EFFECT OF MAGNETIC FIELD STRENGTH AND EXPOSURE TIME ON PHYSICOCHEMICAL PROPERTIES, BIOCHEMICAL PROPERTIES, MOULD COUNT AND SHELF LIFE OF ARROWROOTS (*Colocasia esculenta)* DURING STORAGE

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been submitted for the award of a diploma or conferment of a degree in any other University or institution.

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Recommendation

This thesis has been examined, passed and submitted with our approval as University Supervisors

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DEDICATION

This work is dedicated to my parents, Mr. Peter Ngugi and Mrs. Mary Wanjiku who made the foundation of my education.

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ABSTRACT

Arrowroot, an important food crop, experiences significant post-harvest losses due to physicochemical deterioration, biochemical degradation, and microbiological spoilage resulting to a short shelf life. This study used a 4×3factorial arrangement in a completely randomized design (CRD) taking into account repeated measures on day 1, 7, 14, and 25, to include four levels of magnetic intensity (0, 6, 7, and 8 μT) and three exposure times (30, 60, and 90 minutes). Key physicochemical properties including weight, firmness, and colour were assessed using a weighing scale, penetrometer, and chroma meter, respectively. Biochemical tests included total phenolic content (TPC) measured by the Folin-Ciocalteu method and antioxidant activity assessed using the DPPH assay. Microbial stability was evaluated by mould counts using the Standard Plate Count (SPC) method. Shelf life was determined through the survival method by visually assessing attributes of discoloration, softening, mould growth and odour of the treated samples against the controls. Data was subjected to analysis of variance ANOVA and, Tukey's post-hoc test with a significance level of $\alpha=0.05$. The results showed that magnetic field treatment significantly reduced weight loss ($P < 0.05$), with the 8 μT intensity resulting in the lowest weight loss (45.68% after 25 days) compared to the control. The treatment also preserved firmness ($P < 0.001$) and, reduced browning ($P < 0.01$), with intensities of 7 μT and 8 μT maintaining significantly better firmness and better colour preservation throughout storage. TPC and antioxidant activity increased significantly ($P < 0.05$) in treated samples, with TPC maximum at 286.62 mg GAE/100g after 60 minutes of 7 μT treatment. Mold growth decreased substantially ($P < 0.05$) in treated samples, resulting in lower mould counts. Shelf life was increased from 7 days in the control to 15 days in treated samples ($P < 0.01$). These findings suggested that magnetic field treatment could be a viable non-thermal, chemical-free method for enhancing the post-harvest quality of arrowroots. This method could benefit farmers, food processors, and policymakers by improving post-harvest management practices, enhancing food security, and promoting economic sustainability in arrowroot production and consumption.

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LIST OF ABBREVIATIONS AND ACRONYMS

CAC:	Codex Alimentarius Commission
EAS:	East African Standard
EMF:	Electromagnetic Fields
ET:	Exposure Time
KEBS:	Kenya Bureau of Standards
MC:	Moisture content
MF:	Magnetic Fields
MI:	Magnetic Intensity
PDA:	Potato dextrose agar
RCP:	Recommended Code of Practice
RDA:	Recommended Dietary Allowance
TL:	Taro leaf blight

CHAPTER ONE:
INTRODUCTION

1.1 Background of the study

Arrowroots (*Colocasia esculenta*), also known as taro or locally as *"nduma,"* are cherished for their sweet flavour and nutritional value (Anyango, 2022). Of the *Araceae* family, they are the true green gold, which is consumed year-round in humid and subtropical zones (Matthews *et al.,* 2017). Historically, arrowroot was the most extensively cultivated starch crop before the advent of global trade and agricultural transport, spanning regions from Southeast Asia to Northeast Asia, India, the Pacific Islands, Madagascar, the Mediterranean, and Africa (Matthews, 2004). In 2014, global arrowroot production reached 10.1 million tons across 1.5 million hectares, averaging 6.945 tons per hectare (Ebert *et al.,* 2018). Nigeria leads as the world's largest producer, accounting for 32.4% of the global output, followed by China, Cameroon, Ghana, and Papua New Guinea (Ebert and Waqainabete, 2018). In Kenya, arrowroot farming is burgeoning, particularly in regions like Nyando in Kisumu, Ahero, Muhoroni, Nyeri, Karatina, and Embu (Safi Organic, 2022).

Arrowroots predominantly grow in marshy areas, riverbeds, and swamps. The principal varieties grown in Kenya are the eddoe and dasheen (Mukoya, 2021). The dasheen type is best known for its large tubers and thrives best in marshy areas, while the eddoe type produces smaller tubers and can grow in less water. In deep, well-drained, loamy damp soils, arrowroots are planted from suckers. For optimum growth, they need a soil pH of between 5.5 and 6.5 and a temperature range of 21 to 30 degrees Celsius (Wachira, 2019).

Harvesting occurs 8 to 12 months after planting, depending on the cultivar (Safi Organic, 2022). The process involves manually lifting the tubers from the ground using tools like a long stick with a sharpened point or a cutlass and then detaching them from the stem (Grant, 2021). Arrowroots are available in a range of shades from creamy white to light pink and purple (Lindsay-Jean Hard, 2022). Careful handling during harvest minimizes damage such as bruising, scraping, or breaking of the roots. Upon harvest, the tubers are stored in cool, dark places, and have a typical shelf life of 1week (Grace, 2022). Previous studies

have suggested that roots stored under room temperature could deteriorate as early as 2 days old (Ferdaus, Md Jannatul, *et al.,* 2023). Arrowroot production and post-harvest processing are regulated by standards such as EAS 39 and CAC/RCP 53 to ensure sanitary conditions (KEBS, 2018).

Nutritionally, arrowroots are just like cassava, yam, and sweet potato but probably are less starchy and richer in other nutrients (Lang, 2019). Each 100-gram serving contains 78 calories, 5 grams of protein, 0 grams of fat, 0.7 grams of fiber, and 16 grams of carbohydrates. Moreover, it provides riboflavin, folate, pantothenic acid, niacin, pyridoxine, vitamin C, thiamine, vitamins A, E, K, and other special micronutrients (Firdous, 2020).

Arrowroots can be consumed as a whole when boiled, cooked, or roasted. They are unique in that, they can be ground into flour to be used in baked goods like cakes and cookies, as well as thickening agents for; puddings, jellies, and sauces (Guly, 2012). Additionally, arrowroot powder can be formulated into porridge flour or infant formula as it is easy to digest (Malki *et al.,* 2023). Arrowroots contain a variety of active compounds, including resistant starch, mucilage, anthocyanins, hemagglutinin, non-starch polysaccharides, protein, tarin lectin, and others, all of which have antitumor, antimetastatic, antioxidant, and anti-inflammatory properties (Li *et al.,* 2018). It is also a great alternative for individuals who are allergic to milk or cereal items (Ubalua *et al.,* 2016). These highlights the potential health benefits of arrowroot use as well as its traditional medical uses, both of which warrant further exploration. Arrowroots are a versatile and nutritious food with both nutritional and therapeutic properties, making them a good candidate for future research and development.

Arrowroots are faced with significant post-harvest losses because they have no dormant role in the propagation and lack a bud primal from which regrowth can develop; they typically decay very quickly immediately after harvest (Grace, 2022). The losses that occur during the storage of arrowroots are either primarily characterized by discolouration or secondary characterized by rotting (KEBS, 2018). The lack of preservation techniques,

which results in significant post-harvest losses, is the main obstacle to the usage of arrowroots. The most severe disease in arrowroots, *Phytophthora colocasiae*, results in 25%–50% crop losses and post-harvest corm rotting (Ebert and Waqainabete, 2018). Before post-harvest rot renders arrowroots unsafe for human food, they can be kept under ambient tropical conditions for about two weeks (Gollifer and Booth, 2008).

The primary reasons for these losses include mechanical damage, physiological conditions (respiration, maturity, and water loss), diseases, and pests (KEBS, 2018). In arrowroots, three rots are distinct and significant causes of post-harvest losses: a dry rot caused by *Fusarium solani*; a spongy black rot caused by *Botryodiplodia theobromae*; and a sclerotium rot caused by *Sclerotium rolfsii* (Sloan *et al.,* 2016). It was discovered that all three fungi could infiltrate and infect corms in humid environments. Most spontaneous infections are assumed to come from wounds (Gollifer and Booth, 2008).

Various methods have been developed to control arrowroots' deterioration rate and enhance shelf life. For example, research on the effect of water activity and packaging material on the quality of dry taro that was conducted to determine the shelf life showed that drying reduced the colour quality as well as vitamin composition (Sloan *et al.*, 2016). Control during harvesting is essential to reduce physical injury, which may increase the rate of deterioration. The temperature significantly impacts several elements that cause loss during storage, including the growth of rotting microorganisms and insect infestation. At 10 °C, the rate of rotting and respiration is moderate; below 4 °C, respiration is significantly reduced, albeit chilling harm may occur (KEBS, 2018). Refrigeration, waxing of the roots, and chemical treatment are more storage and preservation techniques (KEBS, 2018).

In food, magnetic fields are an emerging non-thermal green technology that has received particular attention for its use in food preservation. The fundamental idea behind magnetic fields is that because biological cells have magnetically and mechanically heterogeneous structures, introducing a homogeneous magnetic field may cause stress to be distributed differently inside cells, intracellular structures to deform, and membrane permeability to vary (Kondrachuk, 2002). For example, to minimize post-harvest losses in potatoes, the

effects of static and fluctuating magnetic fields (MF) on the features of potato sprouting and shrinkage were examined (Irungu *et al.,* 2022). It was found that the weight loss in potatoes was reduced due to reduced cell activity.

According to a study on the effect of static magnetic field on plant pathogenic fungi, the amount of *Fusarium oxysporum* conidia fell by 83-79% when the growth and sporulation of the fungus were evaluated in the presence of a static magnetic field (Nagy and Fischl, 2004). In a study, with an intensity of 0.35 mT, the application of AC magnetic fields (MF) to potatoes was also found to reduce the number of spoilage microorganisms after exposure (Lysakov *et al*., 2018). Despite this research on the effect of magnetic fields, there is a lack of enough documentation on research done to reduce post-harvest losses using magnetic fields; this becomes a major motivation of this study on the effect of magnetic fields on post-harvest losses in arrowroots caused mainly by fungi.

1.2 Statement of the Problem

Arrowroot is an important cash crop and food source, but its susceptibility to post-harvest deterioration leads to significant economic losses for farmers and food security problems. Post-harvest changes in arrowroots, which are mostly caused by factors such as respiration affect the physicochemical changes, biochemical changes, and spoilage moulds. Faced with major spoilage microorganisms, one of the spoilage moulds, *Phytophthora colocasiae,* causes fungal rot and results in a 25%- 50% loss in arrowroots. Conventional preservation methods such as drying and chemicals have been used, although some of these procedures may result in weight loss, nutritional loss, and changes in the turgidity and colour of arrowroots. There is, however, little information on the use of magnetic fields to cut post-harvest losses in arrowroot preservation. Therefore, this study intends to investigate the impact of magnetic field under different exposure times on the physicochemical, and biochemical changes, microorganism inhibitory effects, and shelf life of arrowroots as a non-thermal preservation method. This study intends to illustrate the advantages and possible benefits of using magnetic fields in preserving the quality and extending the shelf life of arrowroots.

1.3.Objectives of the Study

1.3.1 General Objective

To determine the effect of magnetic field strength and, exposure time on the physicochemical properties, biochemical properties, mould count, and shelf life of arrowroots during storage.

1.3.2 Specific Objectives

i. To evaluate the effect of magnetic field strength and exposure time on the physicochemical properties of arrowroots during storage.
ii. To evaluate the effect of magnetic field strength and exposure time on the biochemical properties of arrowroots during storage.
iii. To determine the effect of magnetic field strength and exposure time on the mould count in arrowroots during storage.
iv. To determine the effect of magnetic field strength and exposure time on the shelf life of arrowroots during storage.

1.4 Research Hypotheses

H_{01}: Varying magnetic field strengths at different exposure times had no significant effect on the physicochemical properties of arrowroots, during storage.

H_{02}: Varying magnetic field strengths at different exposure times had no significant effect on the biochemical properties of arrowroots during storage.

H_{03}: Varying magnetic field strengths at different exposure times had no significant effect on the mould counts in arrowroots during storage.

H_{04}: Varying magnetic field strengths at different exposure times had no significant effect on the shelf life of arrowroots during storage.

1.5 Justification of the Study

The post-harvest quality of arrowroots is of critical concern due to their increasing global production and consumption as one of the most significant food crops (Banjaw, 2017). Even though several preservation methods have been used to address post-harvest losses, these approaches have resulted in nutritional loss and changes in the physicochemical and

biochemical quality of arrowroots (Oxfarm, 2018). As a result, there is a need to investigate alternate and innovative preservation methods, such as the utilization of magnetic fields. Magnetic field (MF) preservation works by slowing respiration, limiting microbial growth, and preserving the structural integrity of food products, making it a promising non-thermal and chemical-free option. This study intends to evaluate the effect of magnetic fields on the post-harvest quality of arrowroots, including weight, firmness, colour, and shelf-life. Previous research has demonstrated that magnetic fields can extend the shelf life of tuber commodities such as potatoes (Irungu *et al.,* 2022). The findings from this study are expected to contribute to sustainable agriculture by reducing post-harvest losses, lowering the reliance on chemical preservatives, and promoting more environmentally friendly preservation methods. Additionally, MF preservation provides an energy-efficient and cost-effective alternative, which is especially useful to producers. The study's goal is to improve the durability and quality of arrowroots during storage, which will improve food security and encourage sustainable agriculture methods (Greenebaum and Barnes *et al.,* 2022).

CHAPTER TWO:
LITERATURE REVIEW

2.1 Overview of Arrowroots

Arrowroot also referred to as taro belongs to the plant family *Araceae*, scientifically known as (*Colocasia esculenta*). It is among the most significant food crops in the world. Over 1500 species are found in the family, which consists of at least 100 genera (Banjaw, 2017). Arrowroot is a traditional tropics root crop farmed for its tasty corms and leaves, and it is regarded to be one of the world's first cultivated root crops (Fujimoto, 2009). The Food and Agriculture Organization (FAO) reports that arrowroot production has doubled over the previous ten years (Oladimeji *et al.,* 2022). The arrowroot is currently the fifth most consumed root vegetable globally (Renee *et al.,* 2020). This indicates that global production is rising, which calls for technological advancement when handling this commodity.

It is believed that arrowroots originated in southern or southeast Asia and were transported to Oceania via the island of New Guinea many hundreds of years ago. It is said to have travelled from Polynesia to the east coast of Africa around 2,000 years ago. It was first transported by travellers to West Africa and then by slave ships to the Caribbean (Onwueme, 1999). Currently, Nigeria is the world's largest producer, making up 32.4% of global output, followed by China, Cameroon, Ghana, and Papua New Guinea (Ebert and Waqainabete, Logotonu M, 2018). Although taro is a common crop in West Africa, how much is produced and consumed in East Africa is unknown.

Arrowroot farming in Kenya is rapidly gaining popularity due to its nutritional worth. Most arrow root farming in Kenya is done in Nyando parts of Kisumu and Ahero Muhoroni (safiorganic, 2022). It has continued to gain much more popularity in the central region due to high rainfall and better soils found in the highlands. According to a report in Daily Nation (seeds of Gold), the production of arrowroots in Kenya has doubled to 3 tonnes per acre compared to previous years, where 1 acre produced 1.68 tonnes (Oxfam, 2018). However, there has been limited data on the production of arrowroots in Kenya over the years.

2.1.1 Variety and Morphology

There are two distinct primary types of arrowroots which are the Dasheen arrow root renowned for its excellent bigger tubers and it thrives best in marshy areas. The other variety is Eddoe, which is noticeably smaller than those of the dasheen type. Most arrow root growers in the nation, especially those in regions with little rainfall, prefer this cultivar. Even with less water received, the cultivar does better (Kay and Gooding, 1987).

Arrowroot is a monocot plant that uses the vegetative propagation method. The plant has green leaves, fine fur on the underside, and funnel-shaped, sharp ends. Its height ranges from 0.5 to 1 meter. During the early stages of growth, the rod-shaped rhizome first appears above ground, burrowing into the soil and enlarging into a fleshy organ. One distinguishing feature of the rhizome is that it is fleshy, whitish/ pinkish, bent like an arrow, and covered with overlapping scales (Dehgan, 2023).

2.1.2 Growth and Production

Arrowroots are considered water crops and do best in environments with abundant water. However, it is necessary to be aware that other varieties of arrow roots do not need to be planted in swampy locations to be successful (FarmLinkKenya, 2017). It is important to remember that certain varieties of Arrow roots, or *"nduma,"* can be grown in areas that are not swampy. The Burundi variety, a hybrid tuber that can thrive in locations with little access to water, illustrates this type (safiorganic, 2022).

Arrowroots thrive best in friable, loamy soil that drains well. Clay soil must be avoided to prevent poor rhizome development and typical rhizome deformation, which tends to break after harvest. If there is adequate rainfall for the crop's growing season, planting it in an open field is advisable. Although the yield will be lower, planting in slightly shaded locations is still possible ((Oxfarm, 2018).

During the planting of arrowroots, the land is prepared by ploughing and harrowing it twice or thrice to create an ideal environment for improved root development, and this is to ensure deep ploughing has been ploughed deeply enough. However, modern agricultural

breakthroughs have led to upland arrow root technology development. Upland technology involves planting arrow roots in trenches to allow for their cultivation in locations other than rivers. The trenches are dug, and the bottom is covered with heavy gauge polythene before being filled with dirt and manure. Since the smaller eddoe variant can withstand less water than the bigger Dasheen variant, it is more adapted to growing in the upland cultivation technique (Nyakundi and Nyakundi, 2021).

When planted, the proper distance between the suckers is 30 cm by 20 cm at a depth of 20 cm. Given that many river basins have dried up due to global warming, this novel farming technique can significantly improve food and income security while aiding Kenya's ability to adapt to climate change. With upland arrowroots technology, the crop is planted in trenches lined with polythene sheeting and filled with a 2:1 mixture of soil and manure. Trenches for planting are set 0.5m apart. A single acre of upland arrowroots tubers may support 29,333 plants, each producing 29,333 tubers (Anyango, 2022).

In production on dry land, it is advised to weed and earth up twice: the first time 45 days after planting and the second time one month later. Fertilizers should be administered at the specified rates for organic and inorganic fertilizers. Weeding during wet/fallow production may be unnecessary because the flood system smothers the weeds, but you can remove the few that survive by hand (Munene, 2021).

2.1.3 Harvesting Techniques and Quality Considerations

Crop maturity varies with varieties and management techniques, although harvesting can begin as soon as five months after planting. Any time of the year is an excellent time to collect arrowroot. The starch content of the arrowroot’s quality rises with time to an optimum level; during this time, there is a decrease in quality primarily brought on by increased tenderness. The output of corms may suffer if the leaves are harvested in excess (Rodrigues *et al.*, 2018).

To maximize shelf life, caution must be exercised during harvest to avoid damaging actions like bruising, scraping, or breaking the corms. The corms shouldn't be dropped or thrown because doing so could hasten their degeneration. Harvesting equipment, such as hoes, forks, machetes, and wooden sticks, are some of the digging implements. The instruments must be used correctly and kept clean to prevent damaging the roots during harvest. Techniques for harvesting include harvesting by hand through uprooting, or they can be dug up with the right tools to raise the corm safely and without damaging it (Britannica, 2022).

The prevention of contamination in fresh arrowroots is crucial to ensure their safety for human consumption and subsequent processing. To achieve this objective, all individuals involved in the cultivation, harvesting, and handling of fresh arrowroots must comply with the regulations specified in EAS 39 and CAC/RCP 53, as established by the Kenya Bureau of Standards (KEBS) in 2018. First, any fresh arrowroots that pose a potential hazard for human consumption or further processing must be identified and separated from the rest of the batch. These unsuitable specimens should be appropriately disposed of to mitigate potential risks (KEBS, 2018). Furthermore, maintaining sanitary conditions throughout the entire process is of utmost importance. Harvesting containers must be diligently sanitized and cleaned to minimize the likelihood of cross-contamination (KEBS, 2018). Additionally, it is essential to exercise great caution when loading fresh arrowroots in the field to prevent any form of animal or human waste contamination (Souza e*t al.*, 2016). By strictly adhering to these regulations and guidelines, growers, harvesters, and handlers can ensure the safety and integrity of fresh arrowroots, safeguarding both consumers and the industry as a whole.

Many elements that contribute to loss during storage, such as the growth of rotting microorganisms and insect infestation, are greatly influenced by temperature. The rate of respiration and rotting are modest at 10 °C and considerably lowered below 4 °C, while chilling harm may still happen (KEBS, 2018). After harvest, the crop may go through the process of curing. The procedure may be done for two to seven days at temperatures between 32 and 40 degrees Celsius and between 85% and 95% relative humidity (KEBS,

2018). Still, fresh arrowroots can be preserved in containers of varying sizes by submerging them in drinkable water. The roots are entirely submerged in potable water and poured into the containers until complete. This method can also be performed in tandem to detoxify the roots known to contain acrid components simultaneously (KEBS, 2018).

2.1.4 Storage and Preservation of Arrowroots

Arrowroots often degrade quickly soon after harvest because the storage organ's root lacks a bud origin via which regrowth can start and a dormancy effect in propagation (Denham *et al*., 2020). The tubers have a low shelf life, ranging from 2 days to 1 week (Grace, 2022). After being harvested, arrowroots are still living organisms, and losses during storage are primarily caused by their physiological and physical state. The leading causes of loss include mechanical damage, physiological circumstances (maturity, respiration, water loss), diseases, and pests. To guarantee efficient storage, root and tuber crops must be thoroughly understood and managed as needed (Abewoy, 2020). This requires taking into consideration the socioeconomic aspects that are prevalent in the production and selling areas.

The successful storage of arrowroots necessitates the consideration of various factors. The utilization of healthy and sound corms as the initial material is a crucial factor (Souza *et al.,* 2016). Additionally, if feasible, a combination of proper curing and fungicide treatment is recommended to enhance storage outcomes (Souza *et al.,* 2016). Adequate ventilation is a crucial factor in preventing spoilage by facilitating the dissipation of heat generated by respiring corms (Souza *et al.,* 2016). Furthermore, protection from rain and direct sunlight is necessary to maintain the quality of stored arrowroots. Regular inspections should be conducted to identify and remove sprouts and rotten corms, ensuring the preservation of the overall storage environment (Souza *et al.,* 2016). By considering these factors, growers can effectively store arrowroots while preserving their quality and minimizing potential losses (Souza *et al.,* 2016).

Arrowroot corms can be stored in pits or heaps under specific conditions as a short-term storage solution. According to Jackson (2011), the corms should be re-buried in burrows, which are then covered with dry plant matter and soil. Additionally, the corms can be piled in heaps and kept moist by watering them daily. To further protect the corms, a thick layer of soft clay or mud should be applied as a covering (Jackson, 2011). These methods provide temporary storage options for arrowroot corms, allowing them to remain in suitable conditions for a period of two to three days (Jackson, 2011).

Arrowroots that have recently been collected can be kept in baskets or boxes of wood. The inside of the crates is coated with a layer of peat, sawdust, wood shavings, or any other suitable absorbent material. Sawdust is also used to fill the gaps between the plant's roots. The roots are finished with sawdust (KEBS, 2018). It is acceptable for the sawdust to be damp, but it must not be soaked. If the sawdust is not moist enough, the roots will perish in a short amount of time. Sawdust that has an excessive amount of moisture encourages the growth of mould and rot. A layer of plastic foil should be placed within the crate so the roots do not become overly dry too quickly. Both the crates and the baskets can be used as containers during shipment at the same time (and even many times), saving money on handling costs and lowering the risk of the roots being damaged during transport (KEBS, 2018).

Plastic bags can be used to preserve arrowroots because they prevent the root vegetable from drying out and losing moisture. The freshness that the roots retain while being preserved is a significant factor in determining how well this procedure will work (KEBS, 2018). Two to three weeks' worth of storage time can be obtained from arrowroots if sealed in an airtight plastic bag or wrapped in plastic film and treated with an effective fungicide such as thiabendazole. After storing arrowroots in plastic bags, you should first submerge them for ten seconds in a 0.4% w/w thiabendazole solution before putting them away.

Treating arrowroots with home bleach containing 0.95 percent active chlorine is also possible. If healthy arrowroots are stored for no more than seven days, regular household bleach is as effective as treating them with thiabendazole. Roots that have just been

collected are packaged in plastic bags. To prevent the development of mould and rot, fungicides must be sprayed on the bags before they may be sealed. A more extended period can be achieved by storing at temperatures below 10 degrees Celsius (KEBS, 2018).

Waxing the roots, refrigeration, and chemical treatment are three more ways the roots can be stored and preserved. The ability of arrowroots to be stored for more extended periods increases when the temperature at which they are stored is lowered. This is because lower temperatures delay the deterioration processes at average storage temperatures. Experiments conducted to determine the optimal temperature for storing fresh arrowroots found that a temperature of three degrees Celsius is optimal. Waxing arrowroots can be maintained and stored by covering them in wax made from food-grade ingredients (KEBS, 2018).

2.1.6 Nutritional Values of Arrowroots

Arrowroot is an excellent source of nutrients, and its roots contain the following nutrients per 100g folate 22 g, pantothenic acid 0.303 mg, niacin 0.600 mg, pyridoxine 0.283 mg, riboflavin 0.025 mg, vitamin C 4.5 mg, thiamine 0.095 mg, vitamin A 76 µg, vitamin E 2.38 mg, and Vitamin K 1 µg (Firdous, 2020). The root also contains antioxidants, including beta-carotene and cryptoxanthin. Additional minerals that are included in arrowroots are copper (0.17 mg per 100 100 g), manganese (0.382 mg per 100 g), zinc (0.23 mg per 100 g), selenium (0.7µ per 100 g), and magnesium (33 mg Magnesium), iron (0.55mg per 100gms), and calcium (43 mg per100g). Potassium (591 mg per 100 g) and sodium are the electrolytes in arrowroots (11 mg per 100 g). Arrowroot tubers are composed of complex carbohydrates (26.46 g per 100 g). As a result, it is a fantastic energy enhancer. It also has a lot of fiber (Firdous, 2020).

2.2 Physicochemical and Biochemical Qualities of Arrowroots

Arrowroots vary in size and weight depending on the level of maturity, cultivar, and the environmental location from which they were harvested. Research has shown that corms with higher moisture content tend to be heavier (Ferdaus *et al.*, 2023). Arrowroot corms range in colour from creamy white to various colours of purple and brown, with the precise

hue controlled by variety and maturity (Saxby, 2020). Although colour might not dictate the shelf life of food, it might indicate the presence of some vitamins due to the pigments present (Sloan *et al.,* 2016). Arrowroots have a similar starchy texture to potatoes; however, it is slightly more fibrous but soft (Ferdaus *et al.,* 2023). Arrowroots have a rather delicate texture, so care should be taken to prevent skin abrasion and damage (KEBS, 2018). Arrowroot tubers turn soft and, when cooked, have a mellow, nutty flavour that is frequently compared to sweet potato. Certain cultivars may be mildly sweet or earthy in flavour.

KEBS guidelines aim to minimize health risks associated with consuming arrowroots. The standards likely address allowable limits for harmful bacteria like Salmonella and E. coli, maximum levels of contaminants such as lead and cadmium, and acceptable ranges for pesticide residues. Additionally, KEBS may specify moisture content limits to prevent mold growth and set quality parameters for size and appearance. Arrowroots are also known for their high concentration of phenolic compounds and antioxidants. Arrowroot corms contain a variety of phenolic chemicals, including flavonoids and phenolic acids, which contribute to their antioxidant capacity (Tosif *et al.,* 2022). These antioxidants serve an important role in the body by neutralizing damaging free radicals, protecting cells from oxidative damage, and lowering the risk of chronic diseases (Warraich *et al.,* 2020). Arrowroot's antioxidant capabilities, which are attributable to its phenolic content, make it a significant dietary component for overall health and well-being.

Arrowroots provide 15% of the daily value for α-tocopherol and 7% of the daily value for thiamine suggested by the USDA (Gollifer and Booth, 2008). A study of the stability of α -tocopherol and thiamine in arrowroots treated with MF may be helpful due to the absence of prior research on the existence and stability of these vitamins in arrowroots. Alpha-tocopherol is a fat-soluble vitamin that is moderately unstable. Although heat treatment and storage cause it to decay, it is stable at high temperatures if no oxygen is present. The more stable molecule thiamine can be vulnerable to heat and destroyed by SO_2 contact (Gollifer and Booth, 2008).

The major enzymes in arrowroots include polyphenol oxidase (PPO), phenylalanine ammonia-lyase (PAL), lipoxygenase (LOX), and peroxidase (POD) (Wang *et al.*, 2022). These phenolic compounds (PPO, PAL, LOX, POD) contribute to a higher percentage of colour in arrowroots (Wang *et al.*, 2022). Polyphenol oxidase (PPO) and peroxidase (POD) are oxidoreductase enzymes that contribute to phenolic oxidation and produce dark-coloured compounds in fresh products (Sikora *et al.*, 2020). The brown or black colour in arrowroots is an undesirable characteristic and can be an indication of spoilage.

Studies on physical and chemical methods for reducing the rate of enzymatic browning in various foods have been conducted (Pundir and Rawal, 2013). For example, the effect of citronella reduced the browning of fresh arrowroots under cold storage (Wang *et al.*, 2022). Hydrogen sulphide has commonly been used to reduce browning in fruits and vegetables (Chen *et al.*, 2017) and water chestnuts (Dou *et al.*, 2021). Chemical methods have been reported to cause negative health implications, such as neurological and hypersensitivity problems (Ullah *et al.*, 2022). Therefore, research on a more efficient physical method that would retain the physicochemical and biochemical characteristics of arrowroots would be of great significance.

2.3 Mould infestation in Arrowroots

Arrow roots can become infected with fungi (moulds), especially the oomycetes Pythium and Phytophthora, through wounds formed after harvesting, while the exact mechanism behind this infection is unknown. The development of the rots happens very quickly, and depending on the size of the corms and the number of infections, they can be entirely decomposed in as little as four to ten days. Hard rot and *Loli loli* are two significant fungal root rots that have no clear cause. While the former kills the corm's vascular system, the latter results in a corm that lacks starch and is spotted with mushy, watery (Williamson-Benavides and Dhingra, 2021). Pythium rots are characterized by their characteristic white colour, dryness, and crumbliness, and they typically begin at the corm's base (Figure 1) (Jackson, 2011). Frequently, a broad region of light reddish-brown tissue will be firm and healthy in front of the rot boundary. The rots caused by Phytophthora are light brown in colour and firm (Figure 2) (Jackson, 2011). Athelia rots are often superficial and manifest

themselves close to the site where suckers have been removed; nonetheless, there are instances in which the roots can penetrate deeply into the corm.

When corms are exposed to high humidity, the roots exhibit thick white strands of the fungus growing out of the rot (Figure 1). For the most part, Lasiodiplodia is a wound pathogen that can cause blights, dieback, damping-off, and storage rots in various plant species (Figure 3). Phytophthora and Pythium are typically the culprits behind the degradation that leads to their isolation from rotting corms. At first, the rots have a white appearance, but subsequently, they turn black. They also have a robust and terrible odour of sourness. Rots caused by Erwinia are frequently foul-smelling white soft rots (Figure 4) (Jackson, 2011).

Unless the corms are sliced apart, it is challenging to identify any of the rots, except for those caused by Lasiodiplodia. The presence of Lasiodiplodia can be recognized because infected corms have an unpleasant odour and a spongy texture, and frequently, masses of powdery black spores appear in regions on the surface of the corm (Gnanesh et al., 2022). The Pythium rot is white and crumbly; Phytophthora rot is firm and light brown; Athelia rot is shallow pink; and Lasiodiplodia rot is black and typically found behind Pythium and Phytophthora rot. Erwinia rots are typically relatively easy to recognize because of their distinct characteristics, which include a foul odour and softness (Opara and Asuquo, 2016).

Some of the effects caused by the spoilage microorganisms are as shown below;

Figure 1:Dry, crumbly rot.
(Jackson, 2011).

Figure 2:Light brown hard rot
(Jackson, 2011)

Figure 3: Black spongy rot.
(Jackson, 2011)

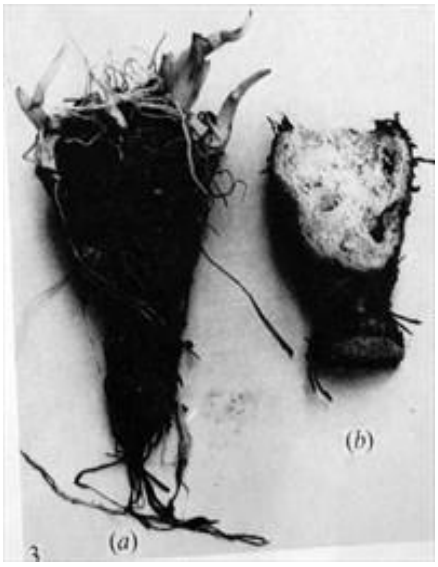


Figure 4: Soft rot

(Jackson, 2011)

2.4 Shelf life of Arrowroots

Shelf life refers to the period during which a food product remains safe to consume and retains its desired sensory, chemical, physical, microbiological, and functional characteristics when stored under recommended conditions (Taormina, 2021). Several factors determine the shelf life of a food product, including its intrinsic properties, such as moisture content, pH, and nutrient composition, as well as extrinsic factors, like storage temperature, humidity, light exposure, and packaging materials (Yousuf *et al.,* 2018). Arrowroots typically decay very quickly immediately after harvest; stored in a cool, dark place, their shelf life can range from 2 days to 1 week (Grace, 2022).

The shelf life of arrowroot corms is affected by different factors that are critical in maintaining their quality over time. Such factors include post-harvest treatment, storage conditions, and the arrowroot cultivar in question. Since arrowroots are perishable, they are prone to physiological changes and degeneration during storage. In arrowroots, several parameters influence their shelf life, including colour, moulds, texture, and odour. The colour of arrowroots can degrade over time due to enzymatic browning and oxidative processes, which are accelerated by exposure to light and air (Sinkiyian Kepue, Mercy, 2024). Moulds are a significant concern, as they can develop on the surface of arrowroots if stored in humid conditions, leading to spoilage and potential mycotoxin contamination. Proper storage in a cool, dry environment is essential to minimize mould growth (Wang *et al.,* 2018).

Texture is another critical factor, as arrowroots can become either too hard or too soft over time. A firm texture is generally desirable, and it can be maintained by controlling the storage humidity and temperature. Excessive moisture can lead to a mushy texture, while overly dry conditions can cause the arrowroots to become hard and desiccated (More *et al.,* 2019). Finally, the odour is a sensitive indicator of spoilage. Fresh arrowroots have a mild, earthy smell, but as they deteriorate, they may develop off-odours due to microbial activity and chemical changes within the tubers.

When it comes to the preservation and use of Colocasia esculenta corms, shelf life is critical. According to research, arrowroots are prone to post-harvest physiological alterations and degeneration over time. Weight loss and the growth of fungal and bacterial infections are examples of these alterations (Opara and Mejía, 2003). Proper storage conditions, such as low temperature and high humidity, have been shown in research to help extend the shelf life of arrowroot corms (Ferdaus *et al.,* 2023).

In addition, surface treatments such as waxing or the use of edible coatings have been investigated to reduce moisture loss and delay senescence, hence increasing shelf life (Koh *et al.,* 2017). There is a question of whether more efficient processing techniques for increasing shelf life, such as the use of magnetic fields, which have previously been utilized on tubers such as potatoes (Irungu *et al.,* 2022), would affect arrowroots shelf life.

2.5 Use of Magnetic Fields in Food Preservation

Traditional methods of preserving food can occasionally result in the loss of delicate nutrients, the denaturation of proteins, and changes in the food's structure, colour, and flavour. Color changes in foods, rather than directly influencing shelf life, serve as visual indicators of the chemical and microbial processes occurring during storage. These color changes can signal alterations in food quality and freshness, but they are not themselves factors that determine how long a food will last. Additionally, there is a potential for the production of undesirable novel compounds, which highlights the significance of techniques of food preservation that do not need heat. These techniques maintain the food's nutritional content while at the same time lowering the risk of contamination by organisms that cause deterioration.

Magnetic field treatment involves exposing food products to electromagnetic fields of varying strengths and frequencies. MF treatment is applied using specialized equipment that generates controlled magnetic fields, with applications ranging from laboratory setups to industrial-scale systems. Magnetic field treatment has shown promise in various scenarios, including post-harvest preservation, seed treatment, plant stress tolerance, microbial control, food quality enhancement, and enzyme inactivation (Miñano et al.,

2020). The effectiveness of MF treatment varies across applications, demonstrating benefits such as reduced microbial growth, decreased sprouting in vegetables, enhanced seed germination, and improved retention of nutritional value.

Magnet field has been used to reduce post-harvest losses in various food commodities. Results of past investigations have demonstrated that microorganisms are inhibited when placed in an electromagnetic field and that these fields have an inhibiting influence on the population of microorganisms (Akinyele, Bamidele, *et al.*, 2012). The effect that causes the antimicrobial impact upon exposure to an electromagnetic field is the field's ability to harm the cell structure and composition. Potatoes exposed to the magnetic field of strength 3.00mT resulted in reduced sprouting, external greening, and weight loss (Irungu *et al.*, 2022). It was found that increasing the magnitude of the electromagnetic field wave caused the development of the fungal isolates to slow down, which was demonstrated by a drop in the spore count. Electromagnetic field (EMF) waves can significantly reduce post-harvest rotting fungus, a significant worry for farmers and food companies.

Therefore, the employment of electromagnetic field waves as a technique for regulating these rotting fungi and, as a result, extending the period that fruits can be stored is possible (Akinyele and Akinkunmi, 2012). It was discovered that subjecting dormant seeds to a magnetic field (MF) increased the pace at which future seedling growth occurred in barley, wheat, corn, beans, certain tree fruits, and other tree species. The MF was standardized to provide the most significant possible improvement in the germination characteristics of maize seeds. An increase in the MF conditions could also alter plants' secondary metabolism. Post-harvest seed improvement using a low-frequency magnetic field is a method that can be utilized for a variety of plant species. This method is beneficial for developing seeds of temperature-sensitive species germinating at lower temperatures. There has been some success with using pre-seed electromagnetic treatments to mitigate the adverse effects of drought on various crop plants (Greenebaum and Barnes, 2022).

According to studies, high-voltage electrostatic field treatments have the potential to alter the physicochemical as well as the structural qualities of food. Field activities associated

with the polarization of organic radicals in the flora biosystems and molecular fatigue could affect the reactions of plants (Saletnik et al., 2022). Consequently, the post-harvest quality of particular fruits is preserved, and the product's shelf life is increased directly due to these actions. According to studies, electric fields can produce ionization of gases in room settings, which then quickly migrate in the direction of the electrode that is opposite from them. It is a non-thermal treatment that is useful in extending the shelf life of fruits. It affects the permeability of the cell membrane, as well as enzyme activity and the inhibition of microbial action (Saletnik *et al.,* 2022). According to Yu *et al.* (1995), electron beam irradiation inhibited the growth of fungi on fresh strawberries, which increased the strawberries' shelf life.

According to a study on the effects of magnetic fields on the growth rate and budding angles of yeast cells, magnetic fields were found to decrease yeast colony growth, solidity, and roundness (Hall and Charlebois, 2021). In another study on the effects of static magnetic field on the growth and sporulation of plant fungi, the magnetic flux density decreased colony growth by 10% (Nagy and Fischl, 2004). According to a study by (Serrano *et al*., 2021), it was found that a static magnetic field increased super-oxidase dismutase, catalase enzyme, and carotenoids in microalgae. This showed that a magnetic field can impact oxidative stress and increase the production of antioxidant pigment (Serrano *et al.,* 2021). A complex magnetic field of 1-250 mT was observed to reduce the fungal growth of *Candida albicans* significantly (Petrini *et al.,* 2021).

CHAPTER THREE:
MATERIALS AND METHODS

3.1 Study site

This research was carried out at Chuka University Chemistry and Food Science laboratories. Chuka University is a public university in Tharaka Nithi County, Kenya. The university is located approximately 186 km from Nairobi along the Nairobi-Meru highway in a rural setting on the eastern slopes of Mt. Kenya. It is on Latitude: 0° 19' 59.38" N Longitude: 37° 38' 45.13" E approximately 2,000 meters above sea level.

3.2 Experimental design

A 4×3 factorial treatment in CRD with repeated measures with treatment combinations of magnetic intensity (6µT, 7µT, 8µT) and exposure time (30, 60, 90 minutes) was used. All experiments were carried out in triplicates. The control was arrowroot samples with no magnetic treatment. The corms were stored for 25 days and analysed on the 1^{st}, 7^{th}, 14^{th}, and 25^{th} days.

3.3 Layout design

The experimental layout for the 4×3 factorial treatment was represented as shown in Table 1.

Table 1: Experimental Layout.

Magnetic field (µT)	Exposure Time	30 min	60 min	90 min
0		0	0	0
6		T630	T660	T690
7		T730	T760	T790
8		T830	T860	T890

Each treatment will be assessed at four storage time points: Day 1, Day 7, Day 14, and Day 25.

The experimental model was as follows:

$Y(ijk)=\mu + \alpha i + \beta j + \gamma k + \alpha\beta ij + \alpha\gamma ik + \beta\gamma jk + \alpha\beta\gamma ijk + \rho ijk$

Where:

Y(ijk): Response variable

μ: Overall mean effect

αi: Effect of Magnetic Intensity at level i

βj: Effect of Exposure Time at level j

γk: Effect of Storage Time at level k

αβij: Interaction effect between Magnetic Intensity and Exposure Time

αγik: Interaction effect between Magnetic Intensity and Storage Time

βγjk: Interaction effect between Exposure Time and Storage Time

αβγijk: Three-way interaction effect between Magnetic Intensity, Exposure Time, and Storage Time

ρijk: Residual (error) term

3.4 Sample collection

Freshly harvested arrowroot tubers were purchased from one of the farmers in Chuka, Karingani ward Tharaka- Nithi county, Kenya. The arrowroots were harvested at maturity, cleaned using running water to remove the dirt, and then air dried. They were then packed in cartons, which were used to deliver them to Chuka University, ready for analysis.

3.5 Treatment of arrowroot corms with magnetic fields

The magnetic fields were generated using Helmholtz coils with a radius of 21 cm and placed at a distance equal to the radii of the coils. The power was supplied to the coils by a direct current (DC) regulated power supply meter (INDOSAW; Type 351070; output 0-20V; 5A). The different magnetic intensities were obtained by adjusting the different voltage and currents. Magnetic intensity of (6μT, 7μT, and 8μT) was produced by a current-voltage combination of (02.4 I, 11.3 V; 02.9 I, 13.7 V; 03.8 I, 17.9 V) respectively. These magnetic intensities were measured using a Tesla meter (Mastifuyi FY876; NEDA DC9V, 6F221604006P). The voltage and current multimeter readings were recorded against the magnetic field intensity they produced. The arrowroot samples were divided into two groups: the treatment group and the control. The treatment group was put in a fabric net, hung between the two Helmholtz coils, and exposed to different magnetic field strengths (6μT, 7μT, 8μT) for different exposure times (30, 60, and 90 min). The control

group was arrowroots with no exposure to the magnetic field. The arrowroot samples were then stored at room temperature between 20 and 27 degrees Celsius and between 85% and 95% relative humidity and assessed on days 1, 7, 14, and 25 after treatment.

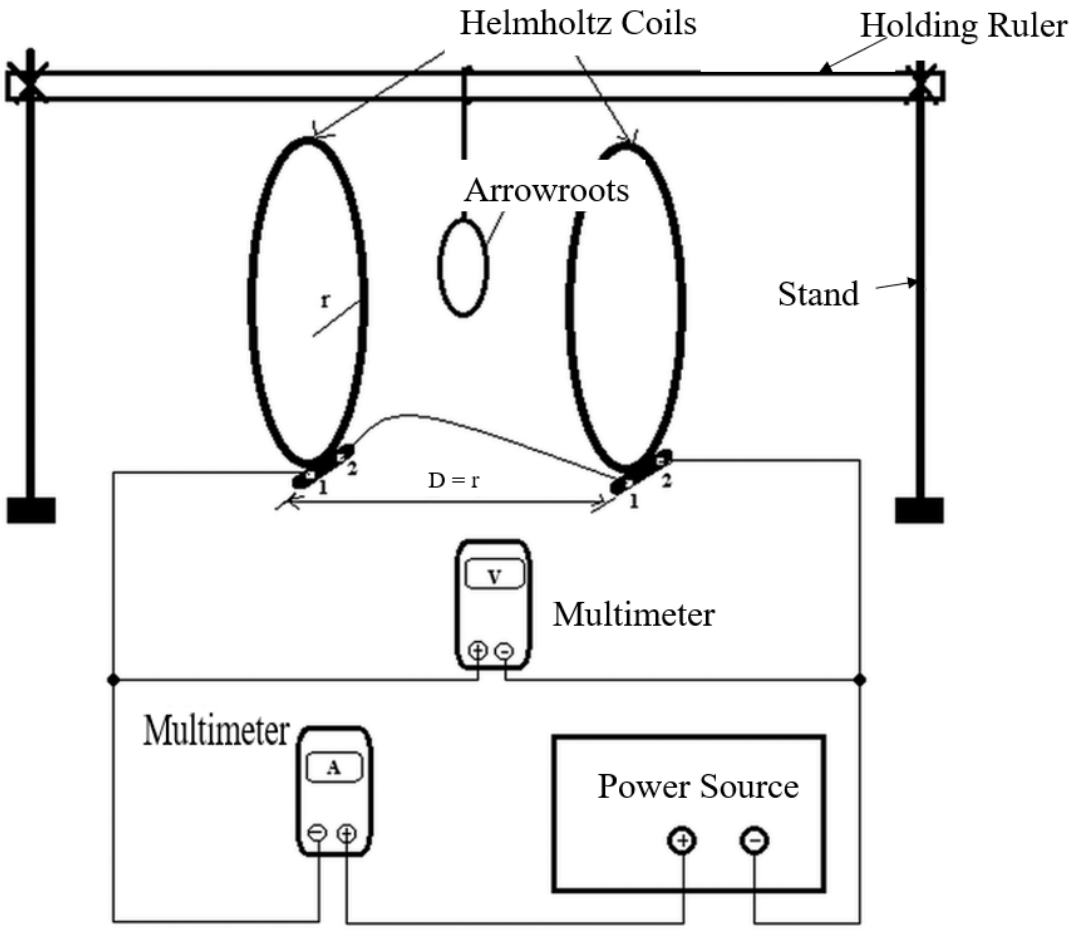


Figure 5*:* Treatment of arrowroot tubers with magnetic fields.
Source; Irungu *et al.*, 2022

3.6 Effects of Magnetic Field and Exposure Time on Physicochemical properties of arrowroots during Storage.

3.6.1 Weight loss

To monitor the weight differences during storage, each arrowroot corm was weighed using a suitable precision-level digital balance (UMS-UK; model UA2204N). This measurement results yielded the initial weight of each tuber, which was then recorded. At each of the set interval days from day 1 to day 25, three samples from each batch treatment were drawn

and weighed, and the weight difference was recorded. This process was repeated up to the end of the storage period. The weight difference was then used to calculate the percentage of weight loss.

The following formula was used to compute the weight loss % for each arrowroot tuber:

$$Weight\ loss\ (\%)\ =\ (Initial\ weight\ -\ Final\ weight)\ /\ Initial\ weight\ x\ 100$$

3.6.2 Colour Analysis

Colour analysis was performed using a chroma meter (KCC-REM-KIM-CR-400-410; Code No. 1878294; Japan) (Xiao *et al.,* 2022). At each of the set interval days from day 1 to day 25, three arrowroot samples from each batch treatment were drawn and peeled at the top and bottom. A clean film was placed on the peeled surface from where the colourimeter was placed for measurement. The colourimeter measured the Lab* values of the selected samples from each batch treatment. The L*, a*, and b* values were used to calculate the browning index (BI) which was then evaluated using a formula previously established (Ng *et al.*, 2014).

$$Browning\ Index\ (BI)\ =\ [100\ (x\ -\ 0.31)]\ /\ 0.17$$

Where;

$$x\ =\ (a*\ +\ 1.75L*)/(5.645L*\ +\ a*\ -\ 0.3012b*)$$

The Lab* values represent; the brightness (L*), red-green (a*), and yellow-blue (b*) colour coordinates of the arrowroot samples.

3.6.3 Firmness Analysis

The texture of arrowroots was measured using a penetrometer (Mod FT 327, Japan). At each of the set interval days from day 1 to day 25, three arrowroot samples from each batch treatment were drawn. A penetrometer with a probe was used to measure the firmness of each arrowroot sample. The penetrometer probe was positioned perpendicularly onto the surface tip of the arrowroot sample, and constant force by hand was gradually applied using the penetrometer until the probe penetrated the tuber to a specified depth, typically 10-20 mm. The maximum force for obtaining the probe's depth was indicated by the penetrometer reading, which was then recorded as the maximum force in Kg/cm^2. The test was repeated on the bottom part of the arrowroot sample for representative measurements.

The maximum force readings for each penetration were recorded and calculated as the average maximum force or firmness value. This value was used to represent the texture of the arrowroot sample.

3.7 Effects of Magnetic Field and Exposure Time on Biochemical properties of arrowroots during Storage.

3.7.1 Total Phenolic Content Analysis

At each of the set interval days from day 1 to day 25, two arrowroot samples from each batch treatment were drawn. The Folin-Ciocalteu technique was used to determine the total phenolic content (Xiao *et al.,* 2022). A 2.0 g sample of arrowroot was homogenized in 8 mL of a 1% (v/v) HCl-methanol reagent before being extracted at room temperature (24°C) for three hours. The extracts were then centrifuged for 10 minutes at 4°C (12,000× g). The extract was then collected in the form of crushed extracts to determine the phenolic content of arrowroot samples. In a clean tube, 0.6 mL of supernatants, 1.6 mL of 1 M sodium carbonate, and 2.0 mL of Folin-Ciocalteu reagent were added and thoroughly mixed. The reaction mixture was reacted in the dark for 30 minutes at 25°C. A standardized gallic acid solution with dilutions of (0, 5, 10, 20, 30, 40) mL was prepared as part of the measuring protocol. A UV-visible spectrophotometer was used to measure the absorbance of the reaction solution at 765 nm. To assess total phenolic contents, a gallic acid (GA) standard curve was used and expressed as a milligram GA equation per gram of fresh weight (mg/g).

3.7.2 Antioxidant Analysis

At each of the set interval days from day 1 to day 25, two arrowroot samples from each batch treatment were drawn. The DPPH method, with some minor modifications, was used to test the antioxidant activity (Harborne, 1999). These modifications included:

- Using a 1% (v/v) HCl-methanol reagent for extraction instead of pure methanol
- Increasing the extraction time from 1 hour to 3 hours at room temperature
- Adjusting the centrifugation speed to 12,000× g for 10 minutes at 4°C
- A 2.0 g sample of arrowroot was homogenized in 8 mL of a 1% (v/v) HCl-methanol reagent before being extracted at room temperature (25°C) for three hours. The extracts were then centrifugated at (12,000× g) for 10 minutes at 4 °C. In 50 mL of

methanol (about 0.3 mM), 6 mg of DPPH was dissolved to create a fresh solution of the compound. The extract was then mixed in a test tube with an equal volume of DPPH solution. The test tube was then incubated at room temperature for 20 minutes in the dark. A UV-VIS spectrophotometer was used to detect the reduction in absorbance at 517 nm. The following formula was then used to compute the percentage inhibition of radicals, which was then recorded as the percentage of inhibition:

- $\%inhibition = \frac{(A_{control} - A_{sample})}{A_{control}}$ x 100
- Where A_{sample} is the absorbance of the sample with DPPH solution and $A_{control}$ is the absorbance of the DPPH solution without extract. The quantity of antioxidants needed to reduce the initial DPPH concentration by 50% was given as the half-maximal inhibitory concentration (IC_{50}).

3.8 Effect of Magnetic Field Strength and Exposure Time on Mould Growth during Storage.

At each of the set interval days from day 1 to day 25, two arrowroot samples from each batch treatment were drawn to determine the mould count in the arrowroot samples during storage. A standard plate count (SPC) method was used for the analysis. A 10 g sample of the arrowroot tuber was weighed and homogenized in 90 mL of sterilized saline solution. Serial dilutions were prepared to 10^{-3}, and 0.1 mL of each dilution was spread on a Petri dish containing potato dextrose agar (PDA). The plates were incubated at 25°C for 5-7 days to allow for mould growth. After incubation, the number of mould colonies on each plate was counted, and the results were expressed as colony-forming units per gram (CFU/g) of the arrowroot sample.

3.9 Effect of Magnetic Field Strength and Exposure Time on The Shelf Life of Arrowroots during Storage.

The shelf life of the arrowroots treated with magnetic fields was assessed using the survival method (Dar *et al.,* 2022). A sample of 24 arrowroots of length (6-8 cm) was used to determine the shelf life of arrowroots. Six samples were the control, while the other 18

samples (2 samples from each magnetic field treatment) were assigned a code for identification. The corms were washed and stored in a dry, dark room at a temperature of (24-28 ^{0}C). They were visually assessed on the 1st, 7th, 14th, and 25th days for the following attributes:

1. Discoloration: Rated on a scale of 1-5 (1 = no discoloration, 5 = severe discoloration)
2. Softening: Rated on a scale of 1-5 (1 = firm, 5 = very soft)
3. Mold: Rated on a scale of 1-5 (1 = no mold, 5 = extensive mold growth)
4. Odor: Rated on a scale of 1-5 (1 = no off-odor, 5 = strong off-odor)

An illustration of the observation record, which was made, is in Appendix 1. The spoiled corms were disposed of to prevent contaminating the other corms. The mean for each attribute rate was calculated and recorded to enable the determination of trends of spoilage among the treated corms and the control.

3.10 Data Analysis

Descriptive statistics were used to summarize the data, including means, standard errors, and coefficients of variation for variables such as weight loss, firmness, browning, total phenolic content, antioxidant activity, and shelf life of arrowroots. Inferential statistics included the Shapiro-Wilk test to check for normality and tests for homogeneity of variance to ensure data consistency. Analysis of Variance (ANOVA) was used to determine the effects of different treatments (magnetic intensity, exposure time) and their interactions

with the dependent variables during storage time. Post-hoc comparisons were conducted to identify specific differences between group means. Additionally, detailed interaction effects analysis, including interaction plots, examined how combinations of factors influenced the dependent variables, providing a comprehensive understanding of the impact of various treatment conditions on the physicochemical, biochemical properties, mould count, and shelf-life properties of arrowroots. A significance level set at ($P < 0.05$) was considered statistically significant. The data obtained from the study was subjected to statistical analysis using SAS software version 9.4.

3.11 Ethical Considerations

A letter of recommendation was obtained from Chuka University. The letter was used to seek clearance from the National Commission of Science and Technology (NACOSTI Appendix III). NACOSTI provided a permit to conduct the research, which served as the clearance for the study. Additionally, the University's ethical approval was obtained for sample collection.

CHAPTER FOUR:
RESULTS AND DISCUSSIONS

4.1 Effect of Magnetic Intensity on Physicochemical Properties

As the first objective of this study, the effect of varying magnetic field strength and exposure time on the physicochemical properties of arrowroots during storage time was evaluated. This study considered the change in weight, firmness, and colour as outlined in subsections 4.1.1 to 4.1.3.

4.1.1 Weight

The study evaluated the effects of magnetic field strength (6 μT, 7 μT, and 8 μT) and exposure time (30, 60, and 90 minutes) on the weight loss of arrowroot corms during storage, examining their impact over short-term (7 days), medium-term (14 days), and long-term (25 days) storage periods and comparing the treated samples with the control as shown in Table 2.

Table 2: Means comparison of the main effects

	Weight loss (%)
Magnetic Intensity	
0	39.0063 ± 3.9176^{a}
6	35.6792 ± 6.5419^{ab}
7	30.6792 ± 0.5419^{bc}
8	26.1985 ± 3.6242^{c}
Exposure time (min)	
0	39.0063 ± 3.9184^{a}
30	36.4134 ± 4.1876^{ab}
60	32.1750 ± 3.7001^{bc}
90	27.7100 ± 3.6122^{c}
Storage time (days)	
7	15.9495 ± 1.20441^{c}
14	32.3063 ± 1.90319^{b}
25	49.4186 ± 2.24647^{a}

Key: Values are presented as means ± standard error of the mean. Means followed by the same letters in a column for each effect are not significantly different at $P < 0.05$.

The results indicated that magnetic intensity and, exposure time significantly impacted weight loss during storage, with P-values showing strong statistical significance ($P < 0.05$).

The results showed that the highest weight loss occurred in control samples (39.01% ± 3.92), with a significant reduction in weight loss as the intensity increased. At 6 µT, the weight loss was 35.68% ± 6.54, which was not significantly different from the control (Table 2). However, at 7 µT (30.68% ± 0.54) and 8 µT (26.20% ± 3.62), the weight loss decreased significantly, with 8 µT showing the lowest weight loss, significantly different from the other intensities. This suggests that increased magnetic intensity helps to mitigate weight loss in arrowroots, potentially due to the suppression of metabolic processes or moisture loss (Qu *et al.*, 2024).

For exposure time, the trend followed a similar pattern with the control showing a, weight loss that was highest (39.01% ± 3.92), with a gradual decrease observed at 30 minutes (36.41% ± 4.19), 60 minutes (32.18% ± 3.70), and 90 minutes (27.71% ± 3.61). Although the differences between 0 and 30 minutes were not significant, exposure times beyond 30 minutes resulted in significantly lower weight loss. The reduction in weight loss with longer exposure times indicated that prolonged exposure to magnetic fields helped to slow down moisture loss in stored arrowroots.

The storage time results showed that weight loss increased significantly with longer storage durations. After 7 days, the weight loss was the lowest at 15.95% ± 1.20, whereas after 14 days, it increased to 32.31% ± 1.90. By 25 days, weight loss peaked at 49.42% ± 2.25, indicating that prolonged storage led to substantial moisture loss and weight reduction in arrowroots. The significant differences between the storage times highlight the natural weight loss that occurs in stored produces over time.

The interactive effect of magnetic intensity (MI) and, exposure time (ET) significantly impacted weight loss during storage, with P-values showing strong statistical significance ($P < 0.05$) as shown in Table 3.

Table 3: Means comparisons of weight loss

Magnetic Intensity (μT)	Exposure Time (mins)	Storage Time (days)	Mean Weight Loss (%)
0	0	7	16.26±0.31[a]
		14	35.58±1.55[b]
		25	55.20±0.31[c]
6	30	7	14.90±0.87[a]
		14	28.68±0.65[b]
		25	58.25±0.03[c]
	60	7	23.73±0.41[d]
		14	44.16±5.06[c]
		25	63.11±0.29[c]
	90	7	17.75±0.81[a]
		14	31.37±0.96[b]
		25	50.39±0.20[c]
7	30	7	13.95±0.69[a]
		14	41.94±2.87[c]
		25	59.86±0.84[c]
	60	7	20.95±0.33[d]
		14	41.33±1.32[c]
		25	50.53±1.77[c]
	90	7	11.10±0.69[a]
		14	27.53±1.17[b]
		25	51.37±0.56[c]
8	30	7	10.94±0.31[a]
		14	34.44±1.41[b]
		25	54.76±0.95[c]
	60	7	10.48±0.36[a]
		14	28.10±0.95[b]
		25	45.68±1.53[c]
	90	7	15.94±0.44[a]
		14	22.44±0.09[d]
		25	50.01±0.22[c]

Key: Values are presented as means ± standard error of the mean. Means followed by the same letters in a column for each effect are not significantly different at $P < 0.05$.

The effect of varying magnetic intensities and exposure times during the short-term storage (7 days) showed that the treatment with 8 μT for 60 minutes was the most effective, resulting in the lowest mean weight loss of 10.48%. This was significantly lower than the 16.26% weight loss compared to the control (0 μT), highlighting the benefit of magnetic

exposure in preserving sample weight in the initial storage period. For medium-term storage (14 days), the treatment with 8 µT for 90 minutes resulted as the most effective, yielding a mean weight loss of 22.44%. This underscored the positive impact of higher magnetic intensities and longer exposure times in maintaining sample integrity over time.

Results from the long-term storage duration (25 days) showed that treatment with 8 µT for 60 minutes continued to be the most effective, achieving a mean weight loss of 45.68%. Notably, this was substantially lower than the highest observed weight loss of 63.11% in samples treated with 6 µT for 60 minutes, indicating that both magnetic intensity and exposure time play crucial roles in reducing weight loss during extended storage. The significant reduction at 8 µT highlights the potential of magnetic fields to slow down respiration rates and enzymatic activities, thus preserving the corms' weight (Liu *et al.*, 2023). This reduction in weight loss at higher magnetic intensities suggested that magnetic field treatment could effectively mitigate weight loss in arrowroot corms, as shown in Fig.6.

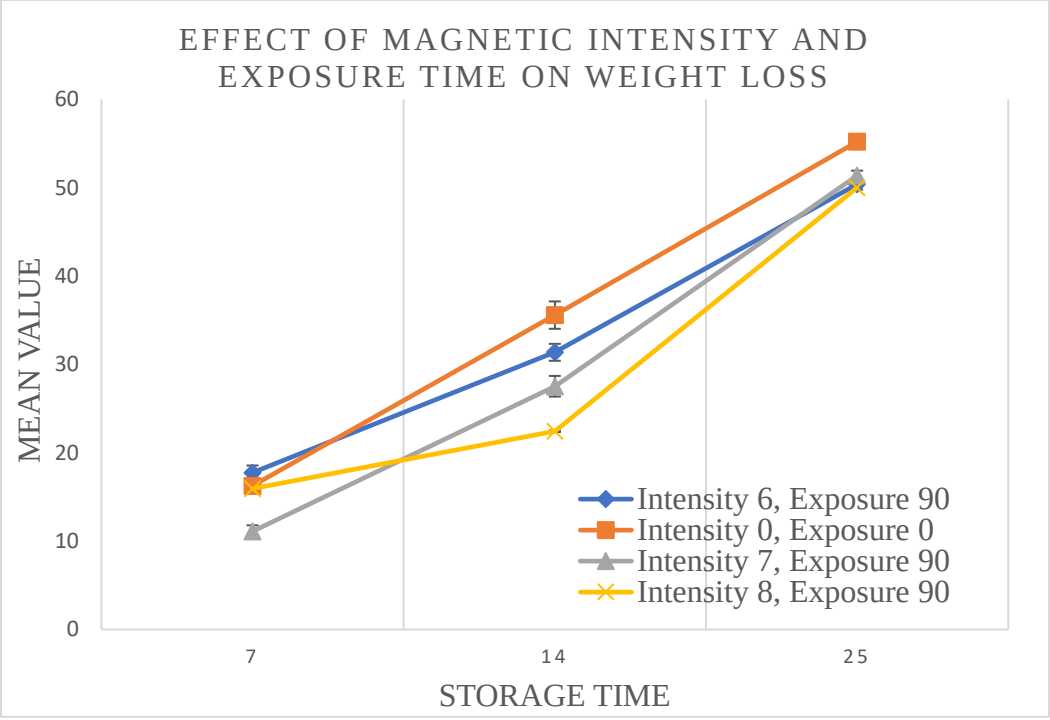


Figure 6: Effect of increasing magnetic intensity and exposure time on weight loss

The results show that as magnetic intensities increased (6 µT, 7 µT, 8 µT), they effectively reduced the rate of weight loss compared to the control (0 µT), thereby maintaining the

weight of arrowroot corms. These significant reductions in weight loss at higher magnetic intensities align with previous studies, which suggest that magnetic fields can reduce physiological changes in arrowroots by slowing down respiration rates, which are related to moisture loss and, hence, weight loss (Qu *et al.,* 2024). Studies by Liu *et al.* (2023) and Basak (2023) on vegetables and fruits, respectively, showed that the application of magnetic fields significantly reduced weight loss by decreasing the metabolic rate and respiration rate of the produce. The analysis of weight loss in arrowroots treated with different magnetic field intensities, exposure times, and storage durations indicated that magnetic intensity (MI) and exposure time (ET) significantly affected the weight loss during storage. The observed gradual weight loss with storage time was consistent with natural moisture loss and metabolic activities. However, the findings of this research suggested that the application of the magnetic field helped to reduce the rate at which the weight loss occurred, particularly at higher intensities.

Research by Tian *et al.* (2018) and Zhu *et al.* (2023) found that magnetic fields decreased weight loss in fresh-cut apples by affecting cellular structure and reducing water loss. Similarly, research on carrots treated with magnetic fields also demonstrated reduced weight loss over the time in which they were stored (Lin *et al.,* 2024). Further, Wei *et al.* (2024) and Saletnik *et al.* (2022) observed that magnetic fields decreased weight loss in tomatoes and potatoes, respectively, thereby supporting the results of this study. These findings align with this study, indicating a consistent mechanism across different types of produce. This preservation method offers a non-thermal, chemical-free alternative to conventional methods, making it a viable option for improving postharvest management practices and reducing economic losses due to spoilage (Irungu *et al.,* 2022).

Overall, the findings of this study suggest that magnetic intensity significantly reduced the weight loss in samples compared to the control. Specifically, treatments with 8 µT were consistently more effective across all storage durations, with the 60-minute exposure showing remarkable effectiveness in both short-term and long-term scenarios. This highlights the potential of using magnetic fields as a preservative method to enhance the longevity and quality of arrowroots during storage. The results emphasize the importance

of optimizing both magnetic intensity and exposure time to achieve the best preservation outcomes.

4.1.2 Firmness

The firmness in arrowroots was analysed both at the top and at the bottom; this is because the top part, which is cut from the stem during harvesting, would most likely have a different structural difference from the tough bottom part; hence, it would vary in the magnetic field permeability. The effects of magnetic field strength and exposure time on the firmness during storage time are shown in Table 4.

Table 4: Means comparisons of the main effects on firmness

	Firmness top	Firmness bottom
Magnetic Intensity		
0	13.6125±0.7364^{a}	12.9125±0.3523^{a}
6	12.1750±0.3116^{b}	12.9875±0.3157^{a}
7	12.1167±0.3506^{b}	13.3625±0.2974^{a}
8	12.5542±0.3802^{b}	13.1833±0.3812^{a}
Exposure time (min)		
0	13.6125±0.7364^{a}	12.9125±0.3523^{ab}
30	12.3625±0.2830^{b}	13.5292±0.3168^{a}
60	12.2542±0.3485^{b}	12.8958±0.3625^{b}
90	12.2293±0.4093^{b}	13.1083±0.3093^{a}
Storage time (days)		
1	13.4100±0.4175^{a}	14.4840±0.1134^{a}
7	11.3650±0.3530^{d}	12.4850±0.2431^{b}
14	12.0950±0.2330^{c}	12.8300±0.3661^{b}
25	12.7900±0.4172^{b}	12.7550±0.4184^{b}

Key: Values are presented as means ± standard error of the mean. Means followed by the same letters in a column for each effect are not significantly different at $P < 0.05$.

The results showed that magnetic intensity, exposure time, and storage time significantly influenced the firmness of both the top and bottom portions of arrowroots. For the top firmness, the magnetic intensity (MI) indicated a highly significant effect ($P < 0.001$), indicating that varying magnetic intensities had a strong influence. Upon treatment with magnetic intensity, the top firmness was highest in the control samples (13.6125±0.7364) and decreased significantly with increasing intensity. At 6 µT, 7 µT, and 8 µT, the firmness

of the top portion dropped to 12.1750 ± 0.3116, 12.1167 ± 0.3506, and 12.5542 ± 0.3802, respectively, indicating a clear negative impact of higher magnetic intensities. This finding aligns with studies by Wang *et al*. (2022), who found similar reductions in firmness in root vegetables under magnetic treatment. In contrast, the bottom firmness remained consistent across all magnetic intensities, with no significant differences observed, suggesting that magnetic intensity alone did not strongly affect the bottom firmness.

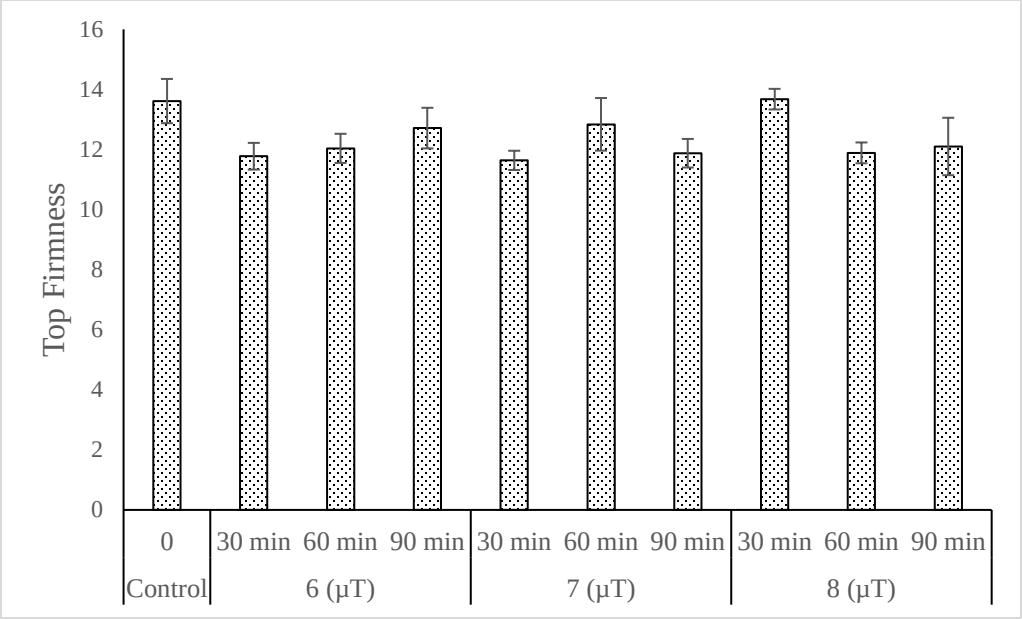
The effect on exposure time also had a significant impact on the top firmness. In the control samples, the top firmness was the highest (13.6125 ± 0.7364), but this firmness steadily decreased with increasing exposure time. At 30, 60, and 90 minutes, the top firmness values dropped to 12.3625 ± 0.2830, 12.2542 ± 0.3485, and 12.2292 ± 0.4093, respectively. This trend indicated that longer exposure times reduced the firmness of the top portion of the arrowroots due to the cell membrane alteration, which related to moisture loss and thus had an impact on the firmness. The bottom firmness showed some variability, with the highest value recorded at 30 minutes (13.5292 ± 0.3168), but it decreased slightly at 60 minutes (12.8958 ± 0.3625) and remained stable at 90 minutes (13.1083 ± 0.3093), suggesting a less consistent effect of exposure time on bottom firmness due to the difference in structural cell membrane composition where the bottom part required more exposure time for magnetic intensity permeability. The exposure time (ET), while not significant alone, was significant in its interaction with magnetic intensity, highlighting the importance of combined treatment where it significantly affected firmness at the bottom ($P < 0.01$).

Storage time had the most pronounced effect on both the firmness of the top and bottom. After 1 day, the top firmness was highest (13.4100 ± 0.4175), but it decreased significantly by day 7 (11.3650 ± 0.3530d). Firmness then increased slightly by day 25 (12.7900 ± 0.4172b), though it did not return to initial levels. The increase in firmness could be attributed to the toughening that occurred due to moisture loss. The bottom firmness followed a similar pattern, with the highest value observed after 1 day (14.4840 ± 0.1134a), followed by a significant decrease by day 7 (12.4850 ± 0.2431b), which remained stable through days 14 and 25. These results suggest that storage time, particularly within the first week, significantly reduces firmness, with the top portion being more affected than the

bottom. This difference is mostly attributed to the fact that the top part loses more moisture due to the cut after harvesting, and its cellular membrane is easily affected by the magnetic intensity. This suggested that increasing magnetic intensity led to a notable reduction in firmness, potentially due to structural changes at the cellular level caused by the magnetic fields (Irungu *et al.*, 2022; Saletnik *et al.*, 2022; Wang *et al.*, 2022).

Previous studies have contributed findings that relate closely to these results. Irungu *et al.* (2022) found that magnetic fields could alter cellular structure and turgor in potatoes, leading to changes in firmness. Similarly, Saletnik *et al.* (2022) investigated the impact of magnetic fields on the post-harvest quality of various fruits and vegetables, observing that magnetic treatment could lead to a reduction in firmness, aligning with the reduction in top firmness seen in arrowroots at higher magnetic intensities. Wang *et al.* (2022) reported that magnetic fields influence the firmness of root vegetables by altering the cellular water content and enzyme activities, which correlates with the changes in firmness observed in arrowroots over different storage times and magnetic intensities. These results support the findings in this study that higher magnetic intensities reduce firmness in arrowroots by potentially disrupting cell wall integrity.

The interaction effects of Magnetic intensity (MI) and exposure time (ET) on firmness are shown in (Fig 6, Fig 7, Fig 8).



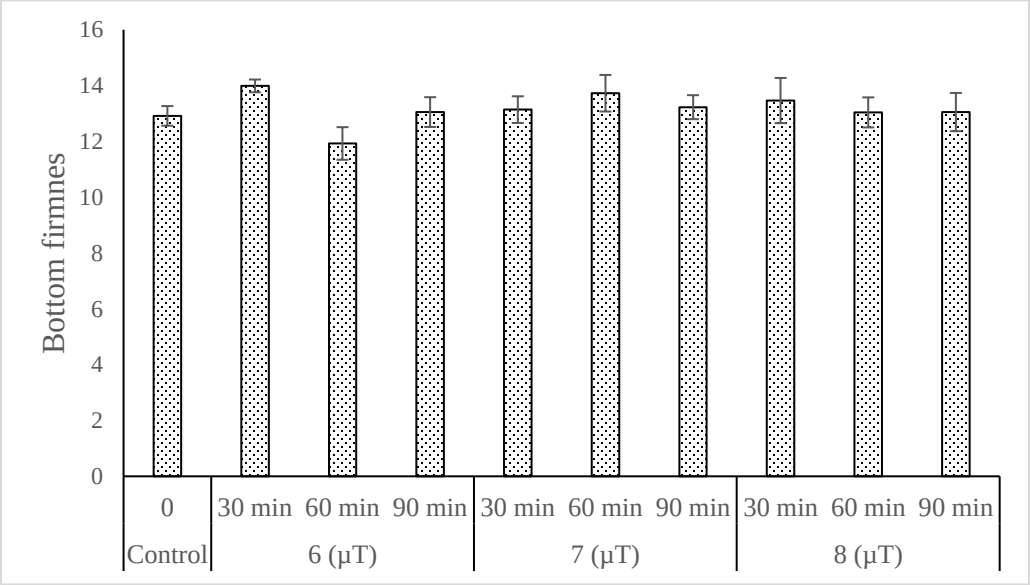
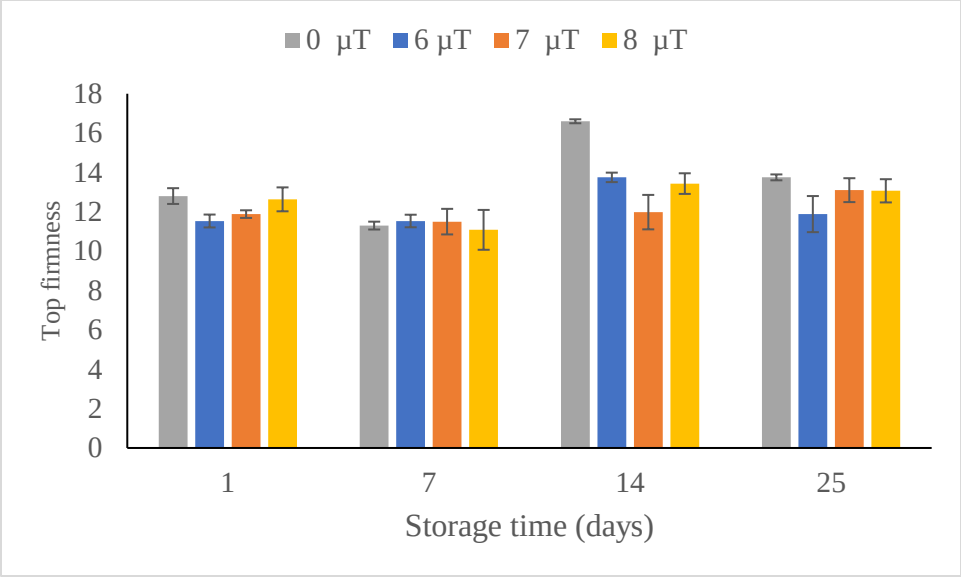


Figure 6. Interaction between Exposure Time and Magnetic Intensity



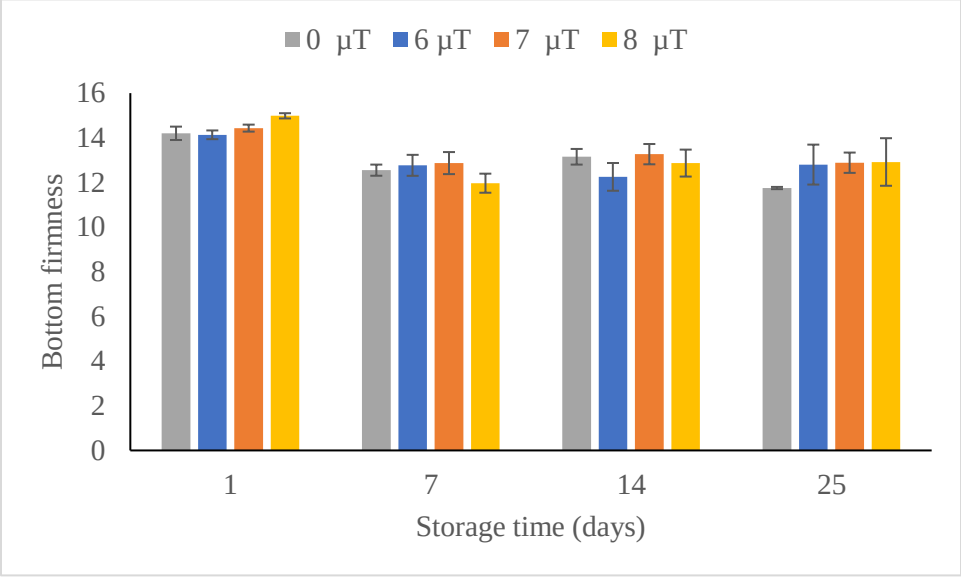


Figure 7. The effect of Magnetic Intensity on firmness during Storage Time

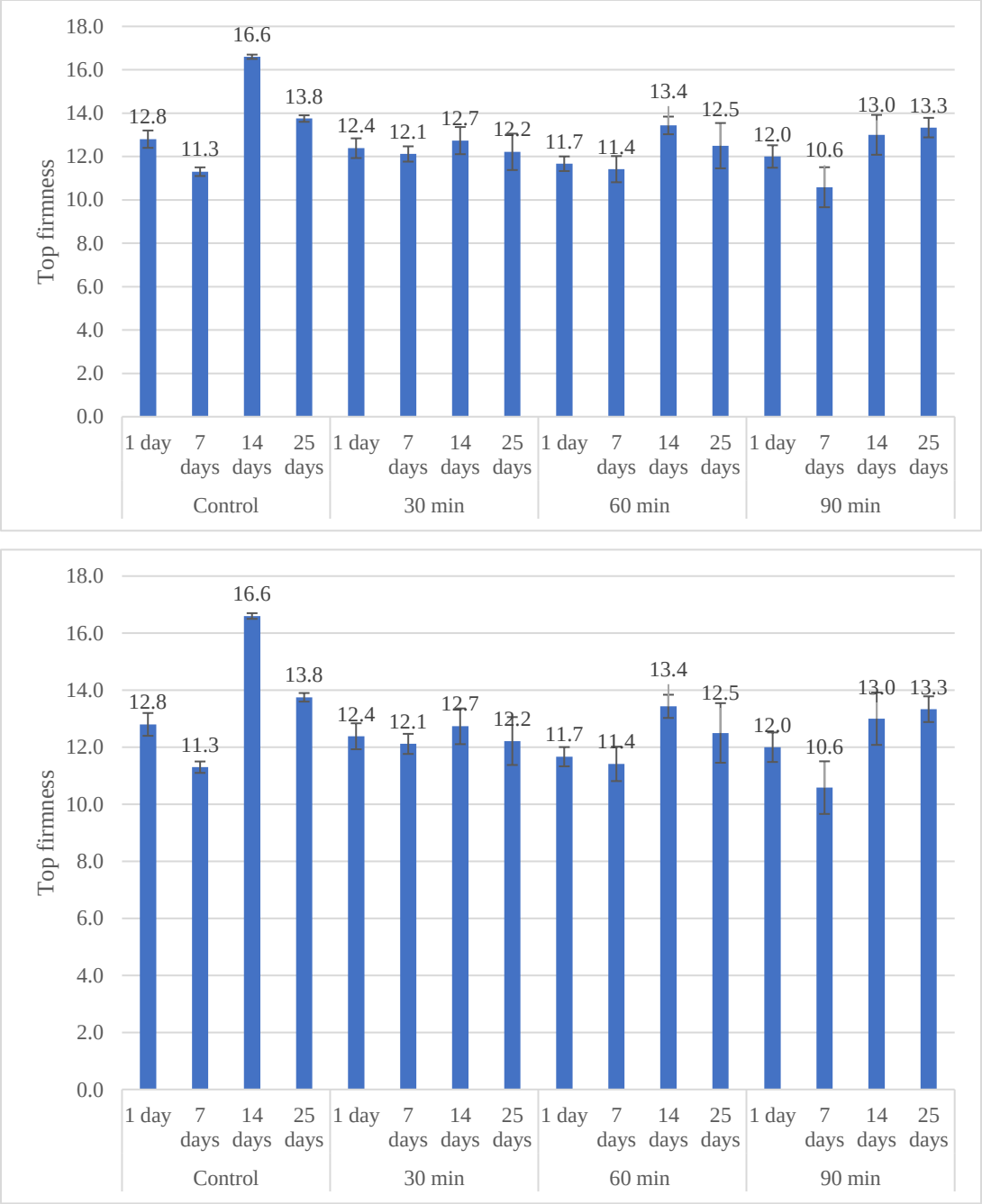


Figure 8. The effect of Exposure Time on firmness during Storage Time

The interaction effects of Magnetic intensity (MI) and exposure time (ET) on firmness Fig 6. shows that the control group maintained the highest top firmness (13.61 ± 0.7364), while the lowest was observed at 6 µT for 30 minutes (11.77 ± 0.4451). The Bottom firmness was at peak at 6 µT for 30 minutes (13.99 ± 0.2287) and was lowest at 6 µT for 60 minutes (11.93 ± 0.5842). The effect of magnetic intensity MI during storage time ST indicated the

highest top firmness at 0 µT at 14 days (16.60 ± 0.1000) and the lowest at 6 µT at 1 day (11.53 ± 0.3273). For bottom firmness, the highest was at 0 µT at 1 day (14.20 ± 0.3000) and the lowest at 6 µT at 25 days (12.80 ± 0.8944). The effect of magnetic intensity MI during storage time in Fig 7. shows variations, suggesting different storage times impacted firmness under varying magnetic intensities. Similarly, the effect of exposure time ET during storage in Fig 8. shows that the joint effects of exposure and storage times significantly influenced firmness, with certain combinations yielding higher firmness (Wang *et al.,* 2022; Saletnik *et al.,* 2022).

The interaction effects (MI*ET) during storage on firmness are shown in Table 5, revealing the specific trends where certain combinations resulted in significant changes in firmness.

Table 5: Means comparisons of the interaction effects on firmness

Intensity	Exposure	Storage	Firmness top	Firmness bottom
0	0	1	12.8000±0.4000[a]	14.2000±0.4000b
		7	11.3000±0.2000[c]	12.5500±0.2500[d]
		14	16.6000±0.1000[e]	13.1500±0.3500[e]
		25	13.7500±0.1500[f]	11.7500±0.0500[g]
6	30	1	11.1500±0.0500[h]	14.6000±0.0000[h]
		7	11.2000±0.2000[h]	13.6500±0.0500[b]
		14	13.6500±0.0500[i]	14.0000±0.5000[j]
		25	11.1000±0.9000[h]	13.7000±0.8000[k]
	60	1	12.5000±0.4000[l]	13.5500±0.0500[m]
		7	12.4000±0.3000[n]	13.3500±0.0500[n]
		14	13.2500±0.3250[o]	10.7000±0.2000[p]
		25	10.0000±0.5000[q]	10.1000±0.1000[r]
	90	1	10.9500±0.1500[s]	14.25000.05000[b]
		7	11.0000±0.5000[t]	11.3000±0.2000[d]
		14	14.3500±0.3500[u]	12.0500±0.0500[v]
		25	14.5500±0.5500[w]	14.6000±0.1000[b]
7	30	1	12.4000±0.3000[x]	14.6500±0.1500[y]
		7	12.0500±0.0500[z]	13.9000±0.1000[d]
		14	11.2000±0.7000[a]a	12.0500±0.0500 [b]b
		25	10.9000±0.9000[c]c	11.9500±0.9500 [d]d
	60	1	11.7500±0.0500[e]e	14.0000±0.0000[f]f
		7	9.6500±0.05000[g]g	11.3500±0.1500[h]h
		14	14.5500±0.3500[i]i	16.1000±0.5000[j]j
		25	15.4000±0.3000[k]k	13.4500±0.5500[l]l
	90	1	11.5000±0.2000[m]m	14.6500±0.2500[n]n
		7	12.8000±0.7000[o]o	13.3500±0.1500[p]p
		14	10.2000±0.7000[q]q	11.6500±0.1500[r]r
		25	13.0000±0.5000[s]s	13.2500±0.7500[t]t
8	30	1	13.6000±0.1000[u]u	15.2000±0.2000[v]v
		7	13.1000±0.1000[w]w	11.5500±0.0500[x]x
		14	13.350±01.3500[y]y	11.2000±0.7000[z]z
		25	14.6500±0.2500[a]aa	15.9000±0.3000[b]bb
	60	1	10.7500±0.0500[c]cc	14.7000±0.1000[d]dd
		7	12.2000±0.5000[e]ee	13.2500±0.3500[f]ff
		14	12.5000±0.3000[g]gg	13.2500±0.4500[h]hh
		25	12.1000±1.1000[i]ii	10.9500±0.7500[j]jj
	90	1	13.5500±0.4500[k]kk	15.0500±0.1500[l]ll
		7	7.9500±0.05000[m]mm	11.1000±0.2000[n]nn
		14	14.4500±0.5500[o]oo	14.1500±0.4500[p]pp
		25	12.4500±0.3500[q]qq	11.9000±1.6000[r]rr

Key: Values are presented as means ± standard error of the mean. Means followed by the same letters in a column and for each effect are not significantly different at $P < 0.05$.

From the results in Table 5, the control samples on day 1, had a top firmness of 12.80 ± 0.4000, and a bottom firmness of 14.20 ± 0.3000. At 6 μT for 30 minutes and on day 1, top firmness was 11.15 ± 0.0500, and bottom firmness was 14.60 ± 0.0000. The highest firmness values were generally observed at shorter storage times and higher magnetic intensities, suggesting that these conditions preserved firmness better. During the storage time, the results reveal that the top firmness was highest at 14 days and lowest at 7, while the bottom firmness was highest at day 1 and lowest at 7 days. The results through the storage time indicate that the top firmness initially decreased but then increased, indicating an initial softening followed by potential hardening or stabilization, which could have been brought about by increased moisture loss due to respiration which then decreased with time. The bottom firmness generally decreased over time, showing continuous softening with longer storage durations (Wang *et al.,* 2022).

Past research has reported similar findings. For instance, Hsieh *et al.* (2020) found that exposure time to magnetic fields significantly affected the texture and firmness of stored produce. Their findings support this current study, where there were significant interaction effects of exposure time on firmness in arrowroots. Lv *et al.* (2022) demonstrated that magnetic field treatment affected the structural properties of cell walls in fruits, leading to changes in firmness, which is consistent with the observed reduction in firmness in arrowroots at higher magnetic intensities and longer exposure times. Wei *et al.* (2024) showed that magnetic fields could modify the biochemical processes in cells, leading to changes in firmness, aligning with the significant impacts of magnetic intensity and storage time on the firmness of arrowroots. Tian *et al.* (2018) studied the effects of magnetic fields on the firmness of apple slices and found a similar pattern of reduced firmness with increased magnetic intensity, which supports the results found in arrowroots. Zhu *et al.* (2023) observed that magnetic field treatment could slow down the softening process in fresh-cut apples, paralleling the effects seen in arrowroots with longer storage times. Basak (2023) investigated the role of magnetic fields in maintaining firmness in stored fruits and vegetables, reporting results that confirmed the protective effects of magnetic fields on firmness, which is also seen in arrowroots. Radhakrishnan (2019) provided evidence that magnetic fields could influence the mechanical properties of plant tissues, leading to

changes in firmness, supporting the findings in this study regarding the impact of magnetic field strength and exposure time on arrowroot firmness.

The firmness of arrowroots, both at the top and bottom, was significantly influenced by magnetic intensity, exposure time throughout the storage time, and their interactions. Higher magnetic intensities generally led to a reduction in top firmness, indicating structural changes at the cellular level caused by magnetic fields (Irungu *et al.,* 2022). The bottom firmness was less sensitive to changes in magnetic intensity but showed significant variation with exposure time and storage time. This is because the bottom part has a tough mucilage skin that primarily protects the corm, while the top part remains open after the arrowroot corms have been harvested by cutting the stem off. This cut part leaves the top part susceptible to moisture loss and invasion by pathogens. The difference between the mucilage at the bottom part and the top part had an impact on the magnetic intensity permeability. The findings suggest that magnetic fields can modulate firmness, potentially by altering cellular turgor and integrity. Notably, higher firmness values were observed at shorter storage times and higher magnetic intensities, indicating that these conditions better preserve firmness (Wang *et al.,* 2022; Saletnik *et al.,* 2022; Lv *et al.,* 2022; Wei *et al.,* 2024; Tian *et al.,* 2018; Hsieh *et al.,* 2020; Radhakrishnan, 2019; Zhu *et al.,* 2023; Basak, 2023).

4.1.3 Colour

The results shown in Table 6 indicate that magnetic intensity (MI) and exposure time (ET) significantly affected the colour during storage, depicted by browning at both the top and bottom of the arrowroots.

Table 6: Means comparisons of the main effects on brownness

	Brownness top	Brownness bottom
Magnetic Intensity		
0	4.58±0.53[b]	3.49±0.43[c]
6	6.64±0.36[a]	5.40±0.18[a]
7	3.95±0.18[c]	3.64±0.15[c]
8	4.56±0.19[b]	4.13±0.25[b]
Exposure time (min)		
0	4.58±0.53[b]	3.49±0.43[b]
30	5.18±0.27[a]	4.77±0.19[a]
60	5.09±0.38[a]	4.50±0.21[ab]
90	5.19±0.43[a]	4.10±0.33[b]
Storage time (days)		
1	4.19±0.30[c]	3.89±0.24[b]
7	5.06±0.30[b]	4.26±0.24[ab]
14	5.72±0.39[a]	4.75±0.25[a]
25	5.60±0.47[ab]	4.63±0.35[a]

Key: Values are presented as means ± standard error of the mean. Means followed by the same letters in a column and for each effect are not significantly different at $P < 0.05$.

The means comparisons for the magnetic intensity and exposure time through the storage time on the colour indicate there was a significant effect, as shown in Table 6. For top browning, the control samples exhibited a browning score of 4.58±0.53, while the samples treated with 6 µT showed a score of 6.64±0.36, initially indicating increased browning due to oxidative stress caused by MF on the anions and cations in oxidative enzymes responsible for colour. However, as intensity increased, it resulted in reduced browning with prolonged exposure and storage times, suggesting the rate at which the enzymes received stability at higher magnetic intensities. This could have been as a result of oxidative stress on colour pigments which are antioxidants composed of free radicals. Free radicals are unstable molecules that can be formed during normal metabolism or in reaction to environmental stimuli like pollution and radiation (Ferdaus, Md Jannatul *et al.,* 2023). Samples treated with 7 µT had scores of 3.95±0.18, demonstrating that higher magnetic intensities generally resulted in less browning compared to the control, supporting the

hypothesis that magnetic fields can inhibit physicochemical changes in colour, which are related to enzymatic browning (Lv *et al.*, 2022; Hsieh *et al.*, 2020).

For bottom browning, control samples had a score of 3.49±0.43, which was higher than the treated samples. At 6 µT, the bottom browning score was 5.40±0.18, higher than the control initially but showing significant reduction over time with increased exposure as the ions got more stable. The scores for 7 µT were 3.64±0.15, indicating less browning compared to the control. The exposure time also significantly influenced browning as short exposure times resulted to high browning while long exposure times resulted to reduced browning as the enzymes had already stabilized.

The interaction effects of magnetic intensity with exposure time (MI*ET) in Figure 9 show that these factors significantly affected the colour of arrowroots. The effect of magnetic intensity (MI) throughout the storage time and the effect of exposure time (ET) throughout the storage time were also significant as shown in Figure 10 and Figure 11.

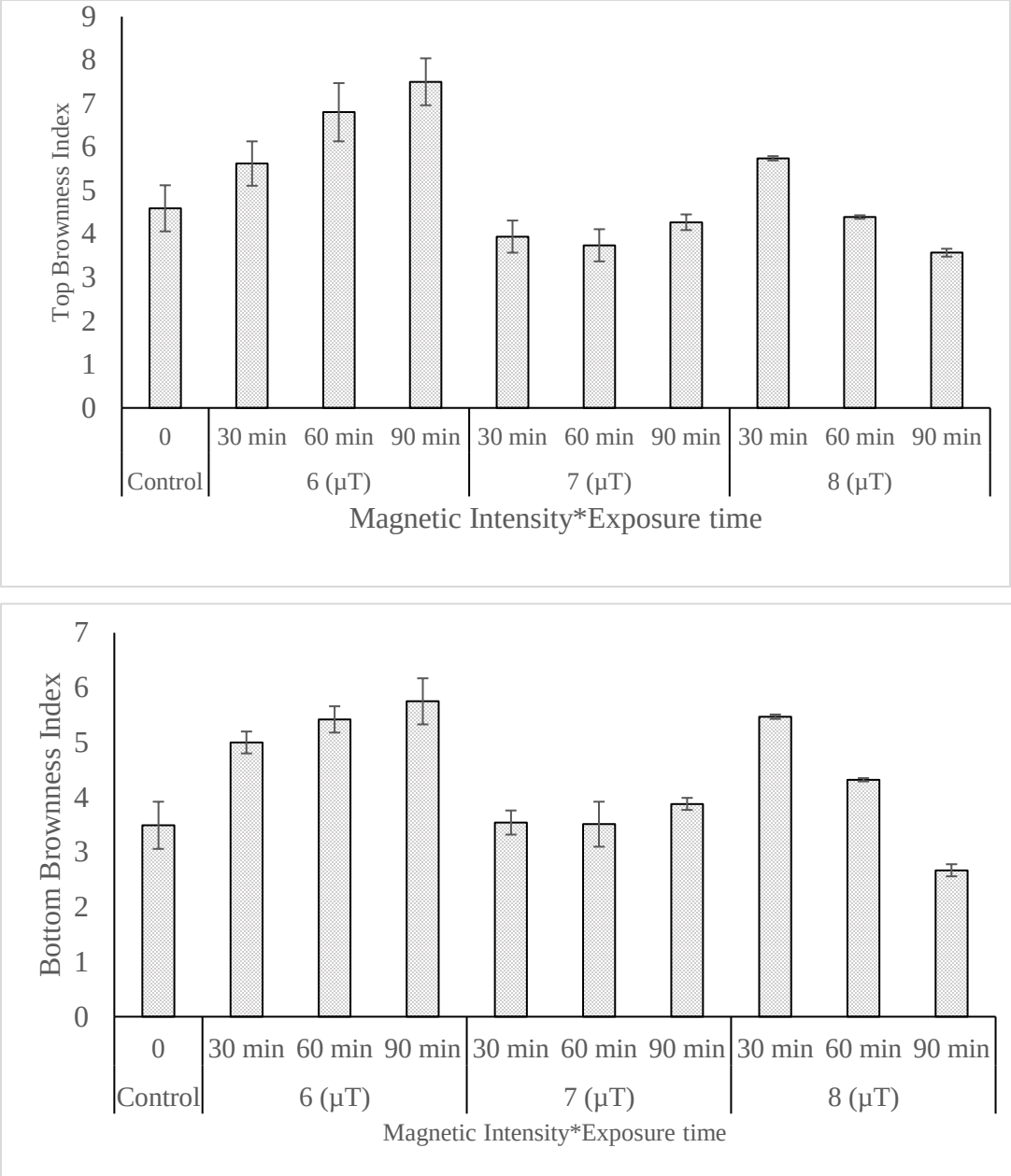


Figure 9. Effect of Interaction between Exposure Time and Magnetic Intensity on colour

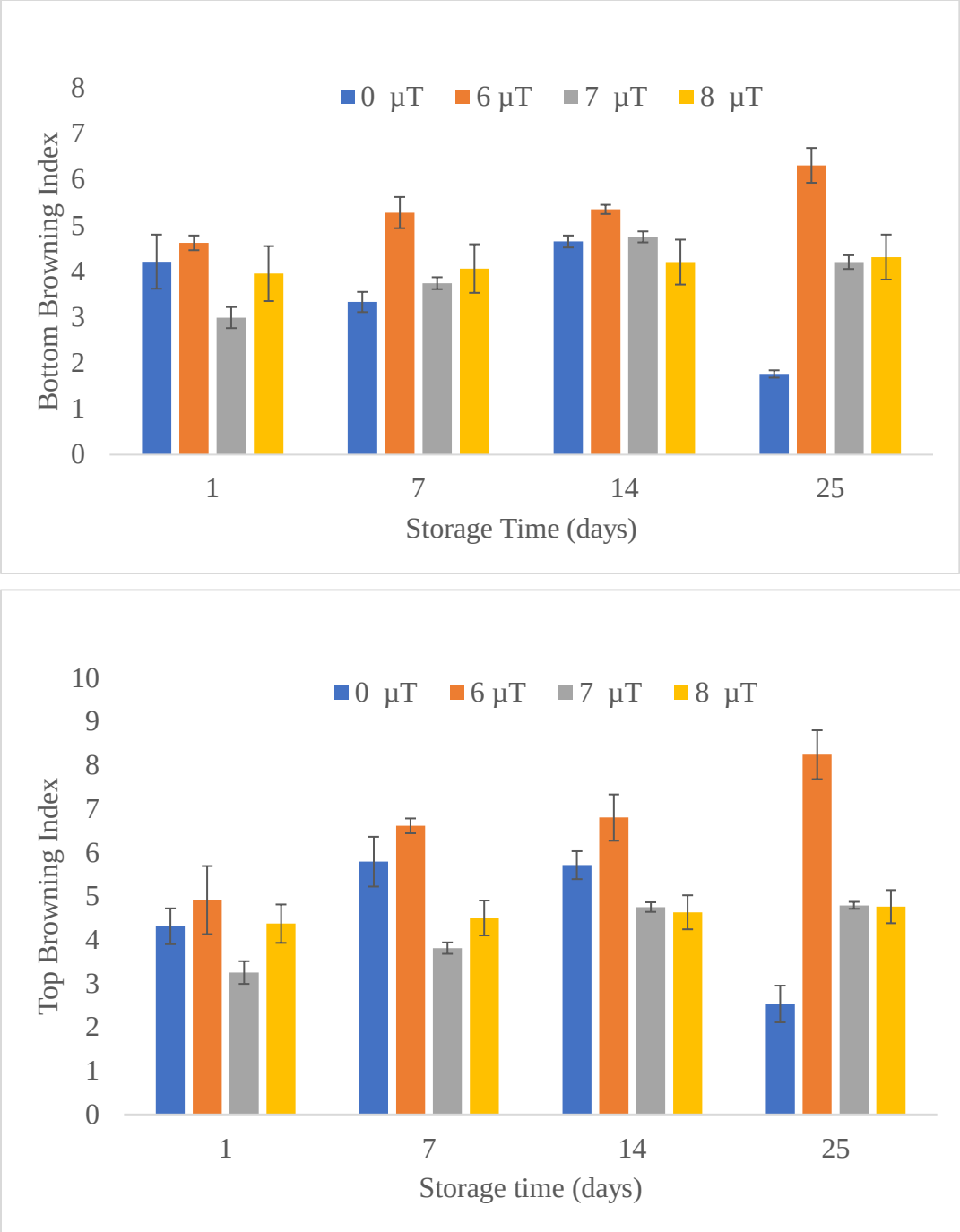


Figure 10. Effect of Magnetic Intensity throughout the Storage Time

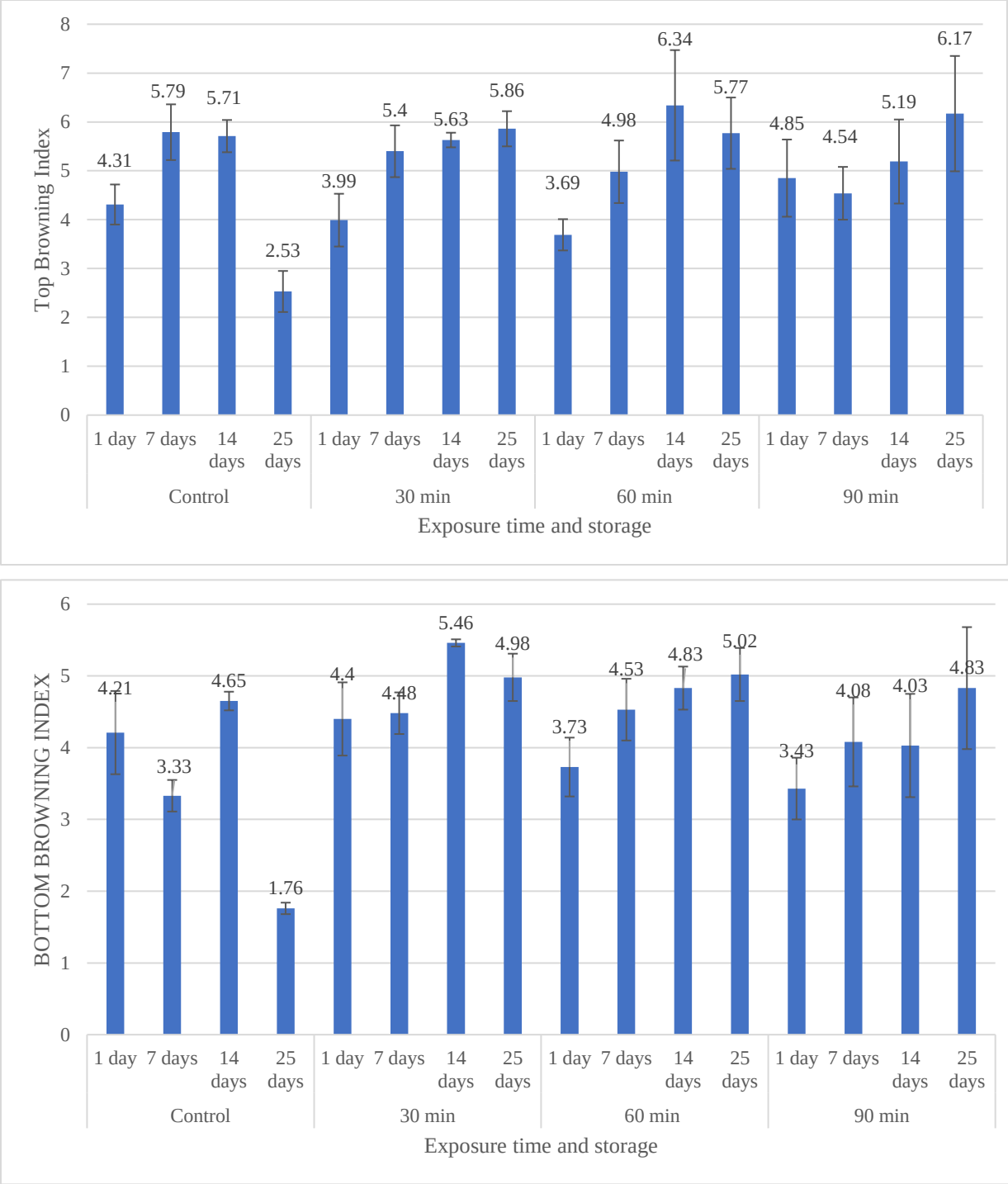


Figure 11. Effect of Exposure Time throughout the Storage Time

For instance, at 6 µT with 90 minutes of exposure, the top browning score was 7.50±0.54, higher than the control but still indicating controlled browning. For storage time, 6 µT-treated samples showed varying degrees of browning reduction over time, with a top score of 8.24±0.56 after 25 days, indicating slower browning compared to the control. These

findings align with previous studies suggesting magnetic fields' role in reducing enzymatic activity responsible for browning, supporting the application of magnetic fields in preserving the physicochemical quality of arrowroots and extending their shelf life (Basak, 2023).

Table 7: Means comparisons of the interaction effects on brownness

Intensity	Exposure	Storage	Brownness top	Brownness bottom
0	0	1	4.31 ± 0.41^{jklmn}	4.21 ± 0.56^{ghijk}
		7	5.79 ± 0.57^{efghi}	3.33 ± 0.22^{klmn}
		14	5.71 ± 0.32^{efghij}	4.65 ± 0.13^{defghij}
		25	2.53 ± 0.42^{p}	1.76 ± 0.08^{o}
6	30	1	3.52 ± 0.42^{mnop}	4.89 ± 0.26^{cdefghi}
		7	6.70 ± 0.08^{cdef}	4.23 ± 0.25^{ghijk}
		14	5.45 ± 0.28^{fghijkl}	5.46 ± 0.11^{bcdef}
		25	6.83 ± 0.02^{cdef}	5.39 ± 0.23^{bcdefg}
	60	1	3.91 ± 0.62^{mnop}	4.50 ± 0.24^{efghijk}
		7	6.93 ± 0.14^{bcde}	5.75 ± 0.16^{bcd}
		14	8.29 ± 0.17^{bc}	5.31 ± 0.24^{bcdefg}
		25	8.08 ± 0.17^{bc}	6.14 ± 0.12^{bb}
	90	1	7.29 ± 0.12^{bcd}	4.47 ± 0.36^{efghijk}
		7	6.19 ± 0.37^{defg}	5.86 ± 0.13^{cbc}
		14	6.67 ± 0.14^{cdef}	5.26 ± 0.26^{ebcdefgh}
		25	9.84 ± 0.11^{a}	7.42 ± 0.17^{a}
7	30	1	2.84 ± 0.04^{op}	2.84 ± 0.04^{lmno}
		7	3.84 ± 0.04^{mnop}	3.84 ± 0.04^{ijkl}
		14	4.28 ± 0.04^{klmn}	4.31 ± 0.04^{fghijkl}
		25	4.84 ± 0.04^{ghijklm}	3.94 ± 0.04^{ijkl}
	60	1	2.86 ± 0.25^{op}	2.51 ± 0.40^{mno}
		7	3.66 ± 0.45^{mnop}	3.51 ± 0.40^{jklm}
		14	4.70 ± 0.30^{hijklm}	4.61 ± 0.41^{efghijk}
		25	4.71 ± 0.29^{ihijklm}	4.51 ± 0.40^{efghijk}
	90	1	4.06 ± 0.05^{lmno}	3.61 ± 0.10^{jklm}
		7	3.94 ± 0.06^{mno}	3.86 ± 0.05^{jkl}
		14	5.25 ± 0.10^{ghijkl}	5.33 ± 0.06^{bcdefg}
		25	4.81 ± 0.10^{ghijklm}	4.16 ± 0.05^{hijk}
8	30	1	5.60 ± 0.01^{efghijk}	5.45 ± 0.03^{bcdef}
		7	5.65 ± 0.03^{efghijk}	5.35 ± 0.03^{bcdefgh}
		14	5.80 ± 0.01^{efgh}	5.45 ± 0.03^{bcdef}
		25	5.90 ± 0.01^{defgh}	5.61 ± 0.02^{bcde}
	60	1	4.29 ± 0.08^{klmn}	4.19 ± 0.07^{hijk}
		7	4.34 ± 0.02^{jklmn}	4.34 ± 0.01^{fghijk}
		14	4.39 ± 0.07^{ijklmn}	4.34 ± 0.01^{fghijk}
		25	4.54 ± 0.02^{hijklmn}	4.41 ± 0.02^{fghijk}
	90	1	3.20 ± 0.08^{nop}	2.20 ± 0.08^{no}
		7	3.50 ± 0.08^{mnop}	2.50 ± 0.02^{mno}
		14	3.70 ± 0.01^{mnop}	2.80 ± 0.02^{mno}
		25	3.85 ± 0.03^{mnop}	2.92 ± 0.07^{mno}

Key: Values are presented as means ± standard error of the mean. This means followed by the same letters in a column, and the interactions are not significantly different at $P < 0.05$.

Other researchers have explored similar applications of magnetic fields on various fruits and vegetables. For example, Tian *et al.* (2018) found that magnetic field treatment reduced the enzymatic activity of polyphenol oxidase in apple slices, which is consistent with the reduced browning observed in the arrowroots. Similarly, Zhu *et al.* (2023) reported that magnetic fields effectively decreased enzymatic browning and maintained the quality of fresh-cut apples. These studies corroborate the findings of the present study, demonstrating that magnetic fields can inhibit enzymatic browning and thus extend the shelf life of perishable products. Furthermore, research by de Souza *et al.* (2022) indicated that magnetic fields could slow down the degradation of chlorophyll in green vegetables, thus maintaining their colour for a more extended period. These findings support the current study's observation that magnetic fields can reduce browning in arrowroots by affecting the enzymatic processes that lead to colour changes.

The application of magnetic field treatments, particularly at 6 μT and higher, effectively reduced the browning of arrowroots compared to untreated control samples. This effect was observed across different exposure times and storage periods, suggesting that magnetic fields can play a significant role in maintaining the physicochemical quality of arrowroots by inhibiting enzymatic browning. These findings are consistent with previous research indicating that magnetic fields can affect the activity of polyphenol oxidase, the enzyme responsible for browning in fruits and vegetables (Saletnik *et al.*, 2022).

Therefore, the study rejects HO_1 and concludes that there is a significant effect of magnetic field strength and exposure time on the physicochemical properties of arrowroots during storage time and that magnetic field treatments can be a viable, non-chemical method to enhance the physicochemical properties of arrowroots. The reduction in weight loss, maintenance of firmness, and inhibition of browning through optimized magnetic field strength, exposure time, and storage duration can help extend the shelf life and improve the quality of arrowroots. Compared to the controls, the treated samples exhibited significant improvements, justifying the use of magnetic fields as an effective strategy for postharvest management (Saletnik et al., 2022).

These results indicate that using a magnetic field with an intensity of 8 μT can effectively reduce weight loss, maintain firmness, and inhibit browning, thereby potentially extending the shelf life of arrowroot corms. This preservation method offers a non-thermal, chemical-free alternative to conventional methods, making it a viable option for improving postharvest management practices and reducing economic losses due to spoilage.

4.2 Effect of Magnetic Intensity on Biochemical Properties

As the second objective of this study, the effect of varying magnetic field strength and exposure time on the biochemical properties of arrowroots during storage was evaluated. This study considered the change in total phenolic content and antioxidant activity as outlined in subsections 4.2.1 to 4.2.2.

4.2.1 Total Phenolic Content

The analysis of the total phenolic content (TPC) in arrowroots treated with different magnetic field intensities and exposure times during storage revealed significant findings. The findings revealed from the mean comparison in Table 8 depict the impact of magnetic intensity (MI) and exposure time (ET) during storage on TPC.

Table 8: Means comparisons of the main effects of TPC

	TPC
Magnetic Intensity	
0	110.49±23.15[b]
6	199.57±15.54[a]
7	215.12±18.30[a]
8	218.53±10.32[a]
Exposure time (min)	
0	110.49±23.15[b]
30	222.80±12.92[a]
60	213.02±17.09[a]
90	197.19±17.09[a]
Storage time (days)	
1	178.49±14.03[c]
7	217.63±14.68[b]
14	279.09±13.91[a]
25	130.65±13.29[d]

Key: Values are presented as means ± standard error of the mean. Means followed by the same letters in a column for each effect are not significantly different at $P < 0.05$.

Arrowroots exposed to magnetic intensities of 6 µT, 7 µT, and 8 µT revealed significantly higher scores in TPC compared to the control. The mean TPC values for 6 µT, 7 µT, and 8 µT were 199.57 mg GAE/100g, 215.12 mg GAE/100g, and 218.53 mg GAE/100g, respectively, compared to 110.49 mg GAE/100g for the control ($P < 0.001$) as shown in Table 8. This suggests that magnetic field treatment enhanced the phenolic content in arrowroots, which could be attributed to the stress response mechanism in plants that boosts phenolic compound synthesis (Kondrachuk, 2002). This finding aligns with studies by Bajcar *et al*. (2022), who found that magnetic field treatment increased the total phenolic content in various fruits by inducing stress responses that stimulate the synthesis of phenolic compounds.

Exposure times of 30, 60, and 90 minutes also significantly increased TPC compared to the control. The highest TPC was observed at 30 minutes (222.80 mg GAE/100g), followed by 60 minutes (213.02 mg GAE/100g) and 90 minutes (197.19 mg GAE/100g), as shown in Table 8. This increase in TPC with shorter exposure times suggests that initial exposure to magnetic fields stimulated the synthesis of phenolic compounds due to activation energy of free radicals in the phenolic compounds, and as the exposure time increased the rate of reaction in enzymatic activity stabilized and no further reactions took place. Similar results were reported by Song *et al.* (2023), who found that exposure to magnetic fields increased the phenolic content in steamed bread with potato pulp substitution.

Significant interaction effects on the total phenolic content were observed between MI and ET, as seen on Figure. 12, the effect of magnetic intensity (MI) throughout the storage time (ST) on Figure. 13, and, the effect of exposure time ET throughout the storage time (ST) on Figure. 14.

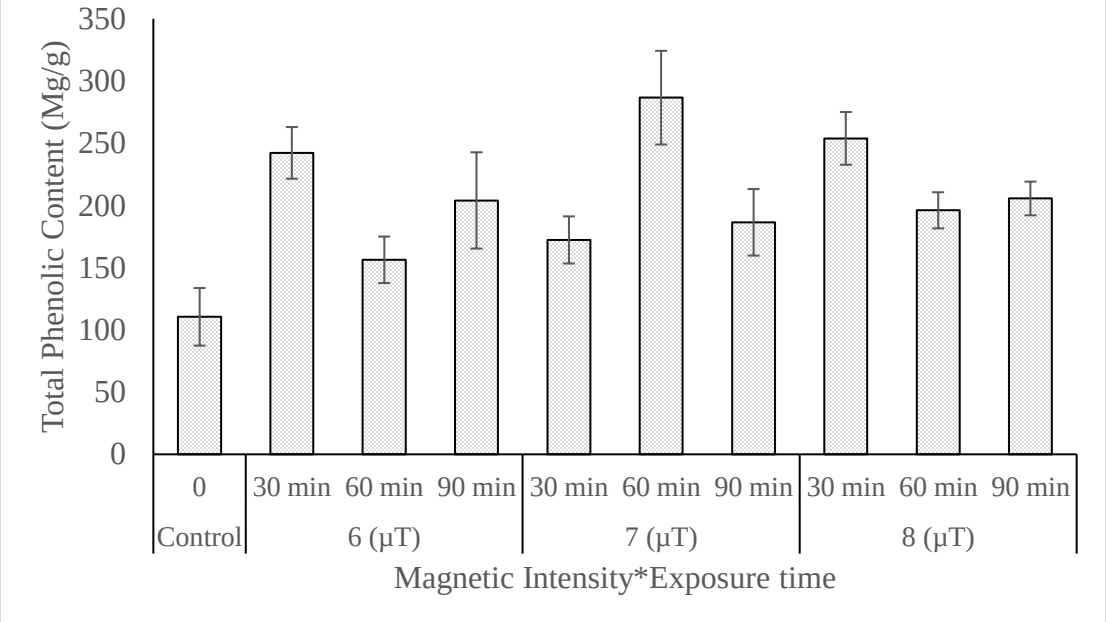


Figure 12. Interaction between Exposure Time and Magnetic Intensity on TPC

The combined treatment of 7 µT for 60 minutes resulted in the highest TPC (286.62 mg GAE/100g), highlighting the synergistic effects of optimal magnetic intensity and exposure time. For storage time, the combination of 7 µT with 14 days of storage produced the highest TPC (332.45 mg GAE/100g), further indicating that specific combinations of

treatment conditions can maximize the phenolic content in arrowroots. The control samples revealed the lowest TPC levels across all time points, reaffirming that the increase in TPC observed in treated samples was due to the magnetic field exposure. The results showed that magnetic field treatment induced physiological stress response in the arrowroots, which stimulated the production of phenolic compounds.

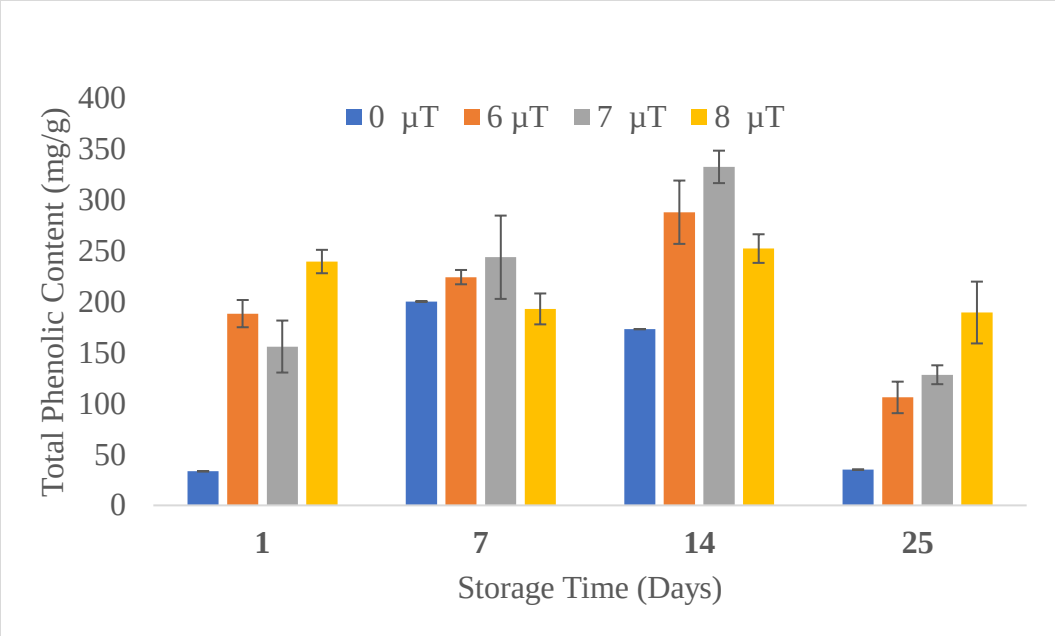


Figure 13. The effect of Magnetic Intensity on TPC during Storage

The control samples showed an initial increase in TPC up to day 14, reaching 279.09 mg GAE/100g, before significantly decreasing to 130.65 mg GAE/100g by day 25. This suggested that while some phenolic content increase may occur naturally due to post-harvest physiological processes, degradation processes dominate later in storage. In contrast, samples treated with magnetic fields (6 µT, 7 µT, and 8 µT) exhibited higher TPC throughout the storage period, with the 7 µT samples showing the highest TPC at 332.45 mg GAE/100g on day 14. This indicated that magnetic field treatment not only delayed the decline in TPC but also promoted an overall higher production of phenolic compounds compared to the control.

Despite the control samples not receiving any MF treatment, an increase in TPC was observed during storage, as shown in Figure 13. This increase in TPC can be linked to normal physiological reactions in arrowroots, such as the stimulation of phenolic synthesis pathways in response to oxidative stress during storage. These responses occur as the arrowroots continue to be exposed to external stimuli such as oxygen exposure and temperature variations. Even without MF treatment, untreated materials naturally produce phenolic chemicals as part of their defence system.

However, it is worth noting that the samples treated with MF had a significantly higher increase in TPC than the control. This suggests that the MF treatment enhanced the stress response, resulting in increased synthesis of phenolic chemicals. The MF-induced stress response appears to have a greater impact on the biochemical processes involved in phenolic synthesis. As a result, while the control samples showed a natural increase in TPC, the higher levels reported in treated samples may be more firmly attributed to MF treatment, which is consistent with earlier research establishing the effect of magnetic fields on phenolic synthesis.

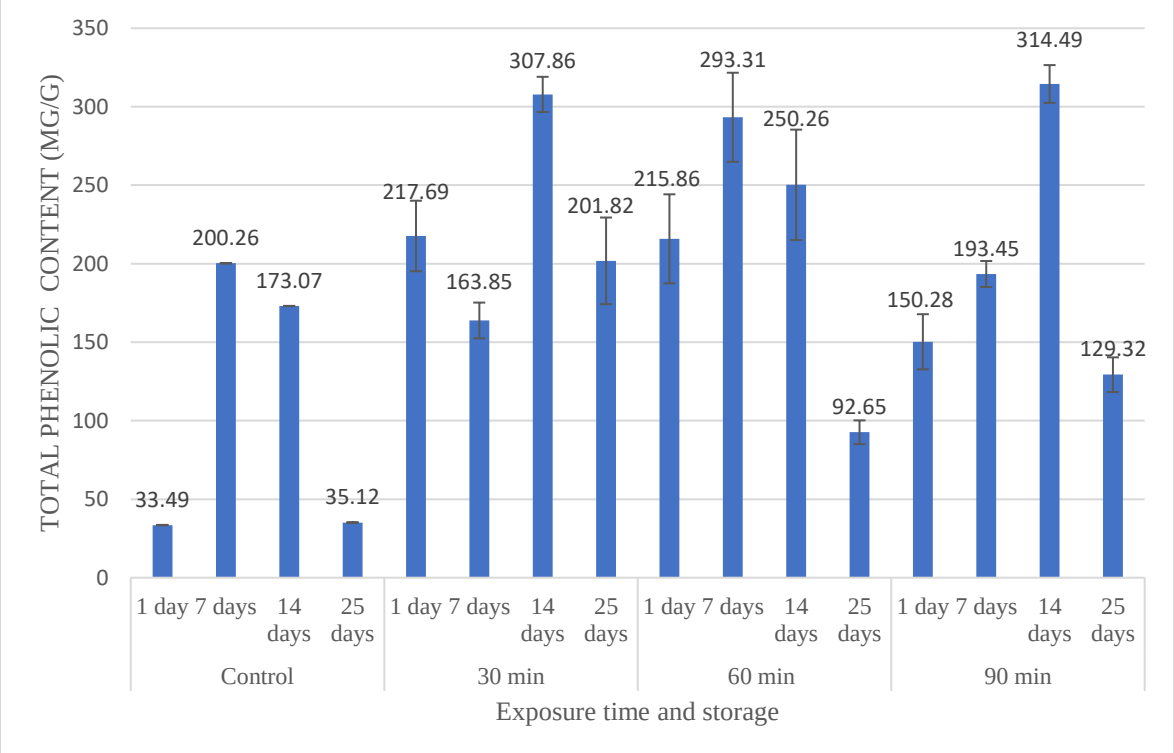


Figure 14. The effect of Exposure Time on TPC during Storage

Throughout the storage time, the results show a significant effect on TPC where the highest TPC value was observed at day 14 (279.09 mg GAE/100g) and then decreased at day 25 (130.65 mg GAE/100g) as shown in Fig.13. The control samples showed a steady decrease in TPC over time, while treated samples showed a slower decrease, indicating that magnetic treatment can help maintain higher phenolic content during storage. This pattern suggests that TPC increases initially, possibly due to continued metabolic activities, but declines as degradation processes take over during prolonged storage (Wang *et al.*, 2022). This finding is supported by Grgić *et al.* (2024), who observed that magnetic fields slow down the degradation of phenolic compounds in oat and barley flour.

The means comparison of the interaction effect on the total phenolic content is shown in Table 9.

Table 9: Means comparisons of the three way interaction effects on TPCs

Intensity	Exposure	Storage	TPC
0	0	1	33.50±0.14^{C}
		7	200.26±0.10^{p}
		14	173.07±0.08^{q}
		25	35.12±0.09^{m}
6	30	1	241.53±2.89^{k}
		7	208.50±0.00^{o}
		14	352.22±0.13^{c}
		25	166.68±0.33^{r}
	60	1	157.05±0.19^{t}
		7	239.87±0.27^{kl}
		14	163.55±0.15^{rs}
		25	64.90±0.30^{B}
	90	1	166.42±0.10^{r}
		7	215.15±0.07^{n}
		14	348.00±0.86^{d}
		25	86.53±0.79^{A}
7	30	1	130.72±0,17^{wx}
		7	149.50±0.00^{u}
		14	280.19±1.44^{h}
		25	128.75±0.07^{x}
	60	1	254.29±1.35^{j}
		7	406.69±0.00^{a}
		14	389.49±0.14^{b}
		25	96.01±0.30^{z}
	90	1	82.96±0.68^{A}
		7	174.93±0.07^{q}
		14	327.65±0.21^{e}
		25	160.21±0.09st
8	30	1	280.80±0.12^{h}
		7	133.55±0.05^{w}
		14	291.17±0.02^{g}
		25	310.03±0.00f
	60	1	236.23±2.06^{lm}
		7	233.36±0.07^{m}
		14	197.73±0.04^{p}
		25	117.03±0.33^{y}
	90	1	201.44±0.29^{p}
		7	211.98±0.13^{no}
		14	267.81±0.56^{i}
		25	141.20±0.08^{v}

Key: Values are presented as means ± standard error of the mean. This means followed by the same letters in a column, and the interactions are not significantly different at $P < 0.05$. Compared to the control, the treatments with magnetic fields significantly improved on the TPC. The control samples showed the lowest TPC, indicating that the absence of magnetic field treatment results in lower phenolic content. The increase in TPC with magnetic field treatments can be justified by the magnetic field's ability to induce stress responses in

plants, leading to an upregulation of phenolic compounds, which play a crucial role in defence mechanisms (Karimi *et al.,* 2021).

Other researchers have explored the influence of magnetic fields on the phenolic content in different products. Gan *et al.* (2024) found that magnetic field treatment could slow down the degradation of phenolic compounds in stored meat products. Tsevdou *et al.* (2022) reported that magnetic fields effectively enhanced the phenolic content in fresh-cut vegetables. These studies support the findings of this study, demonstrating that magnetic fields could stimulate the production of phenolic compounds and thus improve the nutritional quality of perishable products. Furthermore, research by He *et al.* (2024) demonstrated that the application of a magnetic field effectively increased the phenolic content in potatoes by activating enzymes.

The results of the study showed great significance, which lies in its potential application of magnetic intensity not only in extending the shelf life but also in maintaining the biochemical properties and enhancing the nutritional quality of arrowroots. By optimizing magnetic field treatments and exposure times, it is possible to increase the phenolic content of arrowroots, thereby offering a natural and non-chemical method to reduce postharvest losses and improve food quality (Lysakov *et al.,* 2018). Extending the shelf life of arrowroots offers a sustainable solution for postharvest management in food crops.

4.2.2 Antioxidant Activity

The analysis of the antioxidant content in arrowroots treated with different magnetic field intensities and exposure times during storage provided significant findings. The results of means comparison shown in Table 10, illustrate that magnetic intensity (MI) and exposure time (ET) enhanced the antioxidant properties of arrowroots during storage.

Table 10: Means comparisons of the main effects on Antioxidants

	%Antioxidant Inhibition
Magnetic Intensity	
0	75.02±1.92[b]
6	76.63±1.60[b]
7	78.72±2.23[a]
8	79.10±1.61[a]
Exposure time (min)	
0	75.02±4.92[b]
30	79.92±1.67[a]
60	79.29±2.39[a]
90	75.24±1.15[b]
Storage time (days)	
1	77.79±1.74[c]
7	66.33±2.17[d]
14	84.35±1.41[a]
25	82.88±1.40[b]

Key: Values are presented as means ± standard error of the mean. Means followed by the same letters in a column for each effect are not significantly different at $P < 0.05$.

Arrowroots exposed to magnetic intensities of 6 µT, 7 µT, and 8 µT demonstrated higher antioxidant inhibition compared to the control. The mean antioxidant inhibition as seen in Table 10, the values for 6 µT, 7 µT, and 8 µT were 76.63%, 78.72%, and 79.10%, respectively, compared to 75.02% for the control. These results were statistically significant, with $P < 0.05$, suggesting that exposure to higher magnetic intensities effectively increased antioxidant activity. This increase suggests that magnetic field treatment potentially enhanced the antioxidant properties of arrowroots, possibly by inducing oxidative stress responses that aid in boosting the synthesis of antioxidant compounds (Azimian and Roshandel, 2015). This finding aligns with studies by Abdollahi *et al.* (2019), who found that magnetic field treatment increased antioxidant enzyme

activities in almond seeds by inducing stress responses that stimulate the synthesis of antioxidant compounds.

Exposure times of 30, 60, and 90 minutes showed a significant increase in antioxidant inhibition compared to the control, as seen in Table 9. The highest antioxidant inhibition was observed at 30 minutes (79.92%), followed by 60 minutes (79.29%). Interestingly, extending the exposure time to 90 minutes led to a slight decrease in antioxidant inhibition (75.24% ± 1.15), comparable to the control. This increase in antioxidant activity with longer exposure times suggested that prolonged exposure to magnetic fields could further stimulate the synthesis of antioxidant compounds. Similar results were reported by Koukounaras *et al.* (2023), who found that extended exposure to magnetic fields increased antioxidant activity in vegetable seedlings. The decrease in antioxidant inhibition at 90 minutes compared 30 and 60 minutes implies that longer exposure to magnetic fields may not necessarily boost antioxidant capacity. Extended exposure times may result in cellular exhaustion or structural damage, reducing the positive effects reported with shorter exposures.

Significant interaction effects were observed between MI and ET, shown in Figure. 15, the effect of magnetic intensity (MI) throughout the storage time Figure. 16, and the effect of exposure time (ET) throughout the storage time Figure. 17, on antioxidant inhibition.

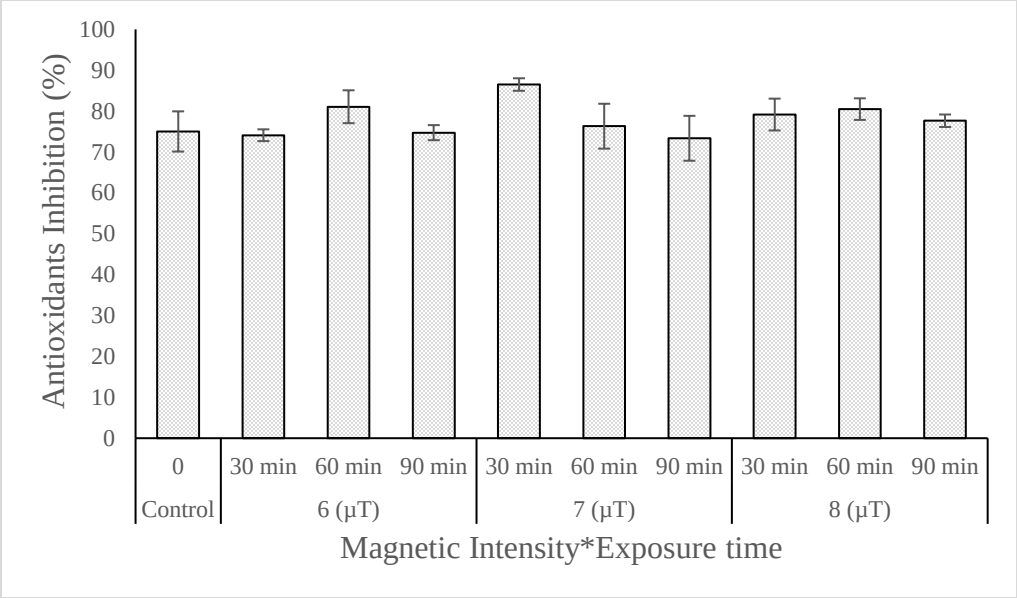


Figure 15:Interaction effect of Exposure Time and Magnetic Intensity on Antioxidant Activity

The effect of exposure time and magnetic intensity on antioxidant activity in arrowroots during storage showed that the combined treatment of 7 µT for 30 minutes exhibited the maximum antioxidant inhibition of 86.50%, showing a synergistic impact between magnetic intensity and exposure period. Higher magnetic intensities led to better antioxidant inhibition, with 7 µT and 8 µT demonstrating substantial improvements over the control. In terms of exposure time, 30 minutes produced the best results for retaining antioxidant activity, with the benefit dropping significantly with prolonged exposures of 60 and 90 minutes. The control samples had the lowest antioxidant inhibition, resulting in decreased antioxidant activity throughout storage. Interestingly, the treated samples maintained increased antioxidant levels, implying that magnetic field treatment helped preserve antioxidant compounds better than in untreated samples.

Magnetic fields caused mild oxidative stress in arrowroots, prompting the production of antioxidant compounds as a defense mechanism. This explains why treated samples exhibited greater antioxidant activity, especially at magnetic strengths of 7 µT and 8 µT. The 30-minute exposure interval revealed to be ideal, most likely because shorter exposure times allow for enough development of stress responses without causing severe damage to cellular structures. The slight decrease in antioxidant activity at 60 and 90 minutes of

exposure could be attributed to prolonged stress that exceeds the favorable threshold, perhaps causing oxidative damage that reduced the plant's ability to manufacture antioxidants effectively. The control group's steady decline in antioxidant activity highlights the natural degradation processes that occur during storage, which were mitigated by the magnetic treatments.

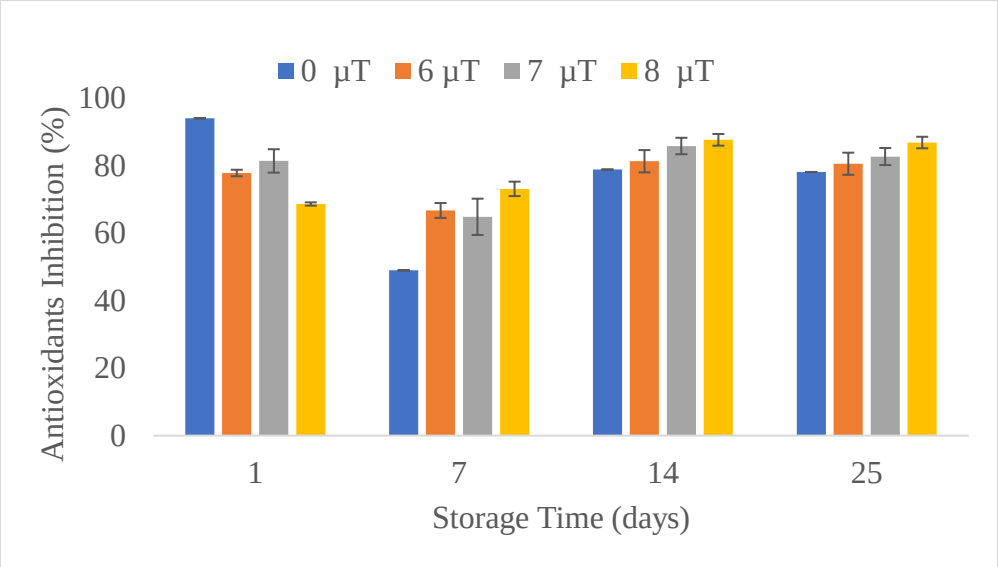


Figure 16. The effect of Magnetic Intensity on Antioxidant during Storage

As shown in Figure 16, antioxidant inhibition decreased initially over the first 7 days of storage before increasing significantly between days 7 and 25. On day 1, antioxidant inhibition levels were lower in treated samples than in controls, although they gradually increased after day 7. By day 25, the treated samples' antioxidant activity had reached or exceeded that of the control. The initial decrease in antioxidant inhibition observed during the first 7 days of storage can be attributed to the fresh state of the arrowroots, where active physiological processes such as respiration and enzymatic activities consume antioxidants. Furthermore, exposure to magnetic fields on day 1 most likely caused mild oxidative stress, resulting in a transitory drop in antioxidant levels relative to the control.

However, following day 7, a significant increase in antioxidant inhibition was seen, which peaked on day 25. The increase is consistent with a stress-induced defensive response caused by magnetic field exposure. As the arrowroots aged, they most likely activated

systems that increased the production of secondary metabolites, including antioxidants, in response to the prolonged stress. The magnetic field treatment may have enhanced this natural response, contributing to the observed increase in antioxidant activity.

Despite these fluctuations, the antioxidant levels between treated and control samples did not differ significantly. This could indicate that while magnetic fields stimulate antioxidant production, the difference in response is subtle and may be influenced by the inherent stability of antioxidant levels in arrowroots during storage.

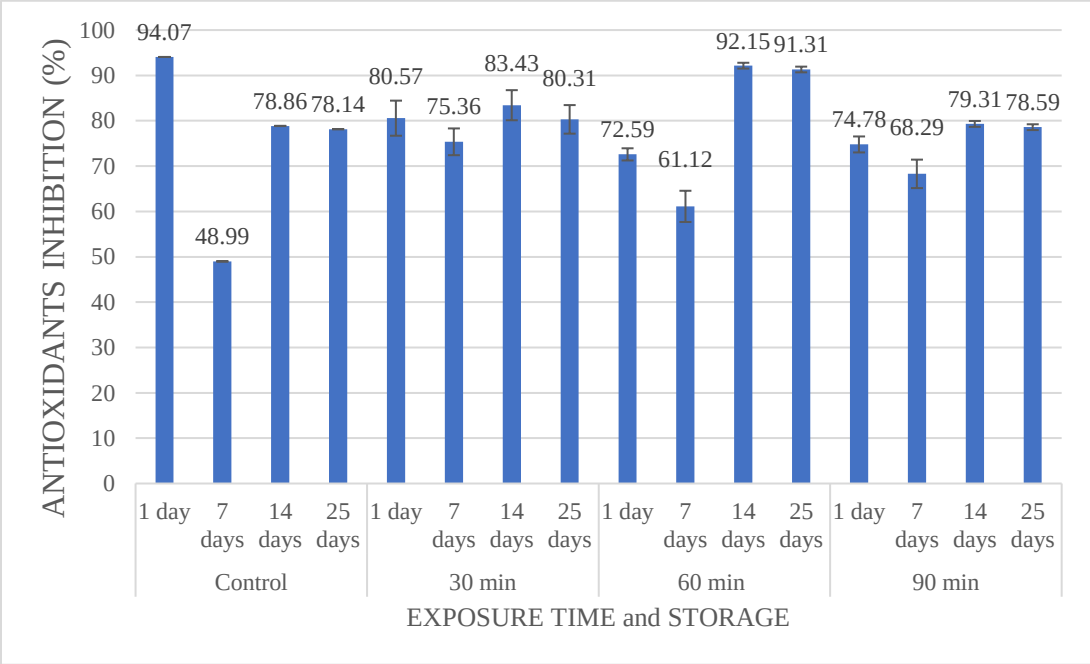


Figure 17. The effect of Exposure Time on Antioxidants during Storage

Initially, antioxidant levels increased, possibly due to ongoing metabolic activities, but they declined as degradation processes predominated during extended storage. The combined treatment of 7 µT for 30 minutes resulted in the highest antioxidant inhibition (86.50%), highlighting the synergistic effects of optimal magnetic intensity and exposure time. For storage time, the combination of 8 µT with 14 days of storage produced the highest antioxidant inhibition (87.69%), indicating that specific treatment combinations can maximize antioxidant properties in arrowroots. The control samples showed a steady decrease in antioxidant activity over time, while treated samples showed a slower decrease, indicating that magnetic treatment could help maintain higher antioxidant activity during

storage. This finding is supported by Azimian and Roshandel (2015), who observed that magnetic fields slow down the degradation of antioxidant compounds in *Artemisia sieberi*.

Compared to the control, the treatments with magnetic fields significantly improved antioxidant inhibition at different exposure times evaluated on different days, as seen in Table 11.

Table 11: Means comparisons of the interaction effects on the Antioxidant inhibition.

Intensity	Exposure	Storage	% Antioxidant Inhibition
0	0	1	94.07±0.01^{a}
		7	48.99±0.00^{s}
		14	78.86±0.03^{hi}
		25	78.14±0.03^{ij}
6	30	1	81.19±0.00^{g}
		7	74.83±2.22^{lmn}
		14	70.50±0.03^{o}
		25	69.86±0.03^{o}
	60	1	77.92±0.00^{ijk}
		7	60.53±0.03^{r}
		14	93.33±0.06^{a}
		25	92.48±0.06^{ab}
	90	1	74.44±0.10^{mn}
		7	64.86±0.03^{q}
		14	80.18±0.09^{gh}
		25	79.44±0.10^{ghi}
7	30	1	93.66±0.00^{a}
		7	85.57±0.00^{f}
		14	87.31±0.00^{ef}
		25	79.44±0.09^{ghi}
	60	1	69.60±0.01^{o}
		7	49.49±0.034^{s}
		14	93.51±0.0.07^{ab}
		25	92.66±0.07^{ab}
	90	1	81.03±0.02^{g}
		7	59.53±0,03^{r}
		14	76.78±0.09^{jkl}
		25	76.08±0.09^{klm}
8	30	1	66.87±0.04^{pq}
		7	65.66±0.00^{q}
		14	92.47±0.09^{ab}
		25	91.63±0.08^{bc}
	60	1	70.24±0.01^{o}
		7	73.33±0.04^{n}
		14	89.61±0.01^{cd}
		25	88.80±0.01^{de}
	90	1	68.87±0.00^{op}
		7	80.47±0.00^{gh}
		14	80.98±0.05^{g}
		25	80.24±0.05^{gh}

Key: Values are presented as means ± standard error of the mean. Means followed by the same letters in a column, and the interactions are not significantly different at $P < 0.05$.

From the interaction effect, the control samples showed the lowest antioxidant inhibition, indicating that the treatment of arrowroots with magnetic field treatment resulted in improved antioxidant levels. The interaction effects between magnetic intensity and

exposure time, throughout the storage time, highlighted that a combination of 7 µT for 30 minutes for 14 days of storage produced the highest antioxidant activity. The increase in antioxidant inhibition with magnetic field treatments could be attributed to the magnetic field's ability to induce stress responses in plants, leading to an upregulation of antioxidant compounds, which play a crucial role in defense mechanisms (Radhakrishnan, 2019). The results demonstrated that applying magnetic fields to arrowroots could significantly enhance their antioxidant content, particularly when optimized for specific magnetic intensities and exposure times.

Research from previous studies that have explored the influence of magnetic fields on antioxidant activity in different products shows results that greatly support this study. Mohammadi *et al.* (2022) found that magnetic field treatment increased antioxidant enzyme activities in tobacco cells, which is consistent with the increased antioxidant activity observed in arrowroots. Similarly, Taghizadeh *et al.* (2021) reported that magnetic fields effectively enhanced the antioxidant capacity in radish seedlings. Xu *et al.* (2022) observed that magnetic field treatment enhanced the antioxidant activity in potato slices, attributing the increase to the activation of antioxidant defense mechanisms. These studies corroborate the findings, demonstrating that magnetic fields could stimulate the production of antioxidant compounds, thus improving the nutritional quality of perishable products.

These results indicate that using a magnetic field with an intensity of 7 µT and above can effectively enhance the biochemical properties of arrowroots. This justifies the use of magnetic field treatments as an effective strategy to enhance the health-promoting properties of arrowroots. By inducing stress responses, magnetic fields can upregulate the synthesis of phenolic and antioxidant compounds, providing a sustainable solution for postharvest management (Radhakrishnan, 2019). Thus, the study rejects hypothesis HO_2, which states that magnetic field strength and exposure time have no significant effect on TPC and antioxidant activity of arrowroots during storage. Thus, exposure to magnetic fields can be a method to enhance the biochemical properties of arrowroots, thereby offering a natural and non-chemical method to reduce postharvest losses and improve food quality (Saletnik *et al.*, 2022).

4.3 Effect of Magnetic Intensity on Mould Growth

The third objective of this study was to evaluate the effect of magnetic field strength and exposure time on the mould count of arrowroots during storage. This study evaluated how the mould population was affected by the latter treatments, as shown in Table 12 below.

Table 12: Means comparisons of the main effects of Mould Count

	Moulds
Magnetic Intensity	
0	13.69±2.01[a]
6	4.10±0.60[b]
7	3.65±0.73[b]
8	2.71±0.48[b]
Exposure time (min)	
0	13.69±2.01[a]
30	3.23±0.53[b]
60	3.58±0.72[b]
90	3.65±0.60[b]
Storage time (days)	
1	2.55±0.72[b]
7	3.93±0.83[b]
14	4.15±1.04[b]
25	7.41±1.14[a]

Key: Values are presented as means ± standard error of the mean. Means followed by the same letters in a column for each effect are not significantly different at $P < 0.05$.

The results from the mould count on arrowroots treated with varying magnetic field strengths and exposure times throughout the storage time indicate a significant reduction in mould growth compared to the control samples ($P < 0.05$). The control samples, which had 0 magnetic intensity, showed consistently higher mould counts across all storage times, confirming that varying magnetic field strengths and exposure times impact mould growth. Specifically, the mould count for the control group was 13.69±2.01 CFU/10g, which was significantly higher than any of the treated samples, demonstrating that magnetic field treatment effectively inhibits mould growth.

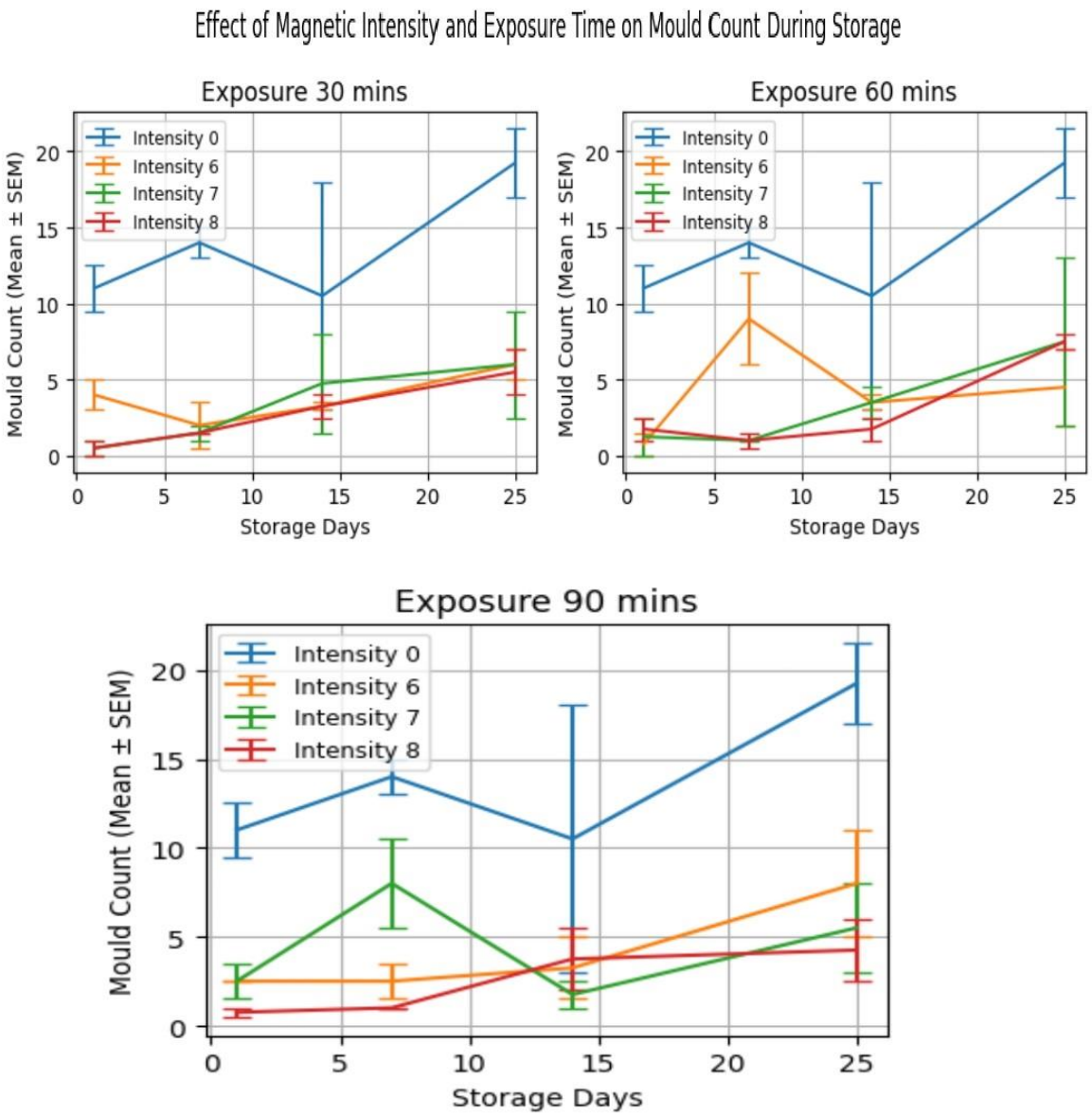
The effect of magnetic field strengths and, exposure times on mould count during storage in arrowroots was significantly reduced as shown in Table 13 and Figure 18. below.

Table 13: Effects of Magnetic Intensity and, Exposure Time on Moulds during Storage

Intensity	Exposure	Storage	Mould mean
0	0	1	11.00±1.50[a]
		7	14.00±1.00 [a]
		14	10.50±7.50 [a]
		25	19.25±2.25 [a]
6	30	1	4.00±1.00 [b]
		7	2.00±1.50 [c]
		14	3.25±0.25 [c]
		25	6.00±1.00 [c]
	60	1	0.75±0.75 [c]
		7	9.00±3.00 [b]
		14	3.50±0.50 [c]
		25	4.50±2.50 [c]
	90	1	2.50±0.00 [c]
		7	2.50±1.00 [c]
		14	3.25±1.75 [c]
		25	8.00±3.00 [b]
7	30	1	0.50±0.50 [c]
		7	1.50±0.50 [c]
		14	4.75±3.25 [c]
		25	6.00±3.50 [c]
	60	1	1.25±1.25 [c]
		7	1.00±0.00 [c]
		14	3.50±1.00 [c]
		25	7.50±5.50 [b]
	90	1	2.50±1.00 [c]
		7	8.00±2.50b
		14	1.75±0.75 [c]
		25	5.50±2.50 [c]
8	30	1	0.50±0.50 [c]
		7	1.50±0.00v
		14	3.25±0.75 [c]
		25	5.50±1.50 [c]
	60	1	1.75±0.75 [c]
		7	1.00±0.50 [c]
		14	1.75±0.75 [c]
		25	7.50±0.50 [b]
	90	1	0.75±0.25 [c]
		7	1.00±0.00 [c]
		14	3.75±1.75 [c]
		25	4.25±1.75 [c]

Key: Values are presented as means ± standard error of the mean. Means followed by the same letters in a column for each effect are not significantly different at $P < 0.05$.

Note: Mould mean values are presented as colony-forming units per 10 grams of sample (CFU/10g). Lower values indicate better preservation and less mould growth. An increase in mould count represents a decrease in quality.



Key: SEM is the standard error of the mean

Figure 18: Effect of magnetic field strengths and, exposure times on mould count colonies during storage.

As the magnetic field strength increased, the mould counts decreased significantly in the treated samples compared to the control. For example, at 14 days of storage, the control group showed a mould count of 10.50 ± 7.50 CFU/10g, while samples treated with 6 µT for 30 minutes had a significantly lower mould count of 3.25 ± 0.25 CFU/10g. Note: Mould mean values are presented as colony-forming units per 10 grams of sample (CFU/10g).

Lower values indicate better preservation and less mould growth. An increase in mould count represents a decrease in quality. This is clearly depicted in Figure. 18, where the line representing the control rises more sharply compared to those of the treated samples. However, by 25 days, the suppressive effect of higher intensities began to decrease, as the mould counts from the samples approached those of the control. The trend shown in Figure. 18 highlights that higher magnetic field strengths were more effective in reducing mould proliferation on arrowroots in 14 days of storage. This finding aligns with studies by Liu *et al.* (2021), who found that magnetic field treatment reduced microbial growth on various surfaces by inducing stress responses that inhibit microbial activity.

The exposure time had a notable effect on mould counts. Samples exposed for shorter durations (30 minutes) at 6 µT showed initial mould suppression, with mould counts remaining at 2.00 ± 1.50 CFU/10g and 3.25 ± 0.25 CFU/10g at both 7 and 14 days, compared to the control's increase to 10.50 ± 7.50 CFU/10g by 14 days. This is depicted in the graphs in Fig 18. where the lines for shorter exposure times stay below the control line during early storage. However, by 25 days, the mould count in this group rose to 6.00 ± 1.00 CFU/10g, when the efficiency of the magnetic treatment could no longer inhibit mould growth, as shown by the graph where the line representing this group curves upward. Interestingly, the intensity 8 µT group, particularly with 90 minutes of exposure, showed the most significant suppression of mould growth by day 25 at 4.25 ± 1.75 CFU/10g. This indicates that both higher magnetic intensities and longer exposure durations have a cumulative effect in reducing mould counts. This decrease in mould count with longer exposure times suggested that prolonged exposure to magnetic fields could further inhibit the growth of moulds. Similar results were reported by Sarraf *et al.* (2020), who found that extended exposure to magnetic fields reduced microbial growth of microalgae which belongs to the same kingdom as moulds.

As storage time increased, the general trend across all groups was an increase in mould count, as shown in Table 13 and Figure 18. The control group started with a low mould count of 1.00 ± 0.00 at 1 and 7 days, but this count increased to 2.50 ± 0.50 CFU/g by 14 days and 2.00 ± 0.00 CFU/g by 25 days. This gradual increase is clearly seen in the graphs

in Figure 18., where the control line rises steadily over time. The treated samples showed lower mould counts, with most treatments maintaining a count of 1.00 ± 0.00 CFU/g at 1 and 7 days. However, by 25 days, many treated samples experienced increased mould counts as the inhibitory effect of magnetic intensity weakened, as shown in the upward trend of the lines on the graphs in Figure 18. These variations observed in mould counts, during storage, suggest that mould growth dynamics can be complex and may depend on other factors such as the specific type of mould, environmental conditions, and the nature of the food matrix. However, the overall trend points to a clear benefit of using higher magnetic intensities and longer exposure times to control mould growth during storage. These findings are supported by Nunes *et al.* (2022), who observed that magnetic fields slowed down the microbial load in fruits during storage and extended their shelf life.

Other researchers have explored the influence of magnetic fields on microbial growth in different produce. Peretto *et al.* (2017) found that magnetic field treatment reduced mould growth in strawberries, which is consistent with the reduced mould count observed in arrowroots. Similarly, Zou and Jiang (2016) reported that magnetic fields effectively inhibited microbial growth in carrots. Furthermore, research by Saletnik *et al.* (2022) demonstrated that the application of a magnetic field effectively reduced microbial growth in tomato products by inhibiting microbial activity. Mosa *et al.* (2018) observed that magnetic field treatment reduced mould growth on wheat grains, attributing the reduction to the inhibitory effects of magnetic fields on microbial proliferation. These studies corroborate the findings, demonstrating that magnetic fields could inhibit the growth of moulds and thus improve the microbial quality of perishable products.

After the statistical significance ($P < 0.05$), it can be confirmed that the reductions in mould counts were not due to random variation but were attributable to the magnetic field treatments. The study, therefore, rejects HO_3 and demonstrates that there are significant differences in the treatments. The study aligns with previous findings that electromagnetic fields can inhibit microbial growth by disrupting cell structures and compositions (Akinyele *et al.*, 2012). This supports the theory that magnetic fields can be a non-thermal method for food preservation, reducing mould and other spoilage microorganisms. This

method shows its potential to reduce post-harvest losses, improve food security, and enhance economic sustainability. For example, the reduction in mould counts observed in treated samples suggests that magnetic fields could be implemented in storage facilities to extend the shelf life of arrowroots, as well as other perishable foods (Irungu *et al.*, 2022).

The significance of this study lies in its contribution to the field of food preservation. By demonstrating the efficacy of magnetic fields in reducing mould growth in arrowroots, the study provides a basis for further research and practical applications in post-harvest management. The findings contribute to the scientific understanding of electromagnetic field applications in food preservation and offer practical solutions for the adoption of electromagnetic field treatments as a viable method for extending the shelf life of perishable food items such as arrowroots, thereby benefiting farmers, food processors, and consumers alike.

4.4 Effect of Magnetic Intensity on Shelf Life

The effect of magnetic field strength and exposure time on the shelf-life quality parameters of arrow roots during storage revealed that increasing magnetic field intensity significantly increased the shelf life and reduced the degradation of quality parameters of arrowroots, as seen in Table 14.

Table 14: Effects of Magnetic Intensity on shelf life

Variable	Magnetic Intensity(µT)	Mean	SE Mean
Discoloration	0	2.500[a]	0.567
	6	2.250[ab]	0.271
	7	2.083[b]	0.255
	8	1.917[b]	0.216
Softness	0	1.750[a]	0.412
	6	1.333[ab]	0.115
	7	1.250[b]	0.138
	8	1.208[b]	0.104
Mouldiness	0	1.625[a]	0.263
	6	1.292[b]	0.141
	7	1.250[b]	0.090
	8	1.250[b]	0.090
Odour	0	1.875[a]	0.295
	6	1.375[b]	0.118
	7	1.417[b]	0.119
	8	1.0417[c]	0.042

Key: Values are presented as means; SE mean- standard error of the mean. Means followed by the same letters in a column are not significantly different at $P < 0.05$.

Note: Attributes were rated on a scale of 1-5, where:

- Discoloration: 1 = no discoloration, 5 = severe discoloration
- Softness: 1 = firm, 5 = very soft
- Mouldiness: 1 = no mold, 5 = extensive mold growth
- Odour: 1 = no off-odor, 5 = strong off-odor Lower scores indicate better preservation, while higher scores indicate degradation.

Higher magnetic intensities, such as 7 µT and 8 µT, consistently resulted in lower mean values for discoloration, softness, mouldiness, and odour compared to the control group across various exposure times and storage durations as shown in Table 14. For instance, at 8 µT, the mean discoloration value was 1.917, notably lower than the control's 2.500, while the mean softness at 8 µT was 1.208, significantly better than the control's 1.750. This

indicated that higher magnetic field intensities helped maintain the firmness and appearance of arrowroots, which are crucial for extending their shelf life. This finding aligns with studies by Saletnik *et al.* (2022), who found that magnetic field treatment increased the shelf life of various fruits by reducing respiration rates and ethylene production, thereby delaying ripening and senescence.

An increase in the exposure time to magnetic fields also positively affected the shelf life of arrowroots, as shown in Table 15.

Table 15: Effects of Exposure Time on shelf life

Variable	Exposure Time(mins)	Mean	SE Mean
Discoloration	0	2.500[a]	0.567
	30	2.083[b]	0.240
	60	2.125[b]	0.258
	90	2.042[b]	0.252
Softness	0	1.750[a]	0.412
	30	1.125[b]	0.069
	60	1.333[ab]	0.115
	90	1.333[ab]	0.155
Mouldiness	0	1.625[a]	0.263
	30	1.333[b]	0.130
	60	1.292[b]	0.112
	90	1.167[c]	0.078
Odour	0	1.875[a]	0.295
	30	1.292[b]	0.095
	60	1.333[b]	0.115
	90	1.208[b]	0.104

Key: Values are presented as means; SE mean- standard error of the mean. Means followed by the same letters in a column are not significantly different at $P < 0.05$.
Note: Attributes were rated on a scale of 1-5, where:

- Discoloration: 1 = no discoloration, 5 = severe discoloration
- Softness: 1 = firm, 5 = very soft
- Mouldiness: 1 = no mold, 5 = extensive mold growth
- Odour: 1 = no off-odor, 5 = strong off-odor Lower scores indicate better preservation, while higher scores indicate degradation.

As exposure time increased from 30 minutes to 90 minutes, the mean values for discoloration, softness, mouldiness, and odour decreased, as shown in Table 15. For example, at 90 minutes, the mean discoloration was 2.042, compared to 2.500 at 0 minutes of exposure time. This suggested that longer exposure times allowed magnetic fields to penetrate more effectively, enhancing the preservation effect. However, the most significant changes were observed at the initial exposure increase (from 0 to 30 minutes), indicating that even short exposure times could substantially benefit the preservation process. Similar results were reported by Li *et al.* (2023) who found that extended exposure to magnetic fields preserved the quality of vegetables during storage.

Storage time also played a critical role in the shelf-life quality factors of arrowroots. Over 25 days of storage, all parameters (discoloration, softness, mouldiness, and odour) significantly degraded, with mean values increasing from day 1 to day 25. The results in Table 16 below show a detailed summary of the effects of various magnetic intensity treatments (0 µT, 6 µT, 7 µT, and 8 µT) and exposure times (30, 60, and 90 minutes) on the shelf-life quality parameters (discoloration, softness, mouldiness, and odour) of samples over different storage times (1, 7, 14, and 25 days).

Table 16: Effects of varying magnetic intensities and exposure times on Shelf life

Intensity	Exposure	Storage	Discoloration	Softness	Mouldiness	Odour
0	0	1	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		7	1.00±0.00	1.50±0.50	1.00±0.00	1.50±0.50
		14	4.00±0.00	3.50±0.50	2.50±0.50	3.00±0.00
		25	4.00±0.00	1.00±0.00	2.00±0.00	2.00±0.00
6	30	1	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		7	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		14	2.50±0.50	1.00±0.00	1.00±0.00	1.00±0.00
		25	4.00±0.00	1.50±0.50	3.00±0.00	2.00±0.00
	60	1	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		7	2.00±1.00	2.00±0.00	1.00±0.00	1.00±0.00
		14	3.00±1.00	2.00±1.00	1.00±0.00	2.00±0.00
		25	4.00±0.00	1.50±0.50	2.50±0.00	2.50±0.50
	90	1	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		7	2.00±1.00	1.50±0.50	1.00±0.00	1.50±0.50
		14	1.50±0.50	1.00±0.00	1.00±0.00	1.00±0.00
		25	4.00±0.00	1.50±0.50	1.00±0.00	1.50±0.50
7	30	1	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		7	2.00±1.00	1.50±0.50	1.00±0.99	1.50±0.50
		14	2.00±0.00	1.00±0.00	1.00±0.00	2.00±0.00
		25	4.00±0.00	1.00±0.00	2.00±0.00	2.00±0.00
	60	1	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		7	1.00±0.00	1.50±0.50	1.00±0.00	1.00±0.00
		14	2.00±0.00	1.50±0.50	1.00±0.00	1.00±0.00
		25	4.00±0.00	1.00±0.00	2.00±0.00	2.00±0.00
	90	1	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		7	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		14	2.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		25	4.00±0.00	2.50±1.50	2.00±0.00	2.50±0.50
8	30	1	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		7	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		14	2.50±0.50	1.50±0.50	1.00±0.00	1.00±0.00
		25	3.00±0.00	1.00±0.00	2.00±0.00	1.00±0.00
	60	1	1.00±0.00	1.00±0.00	1.00±0.00	1.50±0.50
		7	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		14	2.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		25	3.50±0.50	1.50±0.50	2.00±0.00	1.00±0.00
	90	1	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		7	1.00±0.00	1.00±0.00	1.00±0.00	1.00±0.00
		14	2.50±0.50	2.00±1.00	1.00±0.00	1.00±0.00
		25	3.50±0.50	1.50±0.50	2.00±0.00	1.00±0.00

Key: Means are presented as means ± standard error of the mean at $P < 0.05$.

From the table above, the rate of discoloration for the control samples significantly increased over time, reaching a peak at 14 days (4.00±0.00) and remaining high at 25 days (4.00±0.00). In contrast, treatments with magnetic intensities showed varying degrees of

effectiveness. At 6 µT, 30 minutes of exposure resulted in lower discoloration at 14 days (2.50±0.50) compared to the control but was comparable to the control at 25 days (4.00±0.00). Similar trends were observed for other exposure times and intensities, with the most notable improvement seen with 7 µT for 30 and 60 minutes, maintaining lower discoloration levels at 7 and 14 days compared to the control.

The rate of softness in the control group increased over time, reaching a peak at 14 days (3.50±0.50), but returned to initial levels at 25 days (1.00±0.00). Magnetic treatments generally maintained the softness over the storage period. For example, 6 µT for 30 minutes of exposure resulted in consistent softness levels across all storage times, with a slight increase at 25 days (1.50±0.50). Treatments with 7 µT and 8 µT similarly showed minimal changes in softness, indicating better preservation compared to the control.

The mouldiness rates in the control group increased to 2.50±0.50 by 14 days and remained relatively high (2.00±0.00) at 25 days. Magnetic treatments effectively suppressed mouldiness in most cases. For instance, samples treated with 6 µT for 30 minutes and 90 minutes maintained a mouldiness level of 1.00±0.00 up to 14 days, with a slight increase at 25 days. Higher intensity treatments (7 µT and 8 µT) also resulted in lower mouldiness scores, particularly with 60 and 90-minute exposures.

The odour changes followed a similar pattern to mouldiness in the control group, peaking at 14 days (3.00±0.00) and then slightly reducing by 25 days (2.00±0.00). Magnetic treatments helped maintain better odour quality. Treatments with 6 µT, 7 µT, and 8 µT at various exposure times generally resulted in odour scores of 1.00±0.00 to 2.50±0.50, indicating effective preservation compared to the control. These results showed that samples treated with higher magnetic field intensities and longer exposure times showed slower degradation rates. These findings are supported by Liu *et al.* (2023), who observed that magnetic fields slow down the metabolic processes in strawberries, thereby extending their freshness. This demonstrated that while magnetic field treatment could not completely prevent spoilage over long periods, it could significantly slow the process, extending the shelf life compared to untreated controls.

The results in Table 16 on the effects of various magnetic intensity treatments (0 µT, 6 µT, 7 µT, and 8 µT) and exposure times (30, 60, and 90 minutes) on the shelf-life quality parameters (discoloration, softness, mouldiness, and odour) of samples over different storage times (1, 7, 14, and 25 days) are summarized in the subheadings 4.4.1. and 4.4.2. highlighting some of the interactions that maintained the shelf-life parameters best.

4.4.1 The effect of varying Exposure Time at 8 µT Magnetic Intensity on Shelf-life quality factors

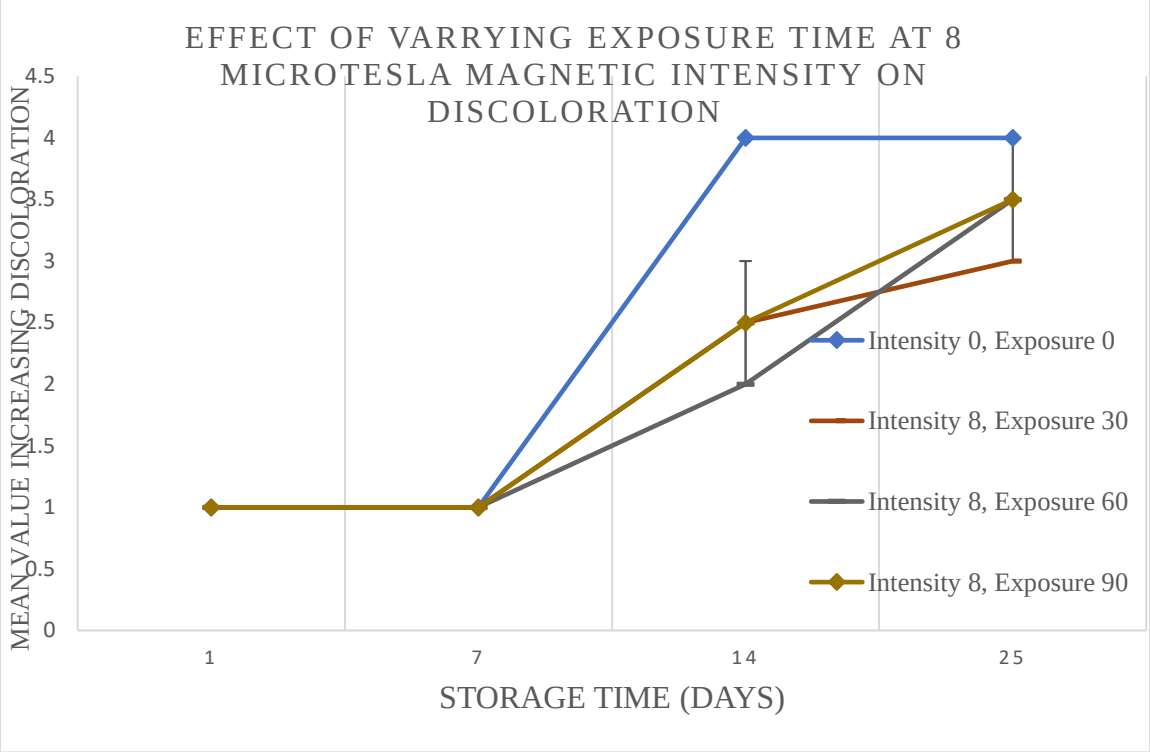


Figure 19. Effect of varying exposure time at 8 µT Magnetic Intensity on the discoloration rates of arrowroots

Figure. 19 above shows a distinct trend in the effect of constant magnetic intensity of 8 µT at different exposure times on the discoloration rates of arrowroots. The samples with 0 intensity and 0 exposure time (control) had a discoloration mean of 1.00 on day 1, which steadily increased to 4.00 by day 25. Samples treated with an intensity of 8 µT and varying exposures (30, 60, 90 minutes) also followed an upward trend but at a reduced rate than the control. The samples treated at 8-30 showed a gradual increase, peaking at around day 14 before stabilizing. The 8 µT/60 min samples exhibited a sharper increase up to day 14 and then stabilized, while the 8-90 samples showed the least discoloration overall,

indicating a possible reduction in discoloration due to higher exposure times at intensity of 8 µT.

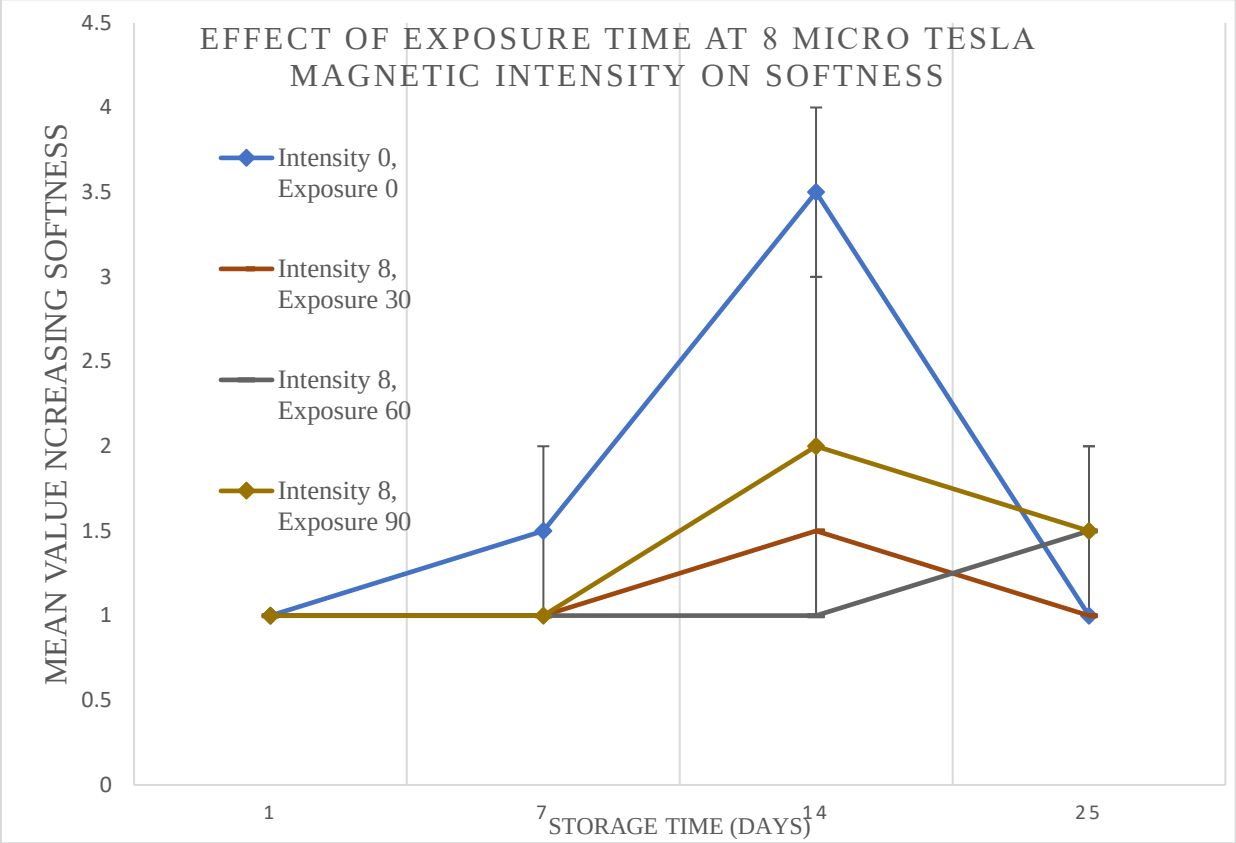


Figure 20. Effect of varying exposure time at 8 µT on the softness rate of arrowroots

The results from the Figure 20. showed that the control had an increase in the softness texture of arrowroot corms. The control had a high softness rate score of 3.50 on day 14, while the treated samples showed a reduced mean rate on how the softness increased, whereby a treatment combination such as 8 µT-60 minutes had a mean rate score of 1.00 on day 14. The 8-90 samples showed the least variation, remaining relatively consistent over the 25 days. This suggests that higher exposure times at intensity 8 µT helped to maintain the texture of the arrowroots. This could have been brought about by the disruption of cellular structures by the magnetic intensities during longer exposure times, which altered the rate of respiration as well as moisture loss (Liu *et al.*, 2023). The downward trend in the rate of softness after 14 days of storage suggests that the corms had become very hard or had decayed and become soggy due to the natural rate of metabolism taking place inside the corm (More *et al.*, 2019).

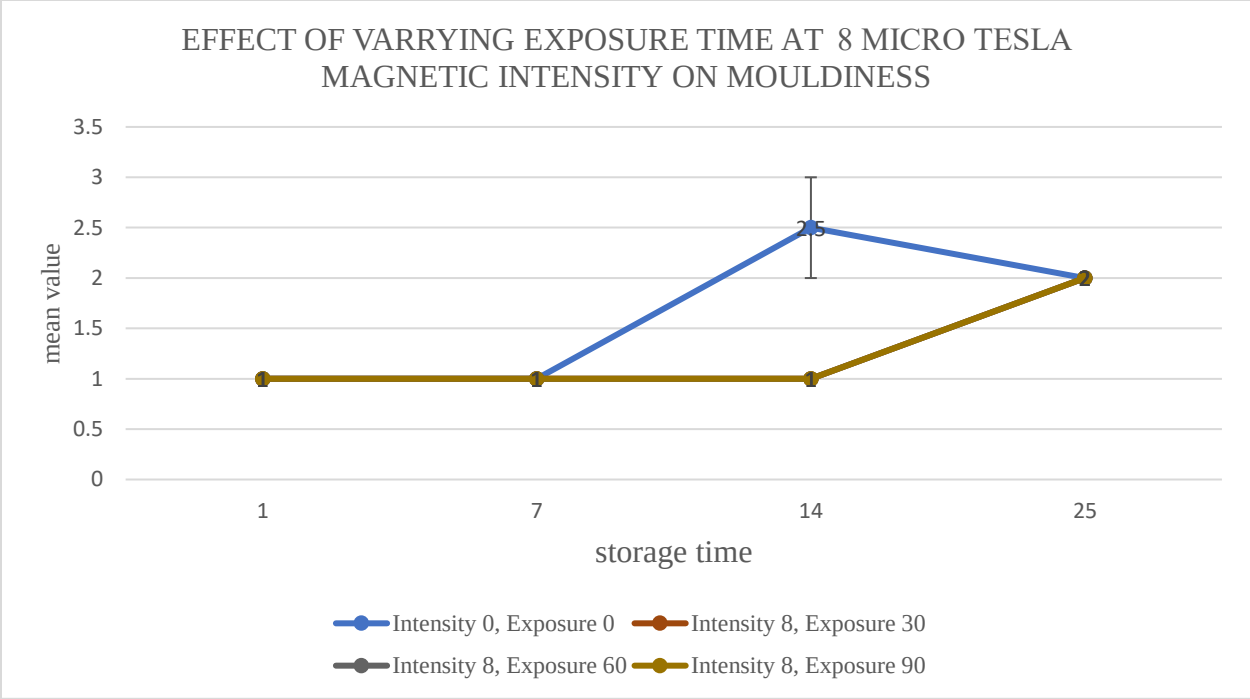


Figure 21:Effect of varying exposure time at 8 µT magnetic intensity on the mouldiness rate of arrowroots

The results in Figure 21. show that the control samples had a steady increase in mouldiness, peaking around day 14 and then slightly decreasing. The 8-30, 8-60 and 8-90 samples showed the least mouldiness throughout the storage period, indicating that higher exposure times at intensity 8 µT helped to reduce mould growth on arrowroots. The downward trend in the control samples indicated that the mouldiness rate had exceeded the threshold of acceptability since the corms might have dried up and become very firm due to moisture loss or had been infected by the hard rot or had become too soft and decayed due to infection by *Loli loli* which causes watery tissues in corms (Hussein et al., 2019). In treated samples, the effectiveness of the treatment reached a point at which it could no longer inhibit mould growth due to external factors during storage, whereby the corms started developing moulds gradually with storage time.

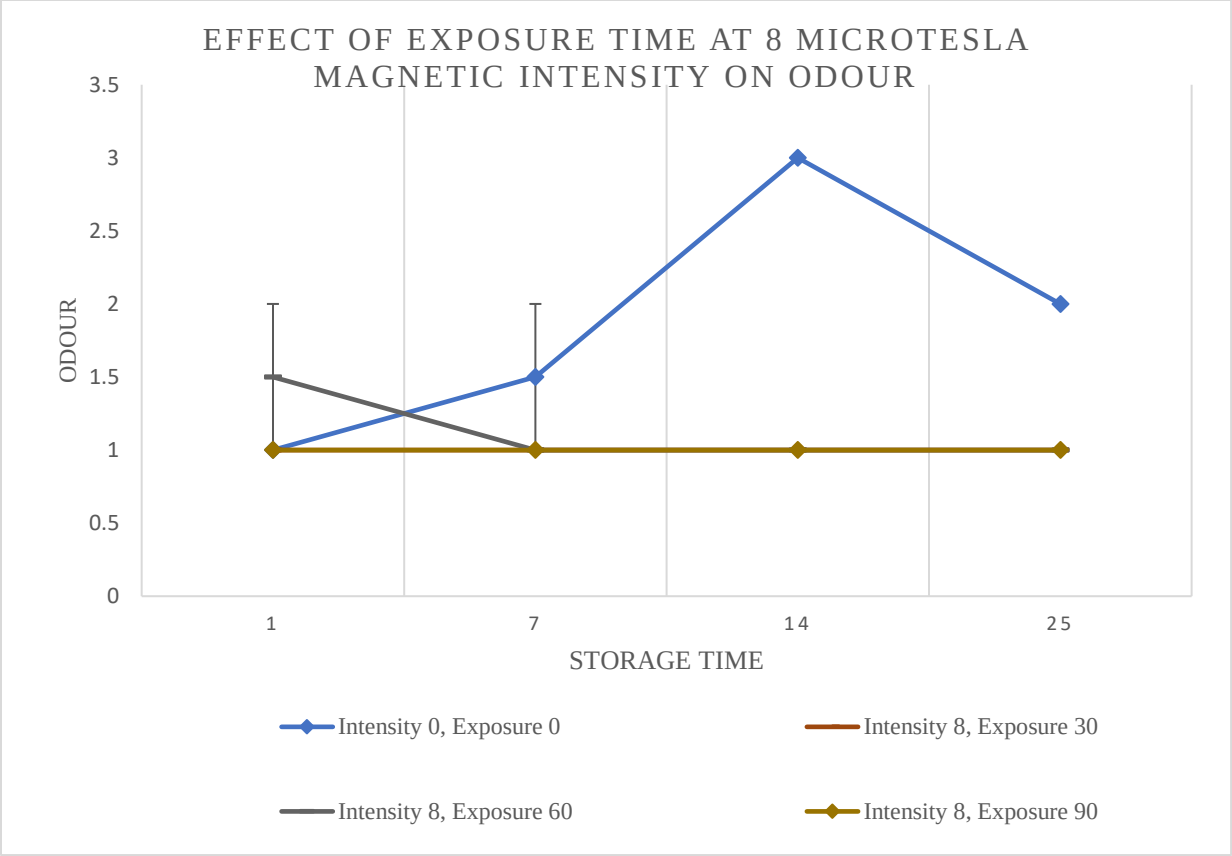


Figure 22: Effect of varying exposure time at 8 μT magnetic intensity on the odour rate of arrowroots

From Figure 22. above, the control samples showed a steady increase in odour over the 25 days, peaking at around day 14 and then decreasing slightly. The steady increase in off odour could have been brought about by infection from lasiodiplodia, which affects corms and causes the infected corms to have an unpleasant odour (Arya Kaniyassery et al., 2024). The 8-30 samples maintained a relatively consistent odour, with a slight increase around day 14. The 8-60 samples showed a similar trend to the control but with less overall odour. The 8-90 samples showed the least odour, maintaining a consistent level throughout the storage period and maintaining the arrowroots' shelf life.

4.4.2. The effect of varying Magnetic Intensity at 60 Minutes Exposure Time on Shelf-life quality factors

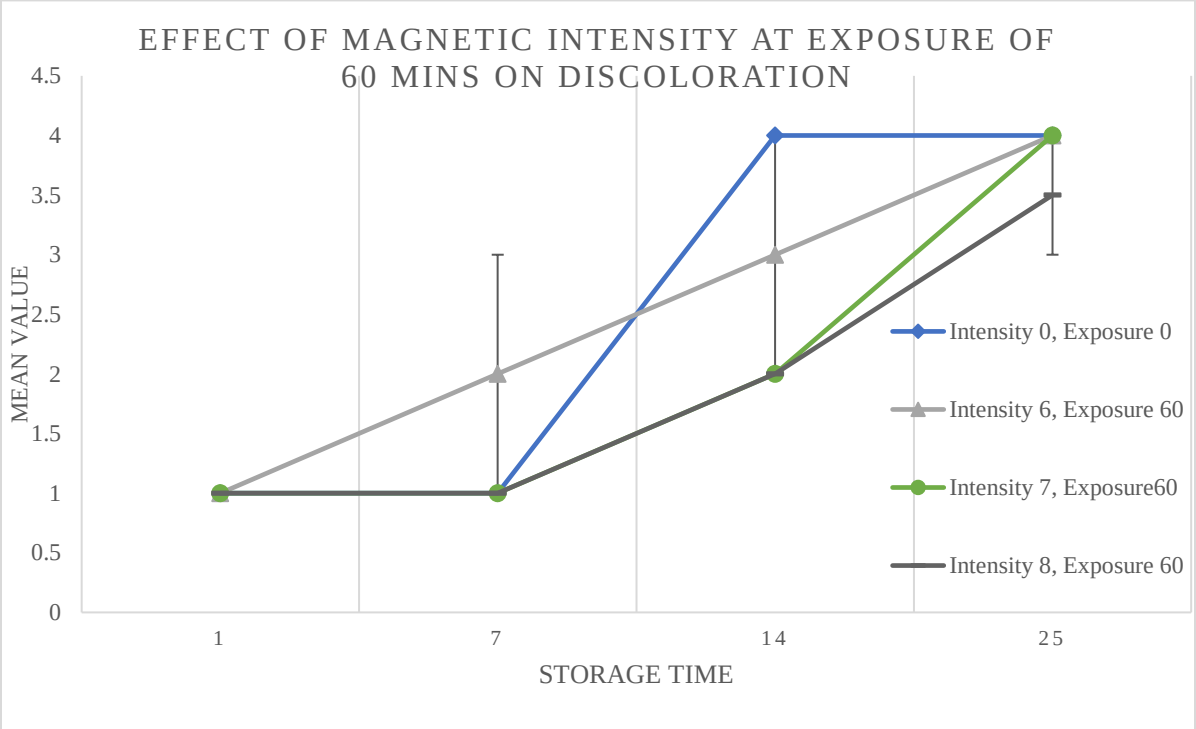


Figure 23: The effect of varying magnetic intensity at 60 mins on the discoloration rate of arrowroots

The results in Figure 23. show the effect of different intensities (6 µT, 7 µT, 8 µT) at 60 minutes of exposure on the rate of discoloration of arrowroots compared to the control. The control showed a steady increase in the rate of discoloration compared to those treated with magnetic intensities. Samples treated with treatment of 6-60 showed a gradual increase, slightly lower than the control. The samples treated at 7-60 showed a moderate increase, while the 8-60 sample showed the least discoloration overall, demonstrating that higher intensities helped to reduce the rate of discoloration over time hence increasing the shelf life of arrowroots.

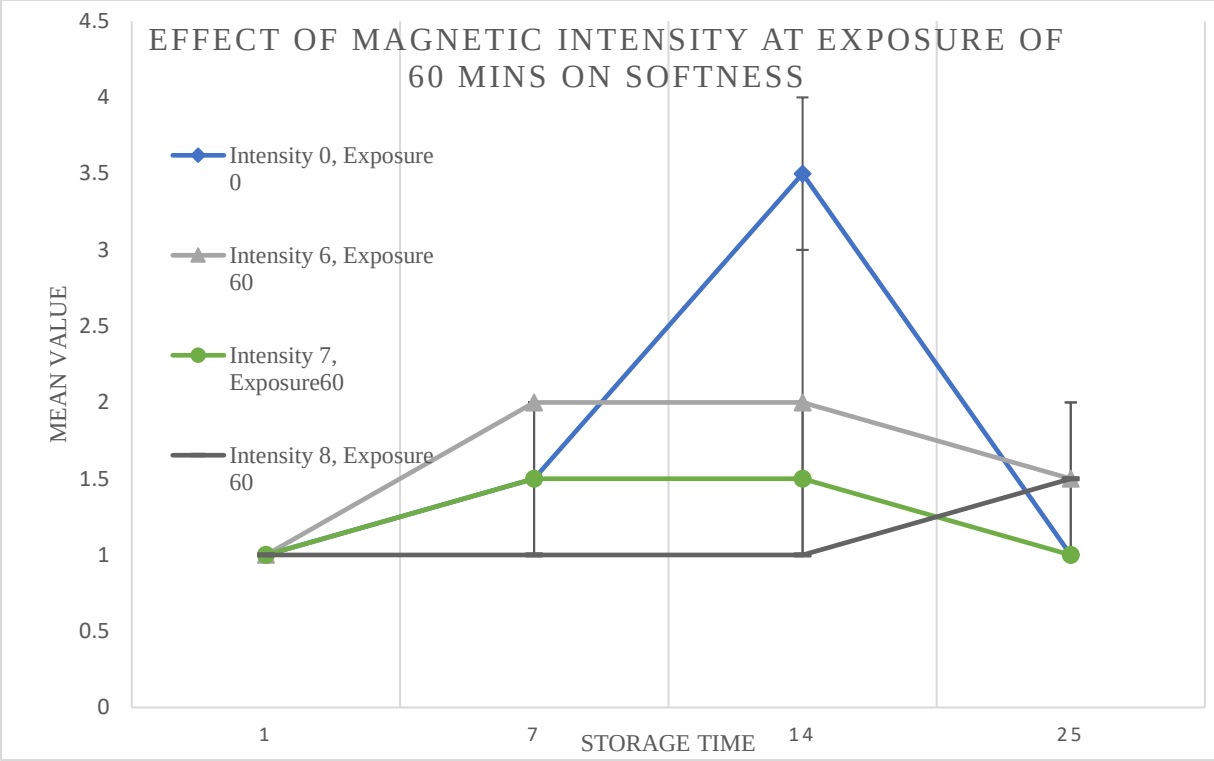


Figure 24. The effect of varying magnetic intensity at 60 minutes exposure time on the softness rate of arrowroots

The results in Figure 24. show that the control samples increased in the rate at which they softened up to day 14 before decreasing. An initial increase in softness rate, which could have been caused by shrinking due to moisture loss, was then followed by either drying up of the corm, making it very tough, or too much softening due to rotting caused by infectious moulds such as Erwinia which causes soft rot or *Loli loli* which causes watery tissues in corms (Wasendorf et al., 2022), hence the downward trend. The samples treated at 6-60 followed a similar trend but at peaks lower than the control. The samples treated at 7-60 showed a relatively steady softness with minor fluctuations. The sample treated at 8-60 maintained the lowest softness throughout the period, demonstrating that intensities helped to maintain the texture of arrowroots, hence maintaining the shelf life. The trend showed that, even though the corms softened or changed in their textural appearance, the magnetic intensities slowed down the rate at which this change occurred.

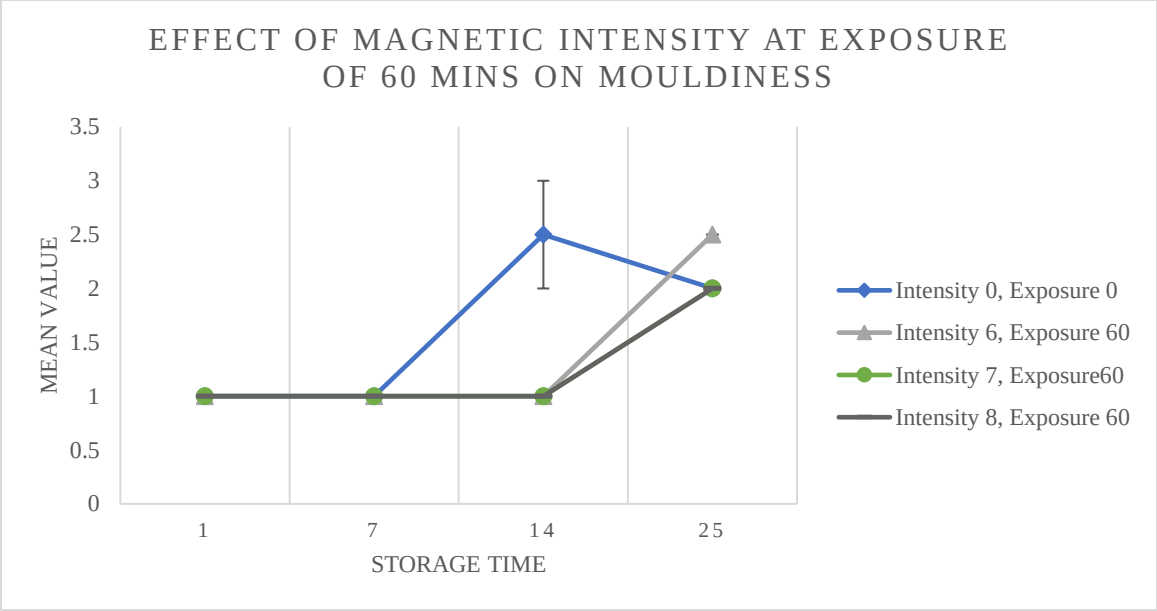


Figure 25: The effect of varying magnetic intensity at 60 minutes exposure time on the mouldiness rate of arrowroots

The results in Figure 25. show that the control samples increased in the mean rate score for mouldiness up to day 14 before decreasing. This increase in mouldiness was because, from day 1 the samples were still fresh and had a lot of moisture which was habitable for mould growth. Usually, mould growth in arrowroots can begin to deteriorate as early as 4 days after harvest (Kuka et al., 2022). The decrease in mouldiness after 14 days was because most samples had already rotten to the point that mould growth was insignificant, as such samples were non-conforming to what could be deemed acceptable. The samples treated at 6-60 showed a slightly similar trend to the control but with lower overall mouldiness. The samples treated at 7-60 showed a controlled mean rate of mouldiness, which slightly started to increase after 14 days of storage, probably showing that the treatment had started falling short of its effectiveness in inhibiting moulds. Samples treated at 8-60 maintained the least mouldiness, indicating that higher intensities significantly reduce mould growth and hence enhance the shelf life of arrowroots.

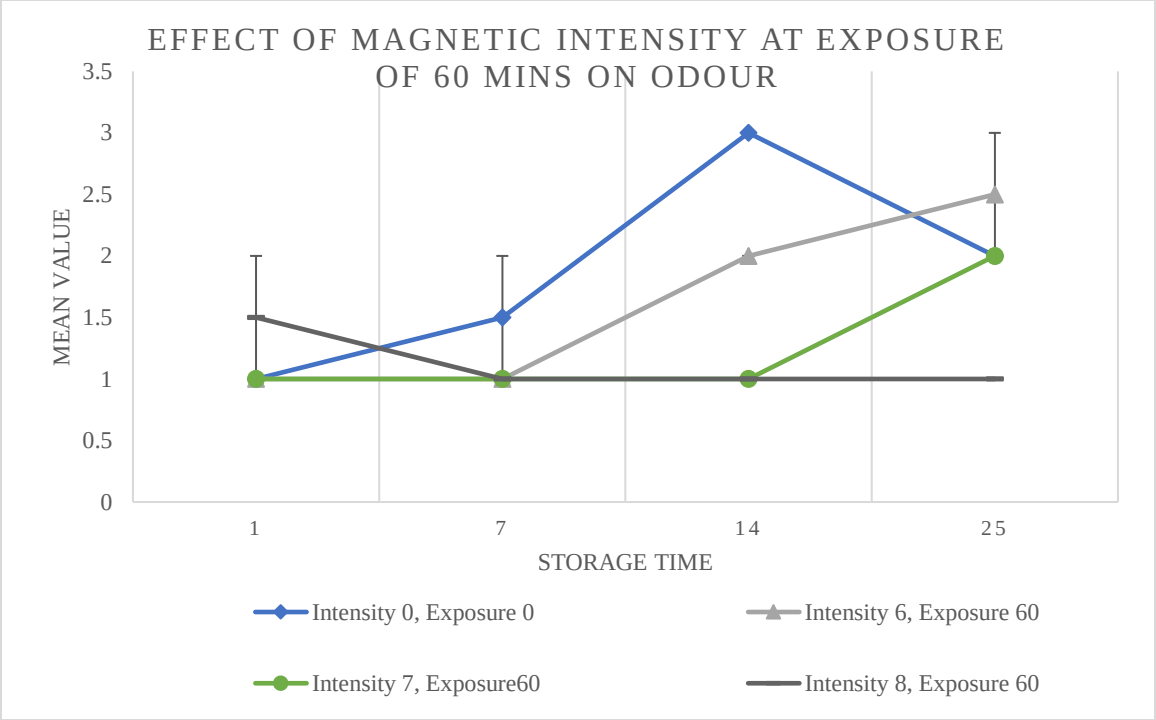


Figure 26: The effect of varying magnetic intensity at 60 minutes exposure time on the odour rate of arrowroots

The results in Figure 26. show that the control samples increased in the mean rate score for odour up to day 14 before decreasing. The increase in the rate of odour was closely related to the increase in mould rate as most samples with mould had started to rot, hence the off odour. The samples treated at 6-60 showed a similar trend but with lower odour rate scores. The 7-60 sample maintains a consistent odour with minor increases, which showed that as the magnetic intensities increased, the rate of arrowroot deterioration was mitigated. Samples treated at 8-60 showed the least odour throughout the period, suggesting that higher intensities helped to reduce odour development.

The study showed that magnetic field treatment could extend the shelf life of arrowroots by reducing the rates of discoloration, softness, mouldiness, and odour, hence extending the shelf life by several days. For example, at 8 µT and 90 minutes exposure time, the treated samples show significantly lower degradation in all parameters compared to the control. This extension could be quantified as follows: if the control samples had a shelf

life of approximately 2-7 days, the treated samples could last up to 13-15 days with noticeable quality maintenance.

This study concurs with previous studies that have demonstrated the potential of magnetic fields to inhibit microbial growth and delay spoilage in perishable foods (Zhang *et al.*, 2024). For example, Nagy and Fischl (2004) found that magnetic fields reduce fungal growth, which aligns with the observed reduction in mouldiness. Similarly, Irungu *et al.* (2022) demonstrated the effectiveness of magnetic fields in reducing weight loss in potatoes, corroborating with the results on firmness and softness in arrowroots. Liu *et al.* (2017) found that magnetic field treatment reduced ice crystal formation in carrot cells due to interference with the cellular structure, which is consistent with the prolonged shelf life observed in arrowroots. Zhao *et al.* (2017) reported that magnetic fields effectively maintained the quality of lotus roots during storage. Furthermore, research by Kang *et al.* (2021) demonstrated that the application of an oscillating magnetic field effectively inhibited ice nucleation and supercooling in mango slices, thereby preserving their quality for a longer period. These studies corroborate the findings in the present study, demonstrating that magnetic fields can extend the shelf life of perishable products by inhibiting processes that lead to deterioration.

Thus, the study rejects $H0_4$ and concludes that there is a significant difference in the shelf life of arrowroots treated with varying magnetic field strengths and exposure times during storage time.

The study was significant as it provided light on a novel, non-chemical method that effectively showed that varying magnetic field strengths and exposure times could significantly enhance the shelf-life, physical properties, and quality of arrowroots. This innovative preservation method holds promise for broader applications in food storage and could contribute to reducing post-harvest losses, thereby supporting sustainable agricultural practices. The study also offered new areas for the exploration of green non-thermal techniques for food preservation which could benefit farmers and food processors by reducing economic losses and enhancing food security.

CHAPTER FIVE:
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary of the Findings

The effects of magnetic intensity and exposure period on the physicochemical parameters of arrowroots during storage were significant. Magnetic intensity (MI) was significantly correlated with weight loss ($P < 0.05$) during storage. Higher magnetic intensities (8 μT) resulted in significantly lesser weight loss compared to the control group and lower intensities (6 μT and 7 μT). This shows that magnetic fields helped arrowroots maintain their weight by possibly decreasing respiration rates and enzyme activity. However, exposure time alone did not have a statistically significant effect on weight loss. Magnetic intensity significantly affected the top firmness ($P < 0.001$), suggesting structural changes at the cellular level. Exposure time had a significant effect on firmness ($P < 0.01$). Additionally, magnetic field treatment had a significant impact on the colour of arrowroots, as measured by the browning index (BI). Higher magnetic intensities contributed to a lower BI, which indicated less deterioration with time. This colour preservation showed that magnetic fields could inhibit oxidative reactions that cause browning, which improved the overall quality of arrowroot.

For biochemical properties, the total phenolic content declined over time. However, samples subjected to higher magnetic intensities showed a substantially slower decline compared to the control ($P < 0.001$), indicating that magnetic fields helped preserve the phenolic content of arrowroots. Antioxidant activity was measured using the DPPH method, showing that higher magnetic intensities preserved higher antioxidant levels throughout storage ($P < 0.05$). This finding emphasizes the beneficial effect of magnetic field treatment on the biochemical stability of arrowroots, which maintains their health benefits over time.

The magnetic field treatment significantly reduced mould growth ($P < 0.05$). Higher magnetic strengths were more effective at inhibiting mould growth than lower intensities and the control group. This reduction in mould count indicated the antimicrobial effects of magnetic fields, making them a viable alternative to chemical treatments for

preserving arrowroots. Magnetic fields contributed to maintaining arrowroots fresh and safe during storage by minimizing mould growth.

The shelf life of arrowroots treated with magnetic fields was significantly extended, with greater magnetic intensities proving to be more beneficial. Magnetic field treatment significantly improved arrowroot quality and shelf life ($P < 0.01$). Higher magnetic intensities (8 μT) extended shelf life by minimizing spoiling and preserving physicochemical and biological characteristics over time. The results showed the potential of magnetic fields as a non-thermal, chemical-free preservation technology, increasing the economic feasibility of arrowroot production by lowering post-harvest losses.

5.2 Conclusion

The findings of this study highlighted the potential of magnetic fields as an innovative and effective method for preserving arrowroots during post-harvest storage. The study demonstrated that using magnetic fields, particularly at higher intensities, significantly reduced weight loss, conserved firmness and colour, and biochemical qualities, inhibited mould growth, and extended the shelf life of arrowroots. Higher magnetic intensities (8 μT) resulted in considerable reductions in weight loss and mould growth, highlighting the beneficial effects of this preservation method. Magnetic fields' ability to limit weight loss was possibly linked to their effect on reducing respiration rates and enzyme activities within the arrowroots, thereby preserving moisture and preventing deterioration.

Furthermore, the study discovered that magnetic fields helped maintain the arrowroots' firmness, with magnetic intensity having a significant influence on top firmness. This finding revealed that magnetic fields induced structural changes at the cellular level, which improved the overall texture quality of the arrowroots over time. The preservation of colour, as evidenced by reduced browning indices at greater magnetic intensities, corroborated magnetic fields' effectiveness in suppressing oxidative reactions that cause discoloration. This is incredibly vital to consumer acceptance and marketability of the product.

Biochemically, the slower decrease of total phenolic content and prolonged antioxidant activity in magnetically treated arrowroots demonstrated the positive impact of magnetic fields on crop nutritional quality preservation. The significant reduction of mould growth observed in all treated samples, particularly at higher magnetic intensities, suggested that magnetic fields could be a viable alternative to chemical preservatives. This non-thermal, chemical-free strategy not only maintains food safety but also meets customer desires for natural preservation methods.

Ultimately, the extended shelf life of arrowroots treated with magnetic fields offered a viable solution to post-harvest losses, which pose a substantial concern for farmers and food processors. Magnetic field treatment has the potential to improve food security, promote economic sustainability, and benefit the agricultural business by minimizing spoilage while maintaining the physicochemical and biochemical features of arrowroot.

5.3 Recommendations of the Study

The results from this study demonstrated the positive impacts of magnetic field strength on extending the shelf life of arrowroots. The research recommends that;

i. Integrate magnetic field treatment with existing preservation techniques such as refrigeration and chemical treatments to further enhance the shelf life and quality of perishable crops.
ii. Organize training programs and workshops for stakeholders in the agricultural sector to raise awareness about the benefits of magnetic field treatment and other non-thermal and non-chemical methods for post-harvest preservation of crops.
iii. Implement magnetic field treatment in post-harvest management of arrowroots and potentially other tuber crops to extend their shelf life and maintain quality.

5.4 Suggestions for Further Research

The study recommends additional study and development in using magnetic fields to preserve various perishable crops, with the potential to revolutionize post-harvest management techniques in food production. Specifically;

i. Investigation on the optimal conditions such as (e.g., magnetic field intensity, exposure time, storage conditions) should be conducted to maximize its effectiveness in preserving various crops.

ii. Further research should be explored on the application of magnetic field treatment on other perishable crops to determine its effectiveness and potential benefits across different agricultural products.

iii. Conduct research on consumer acceptability and marketability of magnetically treated produce to ensure that the adoption of this technology meets market demands and consumer preferences.

iv. Study the long-term effects of magnetic field treatment on nutritional content and overall food safety to ensure that the method doesn't have any unintended consequences.

v. Investigate the potential for combining magnetic field treatment with other emerging preservation technologies for synergistic effects.

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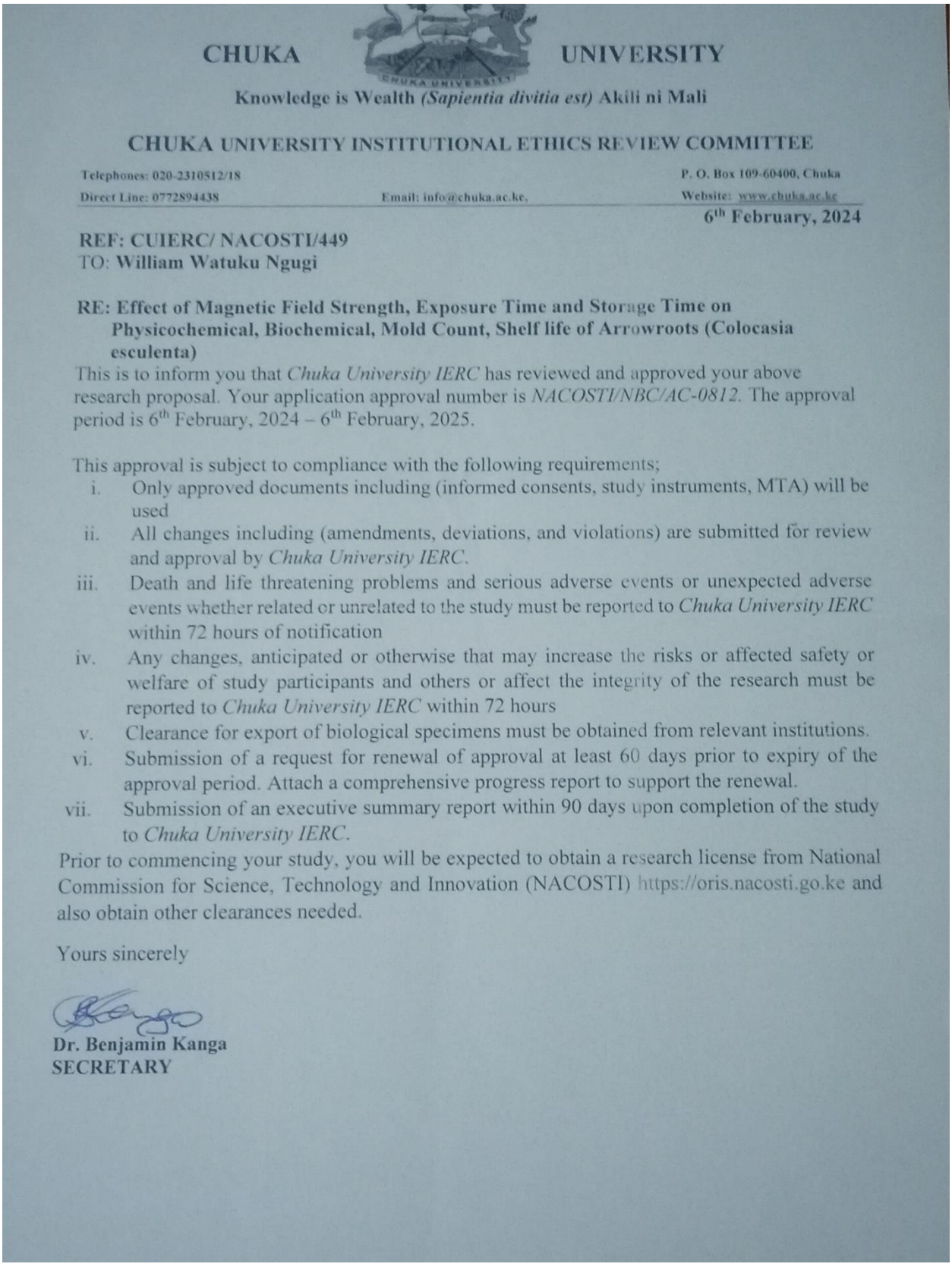
APPENDICES

Appendix I: Shelf-life Scale

Corm ID	**Day inspected**	**Discoloration**	**Rate score**	**Softness**	**Rate score**	**Mould**	**Rate score**	**Odour**	**Rate score**
1	1	Minor	2	Firm	1	No mould	1	Normal earthy	1
2	7	None	1	Slightly soft	2	Minor moulds	2	Slightly musty	3
3	14	Moderate	3	Moderately soft	3	No mould	1	No odour	2
4	**25**	Severe	4	Very soft	4	Severe	3	Strong unpleasant	4
5	**1**	None	1	Firm	1	No mould	1	Normal earthy	1

Appendix II: Chuka University Ethics Approval Letter



CHUKA UNIVERSITY

Knowledge is Wealth *(Sapientia divitia est)* Akili ni Mali

CHUKA UNIVERSITY INSTITUTIONAL ETHICS REVIEW COMMITTEE

Telephones: 020-2310512/18 | P. O. Box 109-60400, Chuka
Direct Line: 0772894438 | Email: info@chuka.ac.ke, | Website: www.chuka.ac.ke

6th February, 2024

REF: CUIERC/ NACOSTI/449
TO: **William Watuku Ngugi**

RE: Effect of Magnetic Field Strength, Exposure Time and Storage Time on Physicochemical, Biochemical, Mold Count, Shelf life of Arrowroots (Colocasia esculenta)

This is to inform you that *Chuka University IERC* has reviewed and approved your above research proposal. Your application approval number is *NACOSTI/NBC/AC-0812*. The approval period is 6th February, 2024 – 6th February, 2025.

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by *Chuka University IERC*.
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to *Chuka University IERC* within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to *Chuka University IERC* within 72 hours
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to *Chuka University IERC*.

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely

Dr. Benjamin Kanga
SECRETARY

Appendix III: NACOSTI Research License

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **520046**

Date of Issue: **28/May/2024**

RESEARCH LICENSE

This is to Certify that Mr.. WILLIAM WATUKU NGUGI of Chuka University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Tharaka-Nithi on the topic: Effect of Magnetic Field Strength,Exposure Time,and Storage Time on Physicochemical,Biochemical,Mold Count and Shelf Life of Arrowroots (Colocasia esculenta) for the period ending : 28/May/2025.

License No: **NACOSTI/P/24/35874**

520046

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

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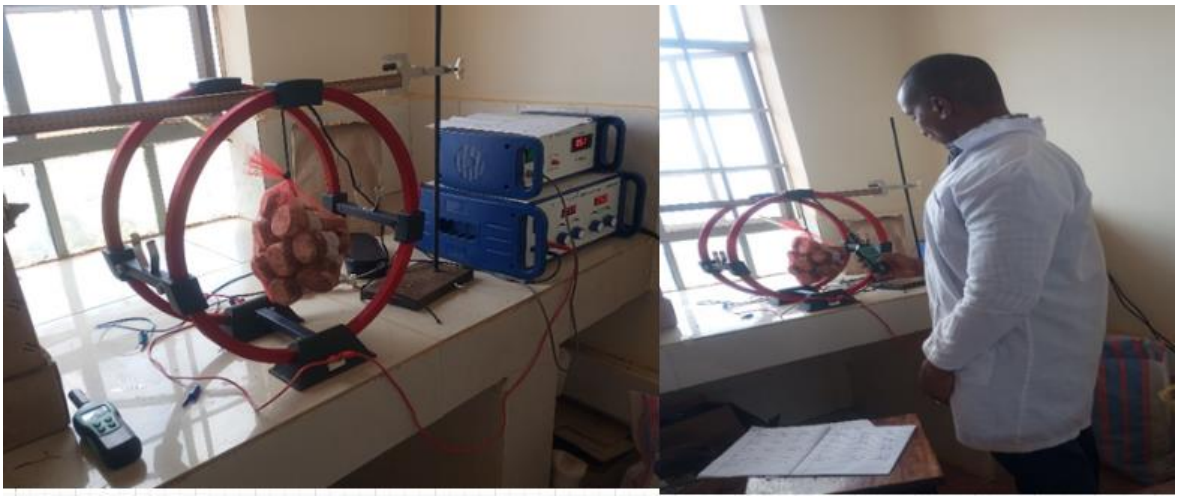
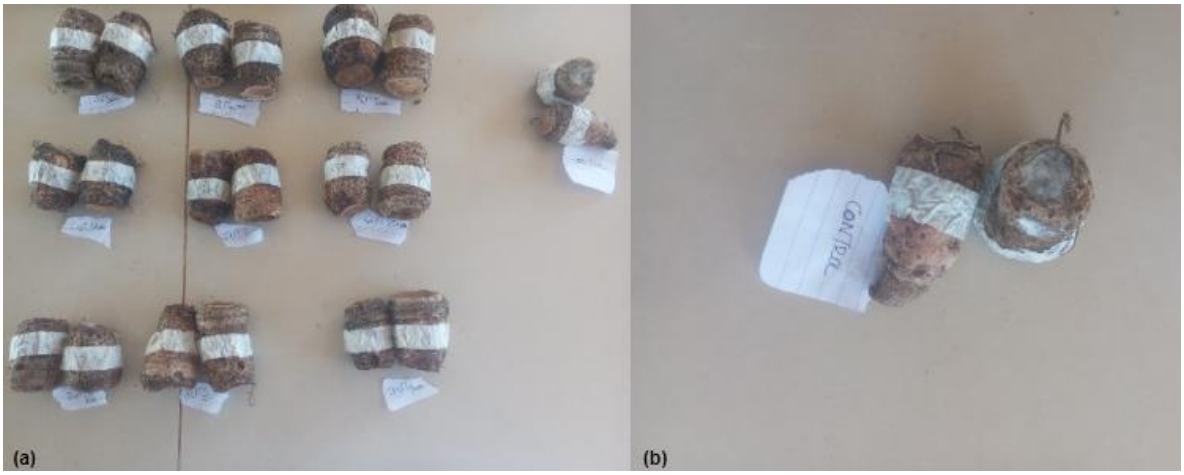
See overleaf for conditions

Appendix IV: Laboratory Pictures



Treatment of arrowroot samples using Helmholtz coil

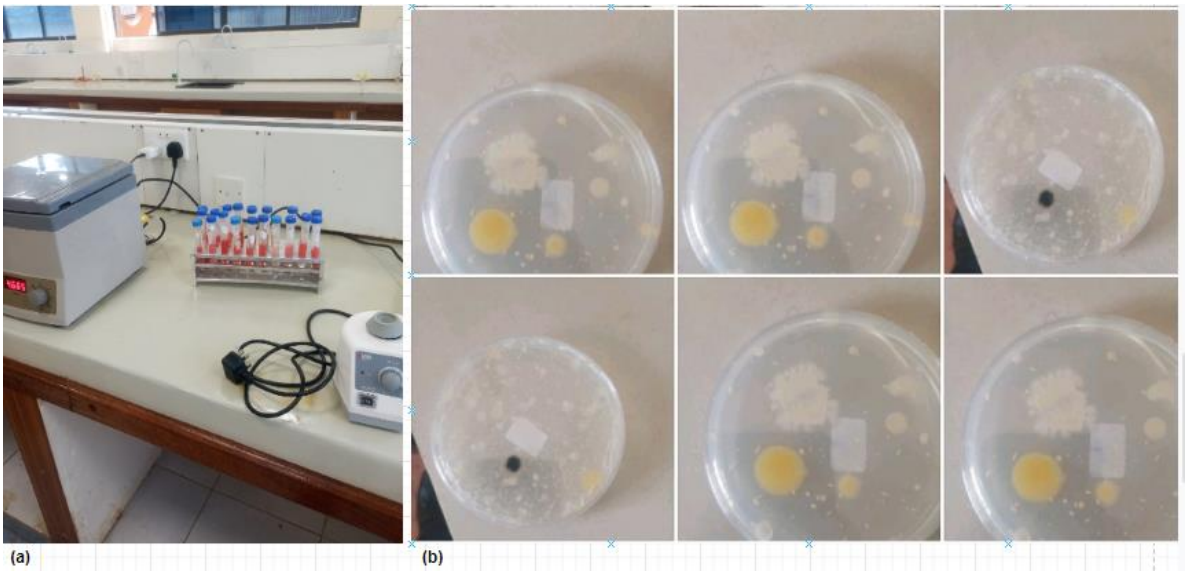


(a) Arrowroot samples on day 14

(b) Arrowroot samples of control on day 14 with mould

(a) Treated arrowroot samples on day 25

(b) Control arrowroot samples of control on day 25



(a) A picture of Total phenolic content and antioxidant extraction using a centrifuge

(b) A picture of mould growth