Under such conditions, seeds deteriorate due to premature germination, rotting, insect pests, and rapid metabolism of food reserves. Trail et al., (2021) again reported factors that affect seed storage life are seed moisture, temperature, and oxygen levels. Store seeds dry and cool, and under low oxygen. These conditions slow the

metabolism of seeds, thereby prolonging storage life. Under this study, the thatch house provides for that environment.

Exposure of seeds to storage temperatures above their optimal range can have a deleterious effect on seed viability. In the warehouse, ambient storage temperatures as observed in this study, often exceed recommended levels ($15^0$C or less) for soybean storage. This negatively affect stored seed energy reserves and germination percentage, even for short-term storage. As reported by a previous study, soybean seeds stored at 30°C maintained germination for only one year, whereas those stored at 10°C retained viability for up to ten years (Delouche, 1977). In northern Ghana, high temperatures in the dry season between $26^0$C- $40^0$C often occur in conjunction with little relative humidity during the dry season (Frimpong et al., 2014). This affect seed variability by rapid moisture loss, increased respiration and deterioration of organic compositions relevant for gemination. This corresponds with Malviya and Gayen, (2024) who noted that, the shelf life of seeds is determined by their inherent aging and loss of viability during storage. To improve seed viability and germination percent in the warehouse, efforts need to be put in place to regulate temperature, moisture and RH (Bayer Africa 2019).

In the current study, the zinc roofed room sustained reasonable germination percentage (88.7%), higher than those of AC room (86.3%) and warehouse (86.3%) at 5 months. That was possible because, even though the temperature was high, it was consistent to that point. The rapid fluctuations promoted high ash, dry matter, carbohydrate, protein percentages and rapid moisture loss. These from the principal component analysis highly and negatively correlated with germination. As a result, the seeds from the zinc roofed room exhibited the

lowest germination percentage by the 10th month storage period, emphasizing the detrimental effects of elevated temperatures and fluctuating humidity commonly found in uncontrolled environments. Our results was similar to the findings of Koskosidis et al. (2022) who found that zinc roofed room decreased the germination percentage of soybean seeds. Even though the zinc roofed room outperformed the AC room at 5 months, the AC room ultimately gave better results at the 10th month probably because, it reduced the temperature in the highest heat periods of the day, which slowed down respiration and decomposition of the organic components, thereby prolonging seed viability relatively at the end. During the storage of oil seed crops in the zinc roofed room conditions, the breakdown of triacylglycerols into fatty acids and glycerol leads to an increase in soluble sugars and carbohydrates. As a result, seeds respire by utilizing glucose, oils, and fatty acids, which consequently reduces the rate of germination and seedling establishment (Barros et al., 2017; Munz et al., 2017). This effect is particularly pronounced in soybeans, where long-term storage can even render seeds incapable of germination (Zhou et al., 2019). Therefore, the stability of fat reserves in soybean seeds is a critical factor influencing their germination and viability. In this study, both the cold room and thatch room effectively maintained fat content throughout the storage period, resulting in a significantly higher germination percentage. Being one of the complex storage traits of seed, carbohydrate content in seed is a manifestation of several factors including storage conditions, storage duration, genetics and environmental conditions. However, the relationship between storage facilities and carbohydrate in regulating seed germination is unclear. It is often presumed that high level of carbohydrate cause Abscisic acid (ABA) accumulation or slow down the decline of endogenous ABA and delay germination

(Arenas-Huertero et al., 2000; Price et al., 2003). Although the ABA content was not evaluated in the present study, the difference in composition of the carbohydrate contents in seeds of the five storage structures seems to be meaningful. All the storage structures increased the carbohydrate content during the 10-month storage period with a translational decrease in germination percentage (Fig. 6). Besides, the carbohydrate content is highly associated with the germination percentage and the number of normal seeds. Similarly, Harakotr et al. (2022) reported that higher carbohydrate content correlate positively with germination percentage and the number of normal seeds. High temperature is a critical environmental factor that significantly influences soybean seed germination. The findings of this study demonstrate that elevated temperatures beyond the optimal range lead to reduced germination efficiency, aligning with previous research indicating heat stress as a major constraint for soybean establishment (Harakotr et al., 2022).

**Experiment 3: Soybean variety, storage bags and storage duration**

Results from this study shows that hermetic storage using the GICS bag preserved seed viability above all other five packaging materials across all three varieties. This is an indication that it is effective for all varieties and genotypes. This technology was equally effective in maintaining acceptable percentages of moisture, normal seeds and protein percentages which highly and positively correlated with germination. Evidence suggest that hermetic storage bags can effectively replace chemical methods in preventing germination deterioration (Odjo et al., 2022, Chigoverah and Mvumi, 2016, Navarro, 2006). Our results for seed germination and number of normal seeds shows a steady decline across all the various storage bags for all the soybean varieties (96%, 95%, 60%) for 0-, 5-

and 10- months averagely. Although this outcome is rare in hermetic storage systems, it could be attributed to high temperature ($27^0$C-$31^0$C) across the storage period. This phenomenon aligns with the findings by Baributsa & Baoua (2022), who reported a decline germination percentage in stored soybean seed. The variations between initial and follow-up storage temperatures might have prompted a reorganization of hygroscopic relationships resulting in the observed germination deterioration.

Excessive water loss such as those observed in this study (Fig. 4.27), can damage cell membranes and reducing water absorption efficiency and invariably reduce germination (Fatokun et al., 2022). Apart from seed genetic profile, the mechanisms of seed viability deterioration are largely attributed to seed storage conditions (Abass et al., 2018; Mendesil et al., 2022).

Paper bags preserved viability similar to the hermetic bags in this study. This is because, the multiple layers protected the seeds from external potential influence. It possibly allowed room for aeration and moisture loss. No physical defects were observed on seeds stored in paper bags, but its high ash and dry matter contents recorded across all varieties could be a possibility that, some organic components were deteriorating. Germination percentages were high (96%, 94% and 50%) for 0-, 5- and 10-month periods. This favourably competes with similar output from the hermetic bag and agrees with an earlier report which underscores the significance of proper packaging and storage strategies to enhance seed quality, crucial for improving sunflower productivity in Tanzania (Sulemani et al., 2025). This finding agrees with Lima et al. (2014) who reported that in the natural environment and freezer, the sesame seeds packed in the paper showed a high percentage of moisture.

Storage bags lined with polyethene (polypropylenes and jute bags) performed similarly in preserving seed quality, recording germination percentages of 96%, 94% and 42% averagely for 0-, 5- and 10- months. Proper ceiling of the lining (polyethene) and the bags prevented direct contact with external materials and equally prevented internal materials from the external. The condition mimicked the hermetic bag situation and preserved quality over the period. Any deterioration could be linked to temperature of the environment.

Polypropylene bags without any lining performed poorly, similar to jute bags in preserving seed quality. (96%, 90%, 40%) averagely for 0-, 5- and 10- months. Those bags may need an improvement if seeds were to be stored in them for long periods. This finding are in line with previous reports on a number of seed storage bags which showed that temperatures inside jute bag and polypropylene bags were higher compared to PICS bags and AgroZ® bags (Kebede et al., 2024). It also agrees with Kebede et al. (2024), who reported that jute bags exhibited the highest decline in germination in the present study. Storage bags may appear to protect viability but may result to seeds deterioration in the near future due to less optimal storage conditions

Dry matter is a key indicator of soybean quality changes and is closely associated with the respiration process of stored soybean seeds (Augusto et al., 2024). While it is generally argued that temperatures above 30°C lead to increased dry matter loss due to higher respiration rates (Augusto et al., 2024; Coradi et al., 2020), an increased in dry matter content was observed in this study despite the hot and dry storage conditions. The significant moisture loss recorded during the storage period likely contributed to this increase, as the reduction in seed moisture resulted in a higher proportion of dry matter relative to total seed mass. Although the respiration rate of the stored seeds and the varietal

resistance to respiration loss were not measured, these factors may have also influenced dry matter retention.

There were substantial variations in the protein and fat contents of the studied soybean varieties. This variation in protein and fat contents was expected due to the substantial differences among the studied soybean varieties. Based on their expected nutritional profiles, 'Favour' generally has a higher protein content (43%) compared to 'Afayak 'and 'Jenguma,' which have 38% (Ministry of Food and Agriculture, 2019). However, the high fat content observed in 'Jenguma' in the current study was an unusual finding, as 'Favour' and 'Afayak' typically have higher fat content than 'Jenguma' (Ministry of Food and Agriculture, 2019).

Additionally, the protein and fat contents of the soybean varieties decreased during the storage period, with the extent of reduction depending on the effectiveness of the storage bags. This reduction in protein content observed over the storage duration may be attributed to high storage temperature (above 32$^{o}$C), leading to accelerated grain metabolism and invariably protein denaturation (Dubal et al., 2024; Ziegler et al., 2021). The trend of reduction agrees with Ziegler et al. (2018) who reported a decrease in crude protein during soybean storage.

The Factor Analysis of Mixed Data was carried out to explore the combined effects of qualitative and quantitative variables on the quality of soybean seeds stored with the various storage bags. For all the varieties, the first two dimensions (Dim1 and Dim2) captured the majority of variability in the dataset and is therefore critical in explaining the differences among individual seed samples.

A clear separation of samples was observed along Dimension 1, which appears to be primarily driven by storage duration. Samples stored for 10 months were grouped distinctly on the negative side of Dimension 1. This clustering suggests a strong association between extended storage and reduced seed quality, possibly due to deterioration in germination potential or compositional integrity. Furthermore, the clustering pattern of the storage bag, suggest that these bags were mainly effective in maintain seed quality during the first five months of storage. These findings underscore the importance of optimizing storage conditions, particularly seed packaging material, to preserve the physiological and compositional quality of soybean seeds.



# CHAPTER SIX

## 6.0 CONCLUSIONS AND RECOMMENDATIONS

### 6.1 Conclusions

Soybean is popular as a highly nutritious, versatile legume that serves as a premier plant-based protein source and a major oilseed crop. The produce is a major food source for humans and it is also widely used in various animal feed. Despite the crop's high potential to improve food and economic security, low seed quality and poor handling conditions posts as serious challenges to increased production of the crop in Ghana. In view of this, exploring ways of improving storage to ensure soybean seed viability for prolonged durations has become an interest area of research. **In the first experiment**, the effect of three seed sources (Upper East, Upper West and Northern regions of Ghana), three soybean varieties ('Favour', 'Afayak' and 'Jenguma') and three storage durations (0-, 5- and 10 months) were evaluated. The three way analysis (source × variety × storage duration) showed significant interaction ($p < 0.05$, $p < 0.01$, or $p < 0.001$) effects for all the indices measured including number of normal seeds, germination percent, protein content, fat content, ash content, dry matter content, moisture content except carbohydrate. 'Jenguma' in the control stored for 10 months maintained the highest number of normal seeds. Similarly, 'Jenguma' seed collected from UWR had the highest fat content, while that from UER had the highest ash content at end of the 10 months storage period. 'Favour' seeds obtained from UWR and stored for 10 months had the highest germination perectage and protein content. 'Afayak' seed sourced from UWR and stored for 10 months exhibited significant increase in the dry matter content, whereas, 'Jenguma' seeds from UER showed the highest moisture loss at the end of the 10 month storage period. Carbohydrate contents

of the seeds was, however, significant ($P < 0.001$) affected by variety × storage interaction. Principal component analysis shows a strong positive correlation between moisture content, protein content, normal seeds and germination percent with perfect correlation for germination and moisture percentages for seeds obtained from Upper East Region. Although Seed germination deteriorated with storage duration across all sources and varieties, the 'Favour' variety exhibited the highest germination percentage irrespective of the sources, whiles 'Afayak' and 'Jenguma' from the Northern Region gave the least. Seeds from Upper West Region exhibited best performance in germination for all three varieties studied after ten months storage. **In experiment two**, the interaction effects of five storage room conditions (cold room, thatch room, zinc roofed room, AC room and warehouse) and three storage durations (0-, 5-, and 10 month) on 'Favour soybean variety from Upper West region of Ghana were evaluated. All the general linear models were statistically significant ($P < 0.01$) There was a positive correlation between germination percentage and the number of normal seeds (r = 0.669). A significant negative correlation between germination percentage and both moisture (r = -0.724) and ash content (r = -0.530). Similarly, moisture content had strong negative correlation with carbohydrate content (r = -0.973) reflecting the interplay between moisture reduction and nutrient concentration, a critical factor for seed quality. Cold room, thatch roofed rooms and warehouses significantly preserved seed viability, while the seeds stored in zinc roofed rooms and air condition rooms deteriorated rapidly. **In experiment three**, the interaction effect of six packaging materials **(**Ghana Seed Inspection Division (GSID) branded polypropylene (PP) bags, GSID Plastic bags, paper bags, jute bags, Jute bags lined with plastic, PP bags and PP lined with plastic) and three soybean varieties obtained from UWR ('Favour', 'Afayak'

and 'Jenguma') which were stored over three storage durations (0-, 5- and 10 month) were evaluated. There was significant three-way interaction on all the indices measured except for fat content. 'Favour' seeds stored in GICS bag for 10 months had the highest number of normal seeds and germination percent. 'Afayak' stored in jute sack lined with poly bag had the greatest decline in protein content over the storage duration. 'Jenguma' seeds stored in fertilizer sacks and stored for 10 months showed the least decline in fat content. Germination % significantly and negatively correlated with ash content, dry matter content, the number of abnormal seeds, and number of dead seeds. In contrast, germination % positively correlated with protein content and the number of normal seeds across all soybean varieties. Germination % showed a positive correlation with carbohydrate content for the 'Favour' variety but a negative correlation for 'Afayak' and 'Jenguma'. Similarly, for 'Favour', germination % was negatively correlated with fat and moisture. However, for 'Afayak' and 'Jenguma', germination % was positively correlated with fat and moisture contents. These results demonstrate the influence of the genetic variability of the different certified seeds which will require closer attention by the breeders for improvement purposes. Hermetic storage and paper bags proved more effective in maintaining seed viability and vigour compared to other conventional packaging options. The research has therefore demonstrated to maintain the viability of certified soybean seeds for longer period, the 'Favour' seed variety should be packaged in hermetic or paper bags and stored in cold rooms, commercialized seed warehouses of thatch roofed rooms, depending on the availability of these facilities in the soya bean growing areas in Ghana.

## 6.2 Recommendations

1. The 'Favour' variety which exhibited superior seed viability across locations and over time should be promoted for increased production of soybean seed.
2. Depending on their availability, cold rooms, thatch roofed houses and warehouses are recommended for storage of soybean seeds in Northern Ghana.
3. Hermetic Packaging and paper bags are also recommended to maintain higher seed viability and vigour for prolonged storage of soybean seeds in Northern Ghana.



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