THE EFECTS OF MAGNETIC INDUCTION ON PHYSICOCHEMICAL, NUTRITIONAL, GLYCOALKALOIDS, ANTIOXIDANTS, AND POSTHARVEST LOSSES OF STORED POTATOES

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A Thesis Submitted to the Graduate School in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Food Science of Egerton University

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DECLARATION AND RECOMMENDATION

Declaration

I declare that this thesis work is my original work and has not, wholly or in part, been presented for the award of any other degree elsewhere.

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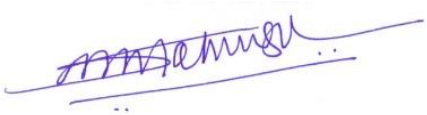
Recommendation

This thesis has been submitted with our approval as University supervisors.



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DEDICATION

This thesis is dedicated to all my family members and friends, who have been supportive during my academic journey.

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ABSTRACT

Worldwide, post-harvest losses (PHLs) of potatoes are predicted to be between 10% and 15% per year. However, losses resulting from inadequate storage techniques may reach 30% in underdeveloped nations. There is, therefore, the need to innovatively identify affordable and sustainable storage mechanisms that can reduce PHLs and prolong the shelf life of potatoes without compromising on their quality. Thus, the aim of this research was to evaluate the effectiveness of magnetic fields (MF) in reducing PHLs in potatoes during their storage. The effects of test variables: sources of magnetic fields (direct current (DC) or alternating current (AC)), magnetic field intensity (1.00 mT, 2.00 mT, and 3.00 mT), and exposure time (20, 40, and 80 seconds) on the physicochemical, nutritional, glycoalkaloids and antioxidants quality of stored potatoes were investigated. Selection of range values for both magnetic field intensities and exposure times were based on prior experimental trials Double Helmholtz coils were used to generate MF. The coils were supplied with either DC or AC. Potatoes were then exposed to MF and stored in either the control or the commercial store for eight weeks. At the end of the storage period, analyses were done following standard methods. In this study, *shangi* potato variety was used due to its dominance in the Kenyan potato market. The AC MF resulted in significant ($\rho < 0.05$) higher specific gravity, dry matter, starch, and the number of sprouts per tuber but lower weight reduction, total sugars, reducing sugars, and non-reducing sugars than DC MF. Exposing potatoes to 3.00 mT of both DC and AC MF resulted in significant ($\rho < 0.05$) lower weight reduction, internal and external greening, sprouting, and the number of sprouts per tuber than in potatoes that were not exposed to MF. Exposing potatoes to 2 mT of DC MF with subsequent storage in the control store resulted in significantly ($p < 0.05$) higher quantities of potassium, magnesium, copper, manganese, chromium, cobalt, and boron. The use of AC MF with an intensity of 2 mT resulted in a significant ($\rho < 0.05$) reduction in α-chaconine, α-solanine, and TG. Exposing potatoes to 3 mT of AC MF and storing them in the control store significantly increased the content of ascorbic acid by 37% in comparison to the fresh tubers. Exposing potatoes to 3 mT of DC MF with storage in the control store and 3 mT of AC MF with storage in the commercial store resulted in an 11% and 21% increase in carotenoids, respectively. The antioxidant activities of potatoes that were exposed to DC MF were comparable to that of fresh tubers. Hence, findings from this study reveal that MF can be used to reduce PHLs in potatoes and thus contribute to sustainable potato agrifood systems.

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LIST OF ABBREVIATIONS AND ACRONYMS

ABA	Abscisic acid
AC	Alternating current
AOAC	Association of Official Analytical Chemists
ATP	Adenosine triphosphate
B	Magnetic flux density/Magnetic induction
BA	6-Benzylaminopurine
BS	Brassinosteroids
BV	Biological value
CAO	Chlorophyllide a oxygenase
CCD4	Carotenoid cleavage dioxygenase 4
CK	Cytokinin
CKX	Cytokinin oxidase/dehydrogenase
CO_2	Carbon IV oxide
DC	Direct current
DNA	Deoxyribonucleic acid
DPPH	1,1-diphenyl-2-picrylhydrazyl
EC	Evaporative cooling
GA	Gibberellic acid/Gibberellins
GAs	Glycoalkaloids
GGP	GDP-L-galactose-phosphorylase
GluTR	Glutamyl-tRNA reductase
G6PDH	Glucose-6-phosphate dehydrogenase
HCL	Hydrochloric acid
HMGR	3-hydroxy-3-methylglutarl coenzyme A reductase
HPLC	High performance liquid chromatography
IAA	Indole-3-acetic acid
M	Magnetization intensity
MF	Magnetic fields
MRI	magnetic resonance imaging
mRNA	messenger RiboNucleic Acid

mT	milli Tesla
NADPH	Nicotinamide adenine dinucleotide phosphate
NST	Number of sprouts per tuber
PHLs	Postharvest losses
PHM	Postharvest management
PSY	Phytoene synthase
RNA	RiboNucleic Acid
SAS	Statistical Analysis System
SDH	Succinate dehydrogenase
Sgt1	Solanidine galactosyltransferase
Sgt2	Solanidine glucosyltransferase
Sgt3	Rhamnosyl transferase
Smt1	S-adenosyl- $_{L}$ –methionine: sterol C24-methyl transferases type 1
SQS	Squalene synthase
SSA	Sub-Saharan Africa
SSR2	Sterol side-chain reductase 2
StCKP1	Solanum tuberosum cytokinin riboside phosphorylase
T	Tesla
TCA	Tricarboxylic acid
TDF	Transcriptionally derived fragments
TG	Total glycoalkaloids
Wb	Weber
WMF	Weak magnetic fields

CHAPTER ONE
INTRODUCTION

1.1. Background information

Potato (*Solanum tuberosum* L.) is the world's most widely consumed non-grain crop and the world's largest tuber food crop in terms of human consumption (Singh *et al*., 2021). It is produced in excess of 369 million metric tonnes annually in more than 130 nations (FAOSTAT, 2021). Potatoes are currently grown for food, animal feed, industrial use, and the production of seed tubers depending on the location, the growth of the country, and historical considerations (Dolniar, 2021). The crop provides a staple diet for the majority of urban and rural populations in East Africa, while in Kenya it is the second most significant crop after maize (McEwan *et al*., 2021; Mwakidoshi *et al*., 2021). Potatoes contain significant amounts of proteins and are an excellent source of low-fat carbohydrates, minerals, and vitamins. It may be used to produce alcoholic beverages like vodka and is a significant source of starch for the entire world (Haverkort *et al*., 2023; Jaiswal, 2020). Due to its relatively quick maturity period, nutritional qualities, employment opportunities, and income potential, it is a robust crop that can safeguard vulnerable lifestyles from the effects of climate change and shifting market conditions (Singh *et al*., 2020; Wijesinha-Bettoni & Mouille, 2019). As a result, it is crucial for ensuring global food and nutritional security.

In Kenya, about 2 million metric tons of potatoes are produced annually, supplying 31.82 kg of food to the country's diet per person per day. They also provide 62 kcal of calories, 1.31 g of protein, and 0.09 g of fat per person per day (FAOSTAT, 2020). In Kenya, there are more than 50 types of certified potatoes with a range of different characteristics. With yields of 30,000–40,000 kg per acre, the *shangi* potato variety matures quickly, has a high output per unit area, and is generally disease resistant. This cultivar has a wide range of applications, particularly in table and industrial processing. As a result, the majority of potato farmers in Kenya favor it. In addition, the variety now controls more than 80% of the nation's potato market. Its shelf life, though, is limited to less than a month (National Potato Council of Kenya, 2019: Sophie, 2019). During the warmer months of January through March and August through September, *shangi* potatoes are harvested in Kenya's major potato-producing regions. Market excess frequently develops, leading to considerable price decreases during the busiest harvesting months. The variation in price per unit of the potataoes is primarily caused by the insufficient post-harvest storage capacity and a lack of

alternative markets. However, after two to three months after end of harvesting season, potato prices increase significantly due to scarcity (National Potato Council of Kenya, 2019). Farmers are unable to hold their produced potatoes for extended periods of time for price speculation, especially during times of scarcity, due to the lack of economical, suitable post-harvest equipment. Hence, they are more vulnerable to shady merchants who will purchase the potatoes for a very low price.

Potatoes suffer severe losses during post-harvest storage, which limits their ability to support food and nutritional security. Potato post-harvest losses (PHLs) are estimated to range between 10% and 15% annually throughout the world. In contrast, developing countries may experience losses of up to 30% due to insufficient storage methods (Gikundi *et al*., 2023; Tadesse *et al*., 2018). Over 19% of Kenya's potato production per acre is lost each harvest season. This amounts to about 815,000 tonnes of spoiled produce annually at the national level, with a market value of about 108 million dollars (Kaguongo *et al*., 2014). The main PHLs, that impact potatoes while they are being stored include excessive moisture loss, the emergence of decay brought on by microbial infection, and sprouting (Degebasa, 2020; Jaiswal *et al*., 2023). Because starch is hydrolyzed to support sprout growth, the commercial value of sprouted potatoes is drastically reduced due to unfavorable morphological changes in the potato, loss of dry matter, reduction in the firmness of potato and increased sugar concentrations. It has also been noted that very high levels of the toxic compounds, α-solanine and α-chaconine increase in potato sprouts and eyes. These compounds predispose some people to illnesses like diarrhea, fever, dyspnea, emesis, convulsions, and gastrointestinal discomforts upon consumption of sprouted potatoes (Sancer *et al*., 2022; Visse-Mansiaux *et al*., 2022). For Kenyan farmers, sprouting potatoes while they are still in storage puts them at risk for unscrupulous purchasers who will pay very little for the potatoes (Kaguongo, 2018: Personal communication). Therefore, high PHLs are one of the main obstacles to the sustainable development of the potato value chain and its contribution to the food security. According to Devaux *et al*. (2021), research and cutting-edge innovation can be employed to identify suitable and sustaneble storage mechanismns that will not only reduce PHLs in potatoes but also help in ensuring a sustainable potato agri food system.

After being harvested, potatoes can be stored under refrigeration. However, the significant accumulation of reducing sugars that cause the potatoes to darken in color, which is accentuated while frying by the production of acrylamide, frequently compromises the process quality of

potatoes exposed to freezing temperatures (Amjad *et al*., 2020). Furthermore, it is expensive to set up such a facility, which deters many smallholder farmers in sub-Saharan Africa and other developing countries from doing so (Akello *et al*., 2022). The use of sprout suppressants, the most effective of which is the synthetic chlorpropham, CIPC, has been another strategy for sustainable potato storage. However, many of these inhibitors have been banned in several countries due to consumer and environmental concerns (Visse-Mansiaux *et al*., 2021). Therefore, it is crucial to find better storage methods that are not only cost-effective but also considerate of consumers and the environment, and do not degrade the potato tuber's nutritional value. That possibility is presented by the utilization of magnetic fields.

Magnetic fields are an emerging non-thermal green technology that has received special attention for its use in food preservation. According to Minano *et al*. (2020), the primary advantage of magnetic fields is their interaction with food, which involves both thermodynamic and quantum effects. Additionally, they have the advantage of lessening the impact of undesirable food changes brought on by heat treatment, such as detrimental effects on the nutrition, color, flavor, texture, and aesthetics of food and food products (Guo *et al*., 2021). Magnetic fields have been employed in food pasteurization, sterilization, freezing of foods, microbiological and biological systems, according to a review by Ahmed and Ramaswamy (2020). The MF are used in food crops to promote or suppress undesirable traits (Radhakrishnan, 2019). Different strengths of electromagnetic fields, for example, have been shown to increase the germination rate in maize, beans, tomato, onions, and oil palm (De Souza *et al*., 2006; Florez *et al*., 2007; Hozayn *et al*., 2015; Odhiambo *et al*., 2009; Sudsiri *et al*., 2016). According to a study by Shabrangy *et al*. (2021) continuous exposure of barley seeds to MF produced by direct current at an intensity of 7.00 mT delayed the growth of shoots and roots, which in turn inhibited organ development in barley seedlings.

Positive findings from studies on the impacts of MF on potatoes include enhanced growth rate and yield (Pittman, 1972; Rakosy-Tican *et al*., 2005), decreased storage mass loss (Lysakov *et al*., 2018), and decreased spoiling microbes (Lipiec *et al*., 2004). Success with the application of MF was anticipated in light of encouraging reports regarding the applicability of other cutting-edge physical techniques to lower postharvest losses in stored potatoes. These techniques include the utilization of microwave radiation, impulsive electric fields, and ultraviolet radiation (Jakubowski, 2018; Jakubowski, 2019; Jakubowski & Krolcyzk, 2020). The effects of MF on potato post-harvest

storage, however, have received little attention. To the best of my knowledge, prior to the beginning of this work, only Lysakov *et al*. (2018) and Jakubowski. (2019) had discussed the effects of MF on sprouting, the internal structure of stored potatoes, weight loss, as well as the starch and simple sugars of stored potatoes. Therefore, it was necessary to look at how MF impacts other important potato quality characteristics when they are in storage. Investigating how MF affected different potato types and from different places was also essential. Also lacking was information on the application of MF to potatoes intended for processing. Thus, the objective of this work, was to assess the possibility of utilizing MF to reduce postharvest losses in stored potatoes. In particular, *shangi* potato variety was used in this study mainly due to its fast maturity, its dominance in the Kenyan potato value chain, and its short postharvest shelf life. The effects of both DC and AC MF on the physico-chemical and nutritional quality of potatoes during their postharvest storage was investigated. Further studies were carried out to understand how effective MF would be in reducing toxic glycoalkaloids in potatoes. Finally, the effects of MF on the content of antioxidants in potatoes was investigated.

1.2. Statement of the problem

Current production of potatoes in Kenya is at 1,860,000 tonnes, while in Africa it is at 26,136,000 tonnes, with global production being at 373,787,000 tonnes (FAOSTAT, 2020). However, potato losses during storage is about 30% in the developing countries (Gikundi *et al*., 2023; Lysakov *et al*., 2018; Tadesse *et al*., 2018) mainly due to sprouting of tubers, excessive moisture loss, and development of decay. One method of preserving harvested potatoes has been the use of cold storage. However, the process quality of potatoes exposed to freezing temperatures is usually jeopardized, nonetheless, by the considerable buildup of reducing sugars that darken the potatoes' color and are enhanced while being cooked by the creation of acrylamide. In addition, the high cost of establishing such a facility deters many smallholder farmers in sub-Saharan Africa and other developing nations from doing so (Akello *et al*., 2022; Amjad *et al*., 2020). Another method for long-term potato storage is the use of sprout suppressants, the most potent of which is the synthetic chlorpropham, CIPC. However, due to consumer and environmental concerns, the use of this chemical inhibitor has been outlawed in a number of nations (Visse-Mansiaux *et al*., 2021). Therefore, it is crucial to innovatively find better storage methods that are not only cost-effective and sustainable, but also one that will not harm consumers and the environment, and that which will not degrade the potato tuber's nutritional value.

Magnetic Fields (MF) have been used to promote or suppress beneficial or undesired traits in food crops (Radhakrishnan, 2019). The effects of MF on potato post-harvest storage, however, have not been thoroughly studied. Only Jakubowski (2019) and Lysakov *et al.* (2018) had previously documented the effects of MF on sprouting, the internal structure of stored potatoes, weight loss, and the simple sugar content of stored potatoes. Therefore, research into how MF influences other important quality metrics of potatoes during storage is necessary. Investigating how MF affects potato varieties from different places and on different types is also essential. Furthermore, there is insufficient data regarding the application of MF to potatoes intended for processing.

1.3. Objectives

1.3.1. General objective

To contribute to food and nutritional security by reducing postharvest losses on potatoes through the use of magnetic induction.

1.3.2. Specific objectives

i) To evaluate the effect of magnetic induction on physico-chemical properties of potatoes.
ii) To determine the effect of magnetic induction on nutritional quality of potatoes.
iii) To evaluate the effect of magnetic induction on glycoalkaloid content of potatoes.
iv) To determine the effect of magnetic induction on antioxidants potential of potatoes.

1.3.4. Hypotheses

i) Magnetic induction has no significant effect on physico-chemical properties of potatoes.
ii) Magnetic induction has no significant effect on the nutritional quality of potatoes.
iii) Magnetic induction has no significant effect on glycoalkaloid content of potatoes.
iv) Magnetic induction has no significant effect on antioxidant potential of potatoes.

1.4. Justification

Potato is a staple crop in many countries due to its good nutrition and short maturation time. It has been an important crop in achieving the UN's Millennium Development Goals on providing food security and eradicating poverty. As a result of its significant role, the year 2008 was named by the UN as the International Year of the Potato (Bradshaw & Ramsay, 2009). However, losses

incurred during storage threaten food and nutritional security especially in the SSA. Magnetic fields have been advocated as the most effective method of controlling PHLs in potatoes (Lysakov *et al.*, 2018). They have effectively been used to promote desirable traits in plants and their products and have also been used to suppress undesirable traits in crops. They have no harmful effects on human health and their uses do not cause any environment concerns. In addition, they are easy to create and utilize as desired. Thus, the idea to use magnetic fields to inhibit sprouting of stored potatoes so as to reduce PHLs is justified. The study will be essentially important in achieving Kenya Government's agenda on food security and nutrition, pillar 3 of pan-Africa's 'Comprehensive Africa Agricultural Development Programme' – CAADP on increasing food supply and reducing hunger as well as United Nation's Sustainable Development Goals 1 and 2 on poverty and hunger eradication through sustainable food and nutritional security.

CHAPTER TWO
LITERATURE REVIEW

2.1. Introduction

Potato (*Solanum tuberosum* L.) is a dicotyledonous crop grown due to its important role in human diet all over the world. (Ikanone & Oyekan, 2014). It originated from the Central Andes of South America, where it was first domesticated about 8000 years ago (Furrer *et al*., 2018). It is believed to contain genetic diversity more than any other crop and this trait has made it possible to be cultivated almost in every region of the world (Navarre *et al*., 2019). A deep, well-drained soil is the ideal soil for the cultivation of potatoes, while a pH of 3.7 is the optimum soil pH for its growth (Lewu *et al*., 2010). Among the tuberous crops that have been domesticated by man for food, it ranks number one in terms of acreage and production (Lewu *et al*., 2010), with China and India being the top two producers of potatoes worldwide (FAOSTAT, 2021). It is the fourth most important food crop in the world after wheat, rice, and maize (Omafuvbe *et al*., 2011) and a staple crop in about 130 countries (Calvo *et al*., 2010). In developing countries, it plays a critical role in food security as its farming provides employment and income to many people (Eltawil *et al*., 2006; Muthoni *et al*., 2010); it is less affected by increases in world food prices (Furrer *et al*., 2018); matures fast within about 4 months and is less affected by changes in climate (Kaguongo *et al*., 2014).

Nutritionally, potato is a rich source of nutrients such as proteins, carbohydrates, vitamin C, folate, potassium, magnesium and iron, besides being a major source of starch worldwide (Adegbanke *et al*., 2018; Ikanone & Oyekan, 2014). It has medicinal value, as it contains good amounts of antioxidants (Wegener & Jansen, 2013). The main antioxidants in potatoes are carotenoids, polyphenols, tocopherols, ascorbic acid, selenium and α- lipoic acid (Bradshaw & Ramsay, 2009; Lachman & Hamouz, 2005). They can be consumed as fresh potatoes (boiled, baked or fried) or can be processed into French fries (chips), potato chips (crisps), frozen and flour (Zaheer & Akhtar, 2016). Industrially, they can also be used in brewing alcoholic drinks such as vodka and akvavit (aquavit) as well as production of starch – that is used as a binder and thickener in sauces and soups as well as an adhesive in the textile industry during papers and boards manufacture (Ikanone & Oyekan, 2014). Nevertheless, consumption of fresh potatoes has decreased with focus shifting to consumption of potatoes that are commercially processed (USDA ERS, 2016). As a result,

storage of potatoes for future commercial use has become paramount. To achieve this, losses accrued during storage, among them sprouting need to be inhibited (Zhang *et al*., 2018).

2.2. Growth of ware potatoes

2.2.1 Seed production

The creation of seed tubers of a higher quality and the use of agricultural practises that are more effective, are two of the most important variables that contribute to an increase in yield. Tubers of high-quality seeds do not have any of the diseases that may be passed on from one plant to another through the seed (Sugiura *et al*., 2018). The tubers must not contain any pathogens that might potentially cause illness; including viruses, bacteria, nematodes, and fungus. They should be absolutely clean. This is owing to the fact that chemical techniques of eliminating illnesses that are propagated by seeds have traditionally shown to be unsuccessful. Seeds are the vector for the disease. Utilizing disease-free seed tubers and conducting thorough field inspections during crop rotations are two possible ways to reduce the risk of illnesses transmitted by seeds (Naik & Buckseth, 2018). A field that has not been used to cultivate seed potatoes for the last three years in a row is preferred (Sugiura *et al*., 2018).

For optimum growth, seed potatoes require sandy loam, a soil with a pH that falls somewhere in the range of 6.0 and 7.0 (Munnaf & Mouazen, 2021). In order to cultivate seed potatoes, the fields first need to be fallowed, and then they should be tilled in the summer. The diameter of seed-sized tubers should be between 30 and 55 millimetres, and their weight should be between 25 and 125 grammes (Naik & Buckseth, 2018). Seed tubers should have fully matured into mature plants, and have multiple shoots that range in length from 2 to 3 centimetres. Heating at a temperature of 8 - 10 °C for 15 - 20 days before planting is the easiest and most effective approach to ensure germination until eye sprouting occurs. Tubers can be protected from precipitation and frost by being kept either in an open space covered with film or in a storage space with active ventilation that is covered.

The seed rate may vary from 2000 - 2500 kg/ha. Planting of the whole tuber is recommended for disease free quality seed production (Naik & Buckseth, 2018). Prior to planting, one should follow the following steps: take out the seed potato from the cold store for at least 10 days; do not bring out the seed bags in direct sun as it may result in rotting due to sudden exposure to high temperature; spread the tubers in thin layer under shade in diffused light for sprouting and allow

sprouts to become 0.5 - 1.0 cm long, thick and green; carry the sprouted tubers to the fields in seed trays or baskets for planting to avoid sprout damage; then remove white, pale, thin sprouted, diseased and rotten tubers (Kodirov *et al*., 2020).

When planting, the farmer should strictly adhere to the guidlelines provided by the experts within their region. Herbicides, earthing, fertilisers, and irrigation should all be used at the appropriate times, as directed by the available guidelines for the location (Naik & Buckseth, 2018). Strategies for protecting plants should include regular inspections (at least three times during the growing season), any tubers that test positive for viruses, brown rot diseases, or any other abnormalities should be discarded. Dehaulming - the process of ensuring that haulms are killed, either via the use of a pesticide or through manual pruning, before the critical limit of aphids is reached, then follows. Elimination of any new shoots that sprout should be done in order to put a halt to the renewal process (Upadhyay & Bashyal, 2020).

Once 15 days have gone since the dehaulming process, the potato tuber can be harvested either manually or mechanically. Following the harvesting of the crop comes the grading and curing processes (Priegnitz *et al*., 2019). After the harvested tubers have spent 15 days in a shaded heap, any that are cut, cracked, bruised, or infected with a disease should be removed. After the tubers have been sorted according to the size of their seeds, they may then be treated with a boric acid solution of 3% and allowed to dry in the air. Tubers that have been treated and are of seed size should be stored in a cool environment (between 4 and 7 °C), hermetically packed in a gunny bag, and labelled with the required information in order to retain their viability (Priegnitz *et al*., 2019).

2.2.2. Impact of environmental conditions during growth and development on tuber quality

The time at which tubers mature is influenced by a number of abiotic factors. Differences in cultivar and season also have a significant bearing on the overall quality. It has been discovered that postponing planting can lessen the number of flaws in the processing of tubers and the colour of fries (Stark *et al*., 2020). The maturation and ripening of tubers, as well as their yield, skin set features, sugar content regulation, and ripeness, are all influenced by fluctuations in temperature and precipitation that occur throughout the course of the year. According to the findings of Stark *et al*. (2020), the processing quality, as judged by fry colour, of the younger tubers that resulted from late planting was superior than that of the older tubers that resulted from early planting. In order to guarantee that the tubers will be of high quality and meet the high nutrient demands that

are required, the soils must contain a sufficient amount of organic matter and nitrogen input (Ayyub *et al*., 2019).

It is possible that more sustainable agricultural practises, such as the use of balanced fertiliser regimens, have led to the increases in potato production as well as economically desirable qualities like tuber size (Ayyub *et al*., 2019). Desiccation of the vines, also known as diquat or Reglone, is another aspect that has a significant bearing on quality. Seed potatoes use this method to control tuber growth by initiating periderm development and stolon elongation at the appropriate stages. This allows for more precise control over the size of the tubers. Potato yield and tuber composition are impacted not only by the variety of potato, but also by the soil, climate, and agronomic practises of the environment in which the potatoes are produced (Quiroz *et al*., 2018). Stark *et al*. (2020) conducted a study that looked at how the variety record was impacted by latitude in terms of both its yield and its sugar content. They made the discovery that places that were further north had a larger ratio of reducing sugar to sucrose in those locations.

A study by Sekhon *et al*. (2020) reported that the production (measured in terms of tuber weight) and nutritional value of nine distinct potato cultivars were both influenced by the climate and the composition of the soil (the mineral make-up, the amount of ascorbic acid, and the phenolic content). According to other findings variations in environmental conditions, such as daytime and night time temperatures, light intensity and duration, cloud cover and humidity, soil type, planting time, and location, have a significant impact on the overall nutritional value of potatoes (Starovoitova *et al*., 2021). Both the geographic location and the genotype had a substantial impact on the overall carotenoid concentration as well as the carotenoid profile. The amount of amylose in tubers, which accounts for around 30% of the starch content (the other 70% of the starch is amylopectin), is similarly affected by the season (Zhao *et al*., 2021b). In addition, Fuentes *et al*. (2019) discovered that the amylose content of the same varieties of tubers grown at sea level was at lower concentration than the amylose content of the same varieties of tubers grown at high altitudes. On the other hand, Fuentes *et al*. (2019) concluded that geographical considerations didn't have much of an effect on the concentration of amylose. The environmental heterogeneity that exists between different research locations is a crucial element that contributes to the presence of these differences. Managing agronomic activities in the context of fluctuating weather conditions from planting through harvesting demands a complicated strategy in order to minimise the potential effects that could jeopardise crop quality (Zhao *et al*., 2021b).

2.3. Growing management practices in Kenya

Farmers in Kenya frequently buy their seed stock through non-authorized methods such as farm savings (also known as "self supply"), local marketplaces, or personal relationships. This is due to the fact that the cost of certified potato seeds is excessively high due to theier high demand and limited availability (Oyoo *et al*., 2022). As a direct consequence of this, the transmission of diseases that are carried by seeds is frequently sped up in informal systems (Wambugu *et al*., 2022). Despite the challenges faced by the industry, farmers continue to grow between 25 and 50 percent of their land with potatoes. This is likely due to the fact that potatoes are important both as a food crop and a cash crop. Potatoes are typically sown by farmers once every other wet season. This is probably because the growing season for potatoes is so short, there are economic incentives to cultivating potatoes, and there is a limited amount of space accessible for cultivation. However, this cycle is much too brief to successfully maintain the fertility of the soil and protect plants from diseases such as bacterial wilt. According to the findings of Musita *et al*. (2019), 68.8% of farmers in Kenya only rotate their crops once every year. Even within the same county, there are farmers that plant potatoes for three or even four consecutive growing seasons at a time. Farmers don't just cultivate potatoes; they plant a wide array of crops to satisfy the needs of their customers and protect themselves from the effects of economic uncertainty. Both Musita *et al*. (2019) and Gikundi *et al*. (2021) made a mention of this fact in their writings.

When selecting potato cultivars for a certain region, it has been shown that flavour, yields, and market accessibility are the three most significant aspects to consider. The high degree of price volatility presents the largest obstacle in the process of marketing potatoes. Seasonal considerations, such as the availability of potatoes, can have a significant impact on the supply and demand of a product throughout the year. The majority of farmers plant potatoes twice a year due to the bimodal rainfall patterns that are typical in most potato farming locales (Wambugu *et al.*, 2022). Due to the poor quality of their storage and the lack of room on their fields to store it, potato farmers have no control over the price that customers pay for their crop. As a result, potato farmers have little say over the price that customers pay for their produce. Farmers are taken advantage of by brokers who conceal information regarding the regional market for potatoes, which is responsible for more than 80 percent of all sales. The majority of the roads that lead to the areas where potatoes are produced become impassable when the wet season arrives. The high cost of delivering the commodities means that merchants will be forced to cut farm-gate pricing as soon

as it starts to rain because of the increased cost of doing so (Musita *et al*., 2019; Mwakidoshi *et al*., 2021).

The most common reason for potato production delays is illness. Bacterial wilt is the most frequently reported illness that affects potatoes while in the field. It is possible that a combination of circumstances, such as planting seeds obtained from unauthorised sources and a lack of rotation, are to blame for the widespread incidence of bacterial wilt in locations that are used for potato production. Due to the prohibitively high cost of certified seeds and/or a general lack of available seeds, majority of farmers in Kenya obtain their seed supply from unofficial sources (Ghebremeskel Ghebreagziabiher *et al*., 2021). According to Rutsaert *et al*. (2021), the informal system, which encourages the use of inferior seeds, can facilitate a faster spread of diseases that are transmitted by seeds. Bacterial wilt presents a substantial risk to the livelihoods of small-scale potato growers in Kenya due to the fact that the approaches that are currently used for control are inefficient. Many farmers rotate their crops in an effort to ward off bacterial wilt, but this method is sometimes ineffectual because the cycles are just a few years long. In addition, growers frequently dispose of potato plants that are not wanted, which renders crop rotation pointless. If no other solanaceous crops are cultivated it is suggested to rotate the planting of potatoes every four years (Hunjan & Sabhikhi, 2020). On the other hand, the majority of Kenya's potato-growing regions just do not have the space for such a lengthy cycle (Kiarie *et al*., 2020). It is absolutely necessary to have a solid crop rotation plan that includes the elimination of volunteers (Shimoda *et al*., 2021).

2.4. Postharvest management practices

The procedures of sorting, washing (or otherwise cleaning), grading, weighing, storing, shipping, and packaging are among the most important aspects of post-harvest management (PHM) (Haverkort *et al*., 2023). They are used by participants in the supply chain to reduce the amount of waste and deterioration that occurs post-harvest. Tubers are sorted in order to distinguish healthy tubers from those that have been damaged or infected, faulty or rotting tubers, and other forms of agricultural waste either by hand or by some sort of machine. An excessive amount of washing can easily harm the skin of the potato, which is why farmers are cautioned against doing so (Musita *et al*., 2019). The easiest way to clean potatoes is to first soak them in water and then scrub them with a soft brush once the water has been absorbed. This should be followed by placing them on a

level surface in the shade or on a rack within a storage shed that has enough ventilation. Rotating the tubers once per day will guarantee that they dry evenly (Yang *et al*., 2021).

Curing potatoes helps them recover from any damage they may have sustained after harvest and keeps them from going bad while being stored or transported. Particularly long-lasting are potato tubers that have been pickled or otherwise preserved (Mahilum *et al*., 2022). Curing helps keep bacterial soft rot and fusarium wilt under control because it increases the material's resistance to decay and decreases the amount of water that is lost (Moon *et al*., 2018). It is worth noting that, potato tubers are graded according to size so that market merchants may make more informed purchasing decisions. There is no one standard that applies across all nations for the classification of potato sizes. The task of grading can be carried out either manually or with the aid of a machine. When the potatoes are graded in advance, it makes it much simpler for the farmer and the buyer to agree on a reasonable price for the tubers based on their size and the purpose for which they will be used (Badrunnesa *et al*., 2021; Tikariha & Soni, 2018).

The prevention of the spread of disease and pests is one of the primary benefits of proper storage. Farmers can benefit from effective storage and be shielded from immediate market gluts and low prices produced by excess supply if they wait sales until prices are higher. This allows farmers to maximise their profit potential. Before they can be kept, potatoes must be washed and allowed to completely dry out (Wale, 2018). Because high humidity is a breeding ground for bacterial and fungal diseases, a store that sells potatoes intended for human consumption needs to have enough ventilation. Items should be kept in a location that is cool, dry, and dark. Because it is important that stores be maintained at a comfortable temperature, mud-brick dwellings with thatched roofs are favoured. When potatoes are being stored, they should either be loosely packed or placed in crates, and they should also be elevated off the ground (Wale, 2018).

In Kenya ninety three percent of merchants convey their potatoes to the marketplace using vehicles (such as a lorry or pick-up truck) or carts pulled by hand, while 7 percent of traders utilises motorcycles. An examination of the rear designs of the vehicles and hand-pulled carts that were used to transport potatoes revealed that 47 percent of them had open backs, while 53 percent had closed backs (Musita *et al*., 2019). This shows that nearly half of all potatoes (47%) are subjected to direct sunlight while they are being transported. Remaining potatoes, after the day’s business activities have ended, are covered with polythene bags and left out overnight at the market. When

stored in polythene bags, potatoes have less access to oxygen and are more prone to absorb heat, both of which might hasten the process by which glycoalkaloids are produced (Musita *et al*., 2019). The fact that potatoes are kept outside and sold in the open air, thereby subjecting them to sunlight, increases the likelihood of glycoalkaloids accumulating in the tubers.

Farmers find it especially challenging to effectively manage stored potatoes in Kenya after they have been harvested due to the prevalence of pests and diseases that prey on them, por harvesting methods that cause harm to the tubers, and inadequate storage conditions (Oyoo *et al*., 2022). Potatoes are typically stored by participants in the value chain in one of the following ways: on the floors of their homes (especially mud-floored homes), by burying the tubers in the soil, stacking them in tarp-covered sacks, and on top of piles of potatoes stored in the shade of trees. Other common methods include piling potato tubers on a mud floor or a concrete floor, either covered or uncovered; keeping them in a dark region (or corner of the home); and employing dark storage that do not allow light to pass through (Gikundi *et al*., 2023; Musita *et al*., 2019).

Before storing potatoes, farmers disinfect the storage areas with pesticides, sort the potatoes, and make sure they are in the best possible condition before putting them away. Potatoes that have been stored are checked by farmers on a regular basis for signs of infection by potato tuber moths. When tuber moths are found, insecticides are utilised to treat the area. In addition, the leaves of *Lantana camara* are placed in the spaces between the potatoes in order to ward off moths. In addition, inspections of potato tubers are carried out to look for diseases such as silver scurf, black dot, skin spot, dry rot, and soft rot, and sick tubers are removed from the crop (Gikundi *et al.*, 2021).

2.5. Nutritional quality of potatoes

2.5.1. Macro and micro-nutrients

Due to their year-round availability, potatoes have replaced many other staple foods in many people's diets. As a consequence of this, a great deal of research has been done on the positive effects that potatoes have on one's health (de Haan *et al*., 2019; Robertson *et al*., 2018; Zaheer & Akhtar, 2016). Potatoes are seeing a boom in popularity due to the high nutrient content they have as well as the general favourable impact they have on health. They contain a variety of important nutrients, including dietary fibre, complex carbohydrates, proteins, and minerals. Eating potatoes is a smart move because they have a higher vitamin C content than other cereals and vegetables

(10-30 mg per 100 grammes), and since vitamin C is a beneficial antioxidant and aids in iron absorption (Singh *et al*., 2020; Timoshnikov *et al*., 2020). Potatoes contain 380 milligrammes of potassium per one hundred grammes, which has a significant effect on the ionic and hydration equilibrium of the human body (Watson & Austin, 2021).

The non-starch polysaccharides (NSP) found in potatoes as dietary fibre can increase the volume of digesta in the small intestine by increasing water binding capacity (WBC) and forming compositions that stimulate the sense of hunger. This is in addition to lowering the caloric density of food and improving bowel function (Lal *et al*., 2020). Potatoes have a water-soluble fibre that has the ability to absorb poisons like bacteria and metal ions (Mehrandish *et al*., 2019).

Since boiled potatoes have a carbohydrate content of about 15% and barely 0.1% fat, they are typically regarded as low-calorie foods. A serving size of 138 grammes of potatoes boiled with the skin removed contains an average of 119 calories, 28 grammes of carbohydrates, 2.5 grammes of fibre, 0 grammes of fat, and 2 grammes of protein (Beals, 2019). Starch, which is made up of amylopectin and amylose in a ratio of 3:1, is the predominant type of carbohydrate in potatoes. A percentage of the starch found in potatoes is "resistant" to being digested by the digestive enzymes that are found in the small intestine, and as a result, it gets transported to the large intestine. These "resistant starches" (RS) are fermented by the bacteria in the large intestines, which results in a decrease in the pH of the gut and the production of short chain fatty acids. The low pH reduces the quantities of potentially toxic ammonia in the intestinal tract and encourages the growth of beneficial colonic bacteria by functioning as pre-biotics (Brit, 2013; Liu *et al*., 2020).

A potato contains dietary fibre in both the flesh and the peel; a 150g potato contains around 2 grammes of this fibre, which is equivalent to roughly 7% of the daily recommended intake. It is considered that the majority consume less than half of the adequate intake (AI) of dietary fibre and that they would benefit from increasing their consumption of foods that are high in fibre (Lal *et al*., 2020). In a study that looked at the function of white vegetables in nutritional intakes, researchers found that white potatoes had a favourable association with increased dietary fibre intakes among both children and adults (Storey & Anderson, 2013). To be more specific, the findings demonstrated that white potatoes contributed more than 20% of the total dietary fibre intake for 6 out of 8 age groups among male potato consumers and more than 16% of the total dietary fibre intake for 6 out of 8 age groups among female potato consumers.

Potatoes are comparable to other root and tuber staples in terms of their crude protein content, which ranges from 2-4 grammes per medium potato (depending on the nutrition data utilised as well as the potato variety and preparation methods). When compared on a dry basis, the level of protein is likewise comparable to that of cereals, and it is higher than the level of protein found in the vast majority of other vegetables that are frequently taken, with the exception of beans (FDA, 2018). The protein found in eggs, which has a biological value (BV) of 100, is often regarded as the reference protein. When compared to other prominent plant sources of protein (such as soybeans, which have a BV of 84 and beans, which have a BV of 73), potatoes have a BV that is significantly higher than the average, coming in at 90 (McGill *et al*., 2013). Potato protein is considered to be a "complete protein" because they contain all the nine essential amino acids (Herreman *et al*., 2020). In point of fact, a study that evaluated the protein and essential amino acid content of commercially available plant-based protein isolates found that potato protein was superior to other plant-based proteins and comparable to animal-based proteins. This was the result of comparing potato protein to other plant-based proteins (Gorissen *et al*., 2018).

Also, it has been demonstrated that potato peptides, such as potato protease inhibitors, exhibit antioxidant action in vitro. Furthermore, there is some preliminary data from studies on humans that suggests potato peptides may possibly have a favourable effect on blood lipids and increase satiety (Beals, 2019). However, it is unknown if the benefits shown in tests, employing higher concentrations of isolates, can be achieved by mere potato consumption. This is because the amounts of these peptides are much lower in the whole potato.

2.5.2. Phytonutrients

Potatoes contain several phytonutrients, including carotenoids and phenolic acids (McGill *et al*., 2013; Mishra *et al*., 2020; Navarre *et al*., 2019). Carotenoids such as lutein, zeaxanthin, and violaxanthin are primarily found in yellow and red potatoes, but white potatoes have trace amounts (Campos & Ortiz, 2020). Potatoes contain between 35 and 795 g of total carotenoids per 100 g of fresh weight. Approximately 10 times more total carotenoids are present in dark yellow cultivars than in white cultivars (Mishra *et al*., 2020). Anthocyanins are phenolic chemicals that are abundant in flowers, fruits, and vegetables and impart hues ranging from red to crimson to blue to purple (Beals, 2019; Sharma *et al*., 2021). Potatoes include acylated petunidin glycosides (purple potatoes) and acylated pelargonidin glycosides (red and purple potatoes) in the highest

concentrations (Campos & Ortiz, 2020). Chlorogenic acid is a secondary plant metabolite and accounts for up to 80% of the total phenolic content of potato tubers. It is primarily dispersed in between the flesh and skin (peel). The flavonoid quercetin is most abundant in red and russet potatoes and has demonstrated antioxidant and anti-inflammatory properties in vitro and in vivo (Friedman *et al*., 2018). The role, if any, that these chemicals may have in reducing inflammatory responses in people requires further investigation.

2.5.3. Anti-nutrients substances in potatoes

The nutritional value of products made from potatoes is diminished due to the presence of a number of unfavourable anti-nutrients that are found in potatoes. Inhibitors of proteolytic enzymes, poisonous substances such as glycoalcaloids, nitrates, and nitrites, and compounds present in polluted environments such as heavy metals and pesticides are all examples of these types of compounds (Thakur *et al*., 2019). Potatoes have a lower accumulation rate for pesticides, herbicides, and heavy metals when compared to other types of vegetables. It is important to note that the majority of these contaminants are found in the potato skin, and may be eliminated by peeling the potato (Schrenk *et al.*, 2020). About fifteen percent of these proteins are known as protease inhibitors, and their primary function is to stop the digestive system from breaking down proteins through enzymatic digestion. Due to the fact that some inhibitors are able to remain stable even when subjected to high temperatures, potatoes need to go through a specific heat treatment in order to render them useless (Andlinger *et al*., 2021).

Glycoalkaloids, including chaconine and solanine, are potentially fatal, naturally occurring components of potatoes. There is about twice as much chaconine as solanine in potato tubers (Benkeblia, 2020; Zhao *et al*., 2021a). It only takes 3-6 mg/kg of a human's body weight for these chemicals to be lethal, and even lower doses (between 1 and 5 mg/kg) can be hazardous. These compounds are regarded as highly dangerous. Based on the findings of previous studies (Percival & Dixon, 2020; Zhao *et al*., 2021a), potatoes with a high glycoalkaloid content (above 11 mg/100 g) have a robust flavour. It is suggested that potatoes, which now have a tolerable glycoalkaloid concentration of 20 mg/100 g, have this concentration decreased to 6-7 mg/100 g. Several authors (Dhalsamant *et al*., 2022; Nie *et al*., 2019) agree that the majority of a potato's glycoalkaloids are found in its outer layer and the layer immediately beneath it.

Nitrates found in potatoes range from 10 to 75 mg/100 g. But hazardous nitrates (III) are frequently present in potatoes at very low concentrations. In and of itself, nitrates (V) are not harmful; but, the microbiota in the gut can converts them to nitrates (III), this can contribute to the creation of nitrosamines, which are known to cause cancer (Ebrahimi *et al*., 2020; Jannat *et al*., 2022). The skin of a potato and the layer that lies directly beneath it have the highest concentration of nitrates in the vegetable. There is a loss of anything from 20 to 70 percent of the tuber after it has been peeled and boiled (Ebrahimi *et al*., 2020; Korshunov *et al*., 2019).

It is possible for potatoes to take in dangerous heavy metals from their surrounding environment, which can be hazardous to the health of both people and animals. In most cases, their concentrations are so low that they are insignificant, since they do not surpass one milligramme per one hundred grammes of potatoes. Concentrations of lead can be anywhere from 0.2 to 1.6 grammes per one hundred grammes of material, but in polluted surroundings, they can even be higher than 100 grammes per one hundred grammes (Hoxha *et al*., 2018; Luo *et al*., 2019). Cadmium concentrations typically fall somewhere in the range of 0.2 to 23 g per 100 g, and they only occasionally go higher than 1 g per 100 g (Gray *et al*., 2019). Both mercury and silver are found in potatoes, but only in such trace concentrations that they are almost impossible to detect. Potatoes also contain a minimal amount of fat, which prevents them from storing pesticides. Pesticides are soluble in lipids but not water, and potatoes do not contain enough fat to do so. When compared to other vegetables, potatoes have an extremely low level of pesticide residue (Beals, 2019; Yigit *et al*., 2020).

2.6. Contribution of potato to the Kenyan food and nutritional security

Kenya is responsible for the production of significant amount of potatoes each year, roughly 2 million tonnes. The tuber is garnering a lot of interest as a possible solution to the myriad problems that the nation is facing, such as hunger, poverty, and climate change. Potatoes have emerged as one of the most significant food crops in Kenya, with an estimated annual production value of KES 13 billion (USD 150 million) at farmgate prices. There are around 800,000 potato farmers in Kenya, and millions of people in both rural and urban areas use potatoes (Waaswa *et al*., 2022). The national long-term development strategy Vision 2030 is intended to transform Kenya into an industrialising, middle-income nation. A growing number of Kenyans believe that increasing food security, income levels, employment opportunities, and nutrition standards through potato

production could assist the country in achieving the goals of Vision 2030. The Vision 2030 was created to transform Kenya into an industrialising, middle-income nation (Chepkoech, 2022).

The crop diversification programmes that are best suited for Kenya are those using potatoes. Tubers already serve as either the major or secondary source of sustenance in a significant number of rural families. In addition to being an excellent source of protein, calcium, potassium, and vitamin C, potatoes also provide an adequate proportion of all of the essential amino acids (Mishra *et al*., 2020; Navarre *et al*., 2019). Also, potato has a very high rate of production. It outperforms wheat, rice, and corn in terms of the amount of food it produces in a given amount of time and land area. One hundred days after it is planted, it is ready to be harvested, and its vegetative cycle is both quick and highly adaptive. Another attribute of the crop is its remarkable resilience to almost any altitude and environment, even that of semiarid and arid locations (Ndegwa *et al*., 2020). In many parts of Kenya, it is already cultivated not just as a primary crop but also as a crop planted during the off season. It is possible to rotate potatoes with a wide variety of other commercial and food crops, including wheat, maize, and barley. Potatoes are favoured by customers in rural areas and urban areas alike for the same reasons: they have low fuel requirements, a short cooking time, and the opportunity for value addition (such as chips and crisps). In addition, the cultivation, distribution, and manufacture of the crop each contribute significantly to the creation of new employment opportunities (Idah *et al*., 2021; Ndegwa *et al*., 2020; Sang, 2021).

Potatoes, in contrast to other cereal commodities, are rarely traded on international markets, which insulates them from the effects of fluctuations in global commodity prices. Only a small portion of its overall output, which is mostly made up of processed commodities, is sold outside (Musita *et al*., 2019). As a consequence of this, the price of potatoes in Kenya is not subject to the vagaries of speculative trading that occurs on global markets. Instead, the price of potatoes in Kenya is determined by the variables of local demand and supply. Additionally, due to the low frequency with which potatoes are sold on the major international commodity markets, the crop is less vulnerable to the negative effects that might be caused by speculation. The potato is a highly reliable crop for food security and can help Kenya achieve a better supply-and-demand equilibrium in the country's food market (Campos & Ortiz, 2020; Waaswa *et al*., 2022).

2.7. Quality parameters of potatoes destined for processing

When determining whether or not a potato can be processed, both the potato's interior and outer characteristics are evaluated; the sum of these characteristics is referred to as the potato's "technological value" (Mareček *et al*., 2015). The outward appearance of a potato reveals a great deal about its characteristics, including its size and shape, the depth and number of hollows (also known as eyes), imperfections, and the thickness of its skin (Neilson *et al*., 2021). The flesh inside of a potato tuber has its own unique chemical make-up and distinct physical characteristics. The quality of a potato's potential as a raw material for use in industrial processing is referred to as its technological value (Mareček *et al*., 2015). Although the cultivar of a potato is a significant factor in determining its technological value, there are a number of other factors that could have an impact on how well it would perform in an environment where it would be processed. Some of these elements are natural, such as the location of the potato fields, the kind of weather that they are exposed to, and the type of soil that they are produced in, while others are more developed, such as the method by which the potatoes are grown (fertilizer rates, irrigation, pesticide treatments, planting and harvesting dates) (Kroschel *et al*., 2020; Stark *et al*., 2020). The effect of the local climate and soil on the chemistry of potato tubers differs depending on where they are grown due to this factor's interaction with the growing environment.

Both the yield and the technological value of potatoes destined for processing are susceptible to changes brought about by various interventions in agrotechnology. The production and chemical composition of tubers that are harvested from potatoes are strongly influenced by the rates at which nitrogen is applied to the soil (Abd El-Azeim *et al*., 2020). When a lot of nitrogen is used, one of the probable outcomes is a rise in the amount of reducing sugars and nitrates, as well as a fall in the amount of starch. In addition, they play a role in the rapidity with which the potato turns brown. Even when plants receive a sufficient amount of mineral fertiliser, certain elements continue to build up in the soil because the plants do not use them. This results in an uneven distribution of the minerals, which makes them less accessible to the plants (Assunção *et al*., 2021; Ayyub *et al*., 2019).

With the use of chemical treatments, losses that are brought on by weed infestations, pest infestations, or potato illnesses can be reduced (Kroschel *et al*., 2020). It is possible that differences in the quality of the potato harvest are caused by the various metabolic reactions of plants to

chemical treatments that are intended to minimise the infestation of potato plants by insects and weeds as well as the invasion of potato plants by diseases. When pesticides are administered at the appropriate times (and at the appropriate rates), the resulting potato tubers have very low quantities of the pesticides. The use of fungicides and sprout inhibitors in cold storage results in an increase in the development of these compounds, particularly in the potato skin; however, these chemicals can be eliminated by peeling the potato. The times of planting and harvesting have a significant impact on the chemical composition of processed potato tubers. Because of the formation of protective layers on their skins, mature potato tubers are able to maintain their chemical composition over extended periods of time, making them ideal candidates for long-term storage prior to processing (Pszczolkowski & Sawicka, 2018; Vilvert *et al*., 2022).

2.7.1. Potato tubers for starch production.

Starch is the only component of a potato's dry matter that starch plants consider to be valuable enough to harvest. The remaining components are categorised as waste or by-products. Therefore, potatoes that are used for the production of starch should have a minimum starch content of 15% (Lin *et al*., 2018). The cost of processing potatoes with low starch is equivalent to the cost of processing potatoes with high starch, despite the fact that the latter method yields a substantially greater quantity. Given how long it takes to process potatoes after they have been harvested, the potato tubers that are used to make starch should have the following external characteristics: sizes greater than 2.5 centimetres, no signs of disease or mechanical damage, damages no deeper than 5 millimetres, absence of deep eyes, absence of frozen or even slightly frozen tubers, and absence of wet breakdown following freezing injury (Kumari *et al*., 2018). When processing potatoes for starch, it is important to keep in mind that optimal conditions include a high starch content, granule sizes between 20 and 60 µm, and a low level of insoluble non-starch (INS) elements such as cellulose, hemicelluloses, lignin, some pectin, and proteins, in addition to foam-forming components. These conditions are optimal when the starch content of the potatoes is also high (saponines, free amino acids, soluble proteins, glycoalkaloids, etc.). In addition to this, the flesh of the potato should be resistant to browning (Dite Hunjek, 2021; Meng *et al*., 2022).

2.7.2. Potatoes for the food industry

The food production industry has always had the most stringent criteria for the processing of potatoes (Bader & Rahimifard, 2020), and these requirements have only become more stringent

over time. The reasons for this include a growth in consumer demand for potato-based products such as French fries, potato chips, flakes, granulate, and potato grit, as well as developments in the efficiency and competitiveness of the industry that processes potatoes. Raw materials that are utilised in the food business are required to satisfy quality requirements that are both general (applicable to several industries) and sector-specific (exclusive to a single sector) (strictly connected with a type of the finished product) (Silva *et al*., 2019). The internal and external characteristics of a potato that are discernible after cutting it are included in the general quality standards for potatoes that are destined for use in the food industry. According to Sharkar *et al*. (2019), potatoes are considered to be healthy, fully developed potatoes if they are; uniformly shaped and sized potatoes that have a minimal number of shallow hollows (eyes) and are neither damaged nor frozen nor over-chilled and have a greenish hue to their flesh.

When it comes to potatoes that are going to be used in the food industry, there are additional varietal elements that must be determined in addition to the general criteria. The smoothness and thickness of the skin, the natural colour of the flesh, the susceptibility of potatoes to discoloration when raw and after cooking, the amount of dry matter and starch in potatoes, the amount of reducing sugars in potatoes immediately following harvest and during storage, and the limited ability of potatoes to increase their reducing sugars content due to storage at low temperatures (roughly 4 °C) (Silva *et al*., 2019). Chips can be made from fresh potatoes, while French fries can be made from dried potatoes (Wayumba *et al*., 2019). Because the requirements shift depending on the manufacturing technique that is being utilised, it is necessary to take a specialised approach and have a discussion in order to select the appropriate potato cultivars for use in the production of foods like chips, French fries, and dry foods.

2.7.3. Potatoes for chips production

Because industrial processing takes place throughout the year, with the exception of brief times for maintenance work, the potatoes that are used to make chips have to be suitable for long-term storage in addition to meeting the conventional quality requirements. The types of potatoes that are utilised are chosen in order to ensure a steady supply of high-quality components throughout the course of the year. The potatoes for the creation of chips must have a round or oval form and range in size from 40 to 75 millimetres. On the inside, the composition should include a percentage of dry matter that falls between 21% and 25%, a percentage of starch that falls between 16% and

20%, and a percentage of reducing sugars that falls below 0.25% (Adeyanju *et al*., 2021; Rytel *et al*., 2021). It is essential that the tuber's cross section contains an even distribution of reducing sugars throughout its entirety. Reducing sugars should not be concentrated in the vascular system (ring), the stem end, or the bud end of the potato tuber. These parts of the tuber are known to provide a bitter flavour. Because the entire technological process, beginning with peeling the potatoes and ending with packaging the finished product, does not take more than thirty minutes, the sensitivity of potato flesh to enzymatic discoloration is only significant to a lesser extent. Following being fried and dried to a moisture level of barely 2% while still containing 33-39% fat, the product can never turn grey, even though potato flesh is susceptible to chemical discoloration (Rytel *et al*., 2021).

2.7.4. Potatoes for French Fries production

Potatoes that are at least 70 mm in length and are either oblong or oval in shape are used to make French fries. When it comes to the diameter of the cross section of the potato cultivar, standardisation has been accomplished successfully. According to Jaggan *et al*. (2020), the tubers should have a dry matter percentage of 20-23% and less than 0.3% reducing sugar. In addition, high percentage of dry matter and a starch content of between 15 and 18 percent is desirable. Also, it is vital to consider the distribution of reducing sugars in potato tubers since the "sugar-end" effect, which is what gives French fries their characteristic browning at the ends, is most likely to take place only in the final product, after the second cycle of frying (Ngobese & Workneh, 2018; Sobol & Jakubowski, 2020).

The sensitivity of potato tubers to chemical breakdown results in a number of potentially hazardous consequences, one of which is the development of a grey hue in French fries during storage. After being roasted, the tubers of the potato may turn grey. After-cooking darkening is the term used to describe the phenomenon. The non-enzymatic oxidation of complexes that are generated when ambient oxygen combines with iron and phenols, in particular chlorogenic acid, is the root cause of this condition (Rytel *et al*., 2021).

2.7.5. Potatoes for granulate and flakes production

When it comes to dry matter and starch content, the raw materials that are used in the production of dehydrated potato products made from uncooked potatoes (dice, slices, or grit) have very different requirements than the raw materials that are used in the production of dehydrated potato

products made from cooked potatoes (flakes, granulate). Potatoes used in the production of dehydrated products (such as mashed potatoes) must not only meet the standards for general features, but they must also possess the attributes required to allow for long-term storage at temperatures between 6 and 8 °C without losing any of their technological value. In dehydration operations, it is best to use potato tubers that are round or oval in shape and measure between 40 and 75 millimetres in diameter. To be more specific, the following criteria about the internal qualities need to be satisfied: It has a dry matter content of 20-25%, a starch content of 15%-19%, and a reducing sugar content of less than 0.5% (preferably less than 0.3%). These are the percentages of each ingredient's respective dry matter, starch, and sugar contents. According to studies, the flesh of potato tubers should be able to be discoloured by both chemical and enzymatic processes (Haverkort *et al*., 2023; Po *et al*., 2018; Reyniers *et al*., 2020).

2.8. Postharvest losses of potatoes

When potatoes are handled roughly or kept for extended periods of time in unfavourable conditions, losses can occur in the form of sliced, bruised, rotted, greening, sprouting and softened tubers (Emargi, 2021). Losses can also occur when potatoes are stolen. When it comes to potato damage, people working in the supply chain most commonly encounter rotten tubers. This is followed by cuts, bruising, and greening as the next most common types of damage. The use of hand hoes to harvest potatoes causes the greatest amount of damage to the potatoes, and this is highly tied to the technique of harvesting that was used. Farmers appear to be the ones most negatively impacted by the post-harvest losses (PHLs), followed by customers, retailers, and then processors (Sharma, 2020; Tadesse *et al*., 2018). The potatoes suffer the most damage during the production phase, followed by the processing phase, the consumption phase, the transit and handling phase, and lastly the wholesale market phase, which suffers the least amount of damage. Potato tubers frequently become unsuitable for consumption by humans as a consequence of physical deterioration; nonetheless, the value of these tubers is not fully eradicated by economic losses (Tadesse *et al*., 2018).

The potato processors have the highest rate of physical losses, ranging from 4% to 31%, followed by farmers, who suffer from 9% to 16% and dealers who suffer from 11%. Consumers suffer only 5-9 percent. On the flip side, a study showed that proportion of economic loss that can be attributed to the quantity of low-quality potatoes that were sold at a discount over the course of the preceding

two years is largest among farmers (6-17%), then among dealers (9-12%), and it is at its lowest among processors (6-8%) (Haverkort *et al*., 2023). The most common reasons for potato damage and loss are tuber rot, as well as the effects of crop diseases, insect damage, flooding and wetness, sprouting, extremely dry conditions, a lack of rain, and animal damage. Moreover, tuber rot is one of the primary causes of potato damage and loss. Therefore, in order for operators of the value chain to boost tuber sales and profits, they need to create strategies that lower PHLs (Tadesse *et al*., 2018).

Before harvesting and selling their potatoes, the majority of farmers in Kenya wait anywhere from many weeks to even months (Musita *et al*., 2019). As a direct consequence of this, much fewer tubers will be gathered. When tubers are picked 210 days after planting, rather than 120 days, the extended harvesting period can decrease yield by 60%. Additionally, it has been claimed that the yields may reduce significantly (by 70-100%) if harvesting is delayed to 230 days from the planting date (Degebasa, 2020). Post-harvest losses can be attributed to a variety of physical, environmental, and biological reasons, including but not limited to infections, mechanical damage, and temperatures that are excessively high or low (Ierna & Mauromicale, 2020). By causing changes in the tuber's physical and chemical characteristics, the processes of respiration, moisture loss, sprouting, and disease transmission all contribute to an increase in post-harvest losses (Degebasa, 2020).

2.8.1. Physical, biochemical and physiological losses

Tubers are susceptible to a wide variety of physical losses, some of which include those that occur when they are subjected to conditions that are either too hot or too cold, as well as too humid or dry. It is necessary to have adequate storage in order to maintain the necessary temperature, restrict air and gas exchange (ethylene, carbon dioxide, and oxygen), and put a halt to the moisture loss (Choque-Quispe *et al*., 2022). Additionally, the flow of air and transfer of heat are both facilitated by this. It is common practise to disregard mechanical damage when determining the amount of a company's losses. The damage done to the body is a loss in and of itself, but it can also lead to secondary losses in terms of the body's ability to function physiologically and pathologically. During the hilling process, the harvest, and during handling processes like as grading, shipping, and marketing, there is a chance that the grain will sustain mechanical damage (Amicarelli *et al*., 2020). The amounts of harm taken are increased by the dense clouds and the sharp, pointed stones.

Due to the fact that each tuber's level of dry matter and turgidity is unique, even within the same cultivar, the amount of damage that is sustained by the tubers might vary greatly. By increasing the quantity of dry matter in the mixture, you can improve the quality of the braising. To ensure that harvested tubers are not harmed in any way, great care and attention must be paid to them during the handling process. When compared to the healthy tuber, the damaged tuber always has a shelf life that is shorter after it has been harvested (Degebasa, 2020; Gold *et al*., 2020).

2.9. Mechanisms to inhibit postharvest losses

Post-harvest losses are typically broken down into two categories: weight losses and quality losses, despite the fact that differentiating between the two can be difficult at times. The majority of the losses are attributable to physiological processes such as respiration, sprouting, loss of water from the tubers, disease transmission, alterations to the chemical composition and morphological aspects of the tuber, and damage induced by heat. These processes are influenced in various ways by the conditions under which they are stored. All of the aforementioned losses are reliant on the conditions present in the storage facility (Visse-Mansiaux *et al*., 2019; Zhou *et al*., 2021). So, the storage environment can be modified to extend the tuber's shelf life—for example, keeping it cool to stop the growth of microorganisms that cause spoilage—may help cut down on those losses.

2.9.1. Cold storage

During the off-season, the cold storage protects the nation from food shortages that are caused by perishable good spoiling. This protects growers of perishable commodities from having to sell their production at prices that are significantly below market value (Pang *et al*., 2021). A farmer in a rural region who wants to keep seasonal produce for more than a few months could benefit from investing in a solar cold store. As soon as it is placed in the cold storage area, the product begins to release heat into the surrounding air. This air is then directed to the evaporator, where it is removed as a normal part of the mechanical refrigeration cycle. Electric fans that are positioned above the evaporator coils and circulatory fans that are positioned throughout the room and aimed at the produce speed up the process of cooling the air, which in turn speeds up the process of cooling the product (Cheng *et al*., 2020b). The amount of time it takes for the produce to reach the ideal temperature for storage is determined by the overall refrigeration capacity of the equipment, the speed of the air travelling over the evaporator, and the speed at which the air travels over the

fruit. This is assuming that there are no barriers to the airflow around the produce (also known as the pull-down time) (Visse-Mansiaux *et al*., 2019).

2.9.2. Evaporative Cooling

The process of cooling that occurs naturally is called evaporative cooling. Evaporation of water has a substantial cooling effect, and the rate at which it takes place determines how quickly the environment becomes cooler. When dry air is forced across any surface that contains moisture, a process known as evaporative cooling (EC) takes place. Evaporative coolers are therefore made up of a wet, porous bed through which air is drawn, cooled, and humidified as a result of the evaporation of the water (Yang *et al*., 2019). The EC is a storage system that can be used on farms, it requires a low initial investment, and it can extend the shelf life of goods to the point where they can be sold at a higher price after they have been stored. The process then makes use of adiabatic evaporative cooling following the dehumidification of the air with a liquid absorbent (Sajjad *et al*., 2021).

2.9.3. Mechanical refrigeration

In order for a liquid to transform into vapour without the temperature of the liquid itself increasing, it needs a certain amount of heat from the environment around it. The quantity of heat that is dependent on the characteristics of the liquid is referred to as latent heat. The utilisation and removal of this heat results in the production of cold, and the higher the latent heat of evaporation that a liquid possesses, the more effective it is as a medium for cooling. The term for the fundamental concept behind mechanical refrigeration is known as the system of vapour compression (Sleiti *et al*., 2021).

2.9.4. Forced draught cooling

This arrangement is reminiscent of a large-scale cold storage facility with refrigeration capabilities. After the material has been packaged, it is covered with a sheet of canvas or another material, and then a powerful electric fan is used to quickly draw cold air from the room through the material (Obiero *et al*., 2022). In spite of the fact that the produce loses more water as a result of the rapid air flow, the chilling process occurs much more quickly than it otherwise would, and the rate of respiration is greatly reduced (Mugisidi *et al*., 2021). After the product has been allowed to reach a temperature that is relatively close to the ideal temperature for storage, it can then be transferred

to a standard cold store to finish out the duration of its storage life. The vast majority of forced-draft cooling systems rely on the product being contained in the appropriate containers, which are typically fibre board cartons. This is necessary in order for the system to function properly. An adaptation of this method is used on ships and containers that have been specifically designed for the transportation and refrigeration of fresh fruit (Mugisidi *et al*., 2021; Surulivelrajan *et al*., 2022).

2.9.5. Ice-bank cooling

This relatively new piece of equipment releases heat by thawing a sizable block of ice that has been accumulated by a simple refrigeration unit over the course of many days. The air in the store is cooled by being passed through sprays of ice-cold water that have been melted in a different place. This helps remove the heat from the air. By doing things in this way, the store and everything inside of it can be cooled down extremely quickly by air that has a very high relative humidity (Jordan *et al*., 2018). The temperature of the air is brought down by 17.5 °C per day until the holding conditions have been reached. First, the temperature of the air that is being returned is measured (although more accurate results will be obtained by monitoring the temperatures of the bulbs that are at the top of the stack). If the temperature of the return air is within -16.7 °C of the temperature that is set, then the temperature that is set must be dropped at the pace that was specified above. When examining the return air, the best time to do so is early in the morning (between 5 am and 8 am), after the pile has had a sufficient amount of time to cool down during the course of the previous night. Ventilation is an essential component of any cooling system and should never be skipped. Once conditions within the storage are stable, the daily ventilation should be lengthy enough to maintain a temperature differential of –17.2 to –16.7°C between the base of the pile and the top of the pile (Odufuwa *et al*., 2018). Increasingly, fans are being run for shorter periods of time, often ranging from two to four hours before pausing for a minimum of two hours (at the rate of 2 to 4 hours per run with a break of at least 2 hours). The shorter cycles typically have the effect of reducing temperature disparities that are excessive between the top and bottom of the pile. It is important to be aware that the pile tends to become warmer if the fans are turned off for an extended period of time; hence, it will take more time to cool down if this occurs (Odufuwa *et al*., 2018; Tokala & Mohammed, 2021).

2.9.6. Irradiation

During the radiation treatment, a product is either subjected to electromagnetic radiation or to electrons that have been accelerated. Because of the chemical reactions, ionisation, and excitation on the product matter that these radiations cause, the regular operation of living cells is disrupted. Without the need for heat or chemical treatments, ionising radiation is able to eliminate infections, postpone ripening, restrict the growth of sprouts, and hinder the reproduction of insects (Mohamed *et al*., 2021). Irradiation of potatoes at low doses does not compromise the flavour of the potatoes in any way. In an experiment it was discovered that certain doses of gamma radiation did not reliably create changes in the amount of ascorbic acid that was present in potatoes (El-Beltagi *et al*., 2022), the vitamin C content of both irradiated and non-irradiated potatoes decreased during the first seven months of storage at 5°C, but then recovered thereafter. Additionally, the levels of ascorbic acid in the irradiated potato samples were higher than those in the control group. Čošić *et al*. (2021) revealed their findings to the scientific community in reference to the browning mechanism. Irradiated potato tubers had higher levels of O-diphenol than untreated tubers did, and the cortex and vascular bundles expanded more quickly than the pith did. As the dose of irradiation increased, the amount of ascorbic acid in the tissue reduced. The pith saw a slower reduction in ascorbic acid content than the cortex and vascular bundles did (Sarkar *et al*., 2020).

2.10. Dormancy and sprouting of potatoes

2.10.1. Dormancy

Dormancy is when growth momentarily ceases to occur in any area of a plant that contains a meristem (Gumbo *et al*., 2021). Three distinct forms of dormancy can be distinguished. Endodormancy, which takes place post-harvest as influenced by internal physiological factors such as chilling responses; ecodormancy, - influenced by environmental factors such as moisture stress or conditions of storage; and paradormancy. Paradormancy is influenced by external physiological factors like apical dominance, in which the dominant bud or eye is located at the top of the affected structure (Bisognin *et al*., 2018). The amount of time that a plant spends in a dormant state is susceptible to influence from a wide range of circumstances; these include not just those that take place after harvest but also elements such as temperature and light. Because of endogenous stimuli, potato tubers are often dormant before harvest and continue to stay so throughout endodormancy (Haider *et al*., 2022).

The induction phase of a tuber's dormancy cycle comes first, followed by the maintenance phase, and then the termination phase (Saidi & Hajibarat, 2021). The induction and maintenance of dormancy are both caused by interactions and cross-talk between phytohormones, which are hormones that impact how the body processes carbohydrates. Carbohydrates, much like plant seeds, need to be metabolised during the germination phase in order to create energy and substrate for the process of dormancy release in tubers (Li *et al*., 2019; Yuxi *et al*., 2018). The length of time that commercial types remain dormant is quite variable, and cultivars that have greater genetic variety exhibit an even greater range of possibilities in this regard. The AHDB conducted a study on the relative dormancy of a large number of cultivars. This study demonstrated that relative dormancy was maintained even though there were variations in dormancy depending on location and the time of year (AHDB, 2017).

2.10.2. Internal dormancy mechanisms

To begin, the symplastic isolation of the apical meristem during tuber initiation results in the induction of dormancy. The process of vascular separation stops the subtending tuber from feeding the potato buds with metabolites, especially sugar (Mdodana, 2021). This is because sugar is a metabolic by-product of starch. After harvesting, the symplastic isolation process is considered to have begun when the tuber completely detached itself from the stolon as well as the mother plant. The dying of the vines is considered to be the first step in this process. Before the development of buds that are visible to the naked eye, the symplast that lies between the tuber and the apical bud is reconnected (Zhang *et al*., 2021a). It is not known how the ageing of tubers that occurs close to or at the time of dormancy breach affects variations in metabolic flux. There is a great sum of interconnected biochemical pathways that can have an effect, either directly or indirectly, on the awakening of dormant tubers that have been prepared. The artificial breaking of tuber dormancy generated by exposure to or gibberellic acid promotes starch breakdown by raising the metabolic activity of enzymes that degrade starch (Gong *et al*., 2021; Sheikh *et al*., 2022). The rate of respiration and metabolic activity begins to pick up just before the first obvious indicators of sprouting show. As tuber maturity grew, Akoumianakis *et al*. (2016) noticed a decrease in the succinate dehydrogenase (SDH) action as well as glucose-6-phosphate dehydrogenase (G6PDH) action. It is hypothesised that G6PDH is responsible for the limiting enzymatic rate for the pentose phosphate pathway (PPP), which is necessary for the growth of the cell. It is the first stage in the

process of metabolising glucose, and its function is to convert glucose-6-phosphate into 6-phosphogluconolactone (Li *et al*., 2022).

The action of G6PDH also results in the production of NADPH, which is necessary for the elimination of reactive oxygen species (ROS) in the cell. The availability of reduced NADPH is decreased as a result of a gradual decline in G6PDH activity in tubers over time (Loza-Medrano *et al*., 2020). An increase in the activity of reactive oxygen species (ROS) has been linked to signalling pathways that trigger sprouting in tubers and seed germination. Succinate dehydrogenase (SDH) is the enzyme that, according to study carried out by Martínez-Ballesta *et al*. (2020), is responsible for regulating plant development and the waking up of dormancy in tubers. It has been suggested that shifts in the activity of SDH could have an effect on the dormancy of potato tubers. The study also discovered that the beginning of dormancy was associated with a decrease in β-amylase activity, which subsequently increased once more with the beginning of the sprouting process. During the process of tuber formation, the activities of β -amylase, G6PDH, and SDH are thought to cause modifications in carbohydrate metabolism, which may then be responsible for the beginning and maintenance of dormancy in tubers (Akoumianakis *et al*., 2016).

Transition from the early dormancy break to the later phases of sprout development involves a significant reorganisation of transcription. Before bud emergence, large-scale transcriptional reconfiguration activated starch deposits, storage proteins, and lipid mobilisation, as discovered by Liu *et al*. (2015). This continued throughout the sprout's development. Primary metabolism was shown to involve a large number of gene transcripts, including substrate transport and release for bud expansion and the glycolytic pathway, as well as the TCA cycle, gluconeogenesis, fermentation, oxidative phosphorylation, and ATP synthesis (Baltussen *et al*., 2021). In order to gain a deeper understanding of the proteins relevant to tuber dormancy, Liu *et al*. (2015) classified differentially expressed proteins into nine distinct functional groups - metabolism, cell growth and division, protein synthesis and catabolism, cell structure, signal transduction, cell defence, transcription and development. After the dormancy has been broken, there is a rise in the proteins that are involved in the carbohydrate metabolism, including the breakdown of starch; glycolysis; fermentation; amino acid metabolism; and protein (ribosomal) and transport. Reduced levels of RNA regulation and transcripts involved in photosynthesis. Post-translational regulation may be necessary since there is only a weak correlation between mRNA and protein levels, in addition to

the fact that sprouted and dormancy-releasing tubers have distinctive protein profiles (Kotov *et al*., 2021).

As shown by the patterns of gene expression that are present all throughout the transition between dormant and sprouting tubers and following bud emergence, carbohydrate metabolism—both its breakdown and its resynthesis—is connected to the breaking of dormancy (Hasanuzzaman & Fotopoulos, 2019). Sucrose, which is produced from hexoses, is provided in order to satisfy the metabolic requirements of the buds (Anur *et al*., 2020). In the event that there is a deficiency of sucrose in the buds, the storage tissues of the tuber may compensate by releasing a greater quantity of starch (Wang *et al*., 2022). In tubers, the genes involved in the generation of ribosomal RNA play a regulatory role in the process of breaking dormancy. This is due to the fact that rapid protein synthesis and cell division are prerequisites for meristematic tissues, as well as increased metabolic fluxes into the meristem. A reduction in protein gene expression is characteristic of the meristematic activity that follows the induction of dormancy in a cell (Liu *et al*., 2015).

2.10.3. Plant growth hormone interactions

A rise in abscisic acid (ABA) and a decrease in gibberellic acid (GA) are connected to the initiation of dormancy (Saidi & Hajibarat, 2021). It has been determined that ABA and ethylene are essential for the initiation of tuber dormancy, but only ABA is necessary for the durability of tuber dormancy (Wang *et al*., 2022). The concentration of ABA falls when dormancy wears off, and tuber sensitivity to exogenous cytokinin (CK) increases. According to Bromley *et al*. (2014), increased CK sensitivity results in the reactivation of meristematic activity, with an increase in endogenous CK occurring just before or concurrently with the end of dormancy and the beginning of sprout growth (Merelo *et al*., 2022). Ethylene production rates grow as sprouting progresses, and genes involved in ethylene synthesis and degradation exhibit increased expression as well (Draie & Al-Absi, 2018). The expression of StCKP1 (Solanum tuberosum cytokinin riboside phosphorylase), which inhibits the synthesis of CK in potato tubers, controls the level of CK. It has been considered that this exercise helps to extend endodormancy. Importantly, cold temperatures inhibit the activation of protein synthesis by stCKP1 enzymes, suggesting that cytokinin synthesis is lowered when materials are stored at lower temperatures (Huan *et al*., 2020; Saidi & Hajibarat, 2021).

The genes in ethelynesynthesis include regulators of cell cycle progression (cyclins A, B, D, and F), cell division (cell division control 20), cell division proteins: cdt2, cdc6, and cdc45, and dormancy (MAD-box-like transcription factor, ARGONAUTE-4, an auxin-repressed/dormancy-associated protein, and F-box proteins and transcription factors) (Wu *et al*., 2020). Differentially expressed genes are associated with dormancy break. There is a lack of understanding on how cytokinin oxidase/dehydrogenase (CKX) activity affects the dormancy of potatoes. Suttle *et al*. (2014) conducted a study on five StCKX genes that encode proteins with in vitro cytokinin oxidase/dehydrogenase (CKX) activity. They concluded that neither StCKX expression nor CKX activity are responsible for dictating dormancy in bacteria. However, when the genes for cytokinin oxidase/dehydrogenase1 (CKX) were overexpressed, the dormancy period of the tubers was lengthened. This was observed to be the case. This exemplifies why CK is of such critical importance for awakening dormant tubers (Draie & Al-Absi, 2018). Although the intensity of this reaction varies depending on cultivar and environmental factors, there is a positive correlation between the beginning of dormancy break and the rate at which free indole-3-acetic acid (IAA) is depleted from buds.

2.10.4. Environmental conditions affecting dormancy

It is hypothesised that the tuber's ability to enter dormancy is a physiological reaction that prevents it from sprouting when periodic environmental constraints are present. (Shukla *et al*., 2019). Even in settings with ideal climate and other factors, the vast majority of potato cultivar tubers are unable to sprout right away. Dormancy break can occur in the field in some short-day length diploid Phureja species (*Solanum tuberosum var phureja*). On the other hand, the tubers of *Solanum jamesii*, a wild cousin of the modern potato, can remain dormant for several years when preserved at 4°C (Bamberg *et al*., 2020; Gasparini *et al*., 2021). Late maturing clones typically have a shorter dormancy period than their later developing counterparts, which makes it easier for them to break hibernation. During the process of tuber development, the tuber buds enter a state of dormancy, beginning at the tip of the stolon and continuing all the way up to the apical eye (Gong *et al*., 2021). There is a lack of understanding regarding the changes that occur in tuber dormancy following tuber set; nonetheless, dormancy decreases when tuber bulking slows down in the later parts of the growth season. Dormancy in the tuber is induced in the weeks that immediately follow its separation from the haulm.

The level of maturity of the tubers at the time of harvest has a significant impact on dormancy. In their research on the sprouting of seed potatoes, it was found that immature tubers sprouted more quickly than adult ones and had shorter periods of dormancy (Gong *et al*., 2021). It may be challenging to differentiate between multiple stages of development, such as chemical (sugar concentration), temporal (days from planting), and physiological. When potatoes are planted, their physiological age has a significant impact on the later commencement of tuber development as well as the overall life cycle of the plant (Gumbo *et al*., 2021). The age of the tuber at the time of harvest, the conditions in which it was stored, and whether or not it had been damaged all have a role in determining how long the dormancy period will be. When temperatures are high, the soil is dry, and there is a lack of nutrients, the physiological growth of the plant is sped up, and the latent time for forming tubers is shortened. In the beginning of research on seed germination, scientists found that there was a significant correlation between moisture stress and temperature fluctuations on dormancy break (Haider *et al*., 2022).

The amount of damage that is caused to the tubers after they are harvested is influenced by a number of factors, including the temperature of the soil, the amount of sunlight that the plants were exposed to while they were growing, the amount of rain that the plants received, and the length of time that the plants were dormant (Bisognin *et al*., 2018). During the tuber growth process, factors such as high temperatures, inadequate soil moisture, and low soil fertility, for example, all speed up the physiological development process and shorten the latent period. Both pre- and post-harvest environmental conditions can affect how long tubers remain dormant. Temperature appears to be the only environmental factor that has a significant effect on tuber dormancy, despite the fact that other environmental factors can have an effect (Bisognin *et al*., 2018).

In order for tuber development to be successful, the growing environment is absolutely necessary. During the growth and development stage, temperatures that are too high result in the production of tuber chains, secondary growth, and early sprouting, all of which are detrimental to tuber formation and the build-up of tuber dry matter (Zhang *et al*., 2021a). The presence of heat stress in mature tubers of plants is a potential obstacle to dormancy. The day lengths needed for the potato plant to thrive are quite brief. Although long nights are necessary for the tuberization process, various genotypes demonstrate a wide range of photoperiodic responses (de Freitas & Pareek, 2019). It is not entirely known how photoperiod affects dormancy, although it is certainly connected to when tuber growth begins and when it matures. The appearance of sprouts can be

changed if they are kept in the sunlight, even if this may not have much of an impact (Rosen *et al*., 2020).

The size of the tuber has an effect on how long it can remain dormant; generally speaking, smaller tubers have a longer dormancy period than larger tubers. The dormancy of the daughter tubers is influenced by the growth of the seed tubers as they are planted, with immature tubers leading to substantially prolonged dormancy periods for the daughter tubers (up to several weeks longer). Because of the influence that they have on tuber dormancy, which arises during the process of tuber formation, day length, temperature, nutritional content, and the availability of water all play a part in the tuberization process (Bisognin *et al*., 2018; Rosen *et al*., 2020).

Nitrogen deprivation can lead to an increase in abscisic acid (ABA), while high and low nitrogen levels can lead to the development of chain tubers. Nitrogen deprivation can also lead to a reduction in gibberellins. Chain tubers can arise as a result of cycles of high and low nitrogen levels (Van Dingenen *et al*., 2019). Although it is commonly believed that a high nitrogen content will restrict tuber production because it will encourage the development of shoots and roots at the expense of tuberization, a high nitrogen content can actually hasten tuberization by ensuring a high carbohydrate partitioning into tubers, which in turn causes an accumulation of sucrose. This is contrary to the common belief that a high nitrogen content will restrict tuber production because it will encourage the development of shoots and roots at the expense of tuberization (Zhang *et al*., 2022a). The process of dormancy-breaking is speed up by exposure to variable storage temperatures, in contrast to sustained exposure to high temperatures (Rosen *et al*., 2020). Because we want to delay the sprouting process, we need to ensure that the temperatures in the storage area are as consistent as they can be. It has been demonstrated that dormancy can be disrupted by concentrations of carbon IV oxide (CO_2) that are greater than 10%, whereas concentrations of CO_2 that are less than 10% have no effect on the breaking of dormancy (Draie & Al-Absi, 2018).

2.10.5. Cell cycle and changes in dormancy break

It has been known for a long time that the induction of dormancy by prolonged dark photoperiods is associated to a momentary rise in ABA concentrations as well as a halt in the cell cycle. It would suggest that there is a significant genetic connection between diversity and the length of time that cells remain in the arrested state before entering endo-dormancy. Before cells can divide, they must first complete what is known as the "cell cycle," which consists of a succession of phases

that are genetically separate from one another (Haider *et al*., 2021). During these stages, the amount of genetic material contained within the cell may undergo a replication process. Mitosis, also known as cell division, is prepared for by the cell during the ensuing G1 phase (gap 1 of cell growth). When the conditions are favourable, the cell will make the decision to divide and will enter the S phase (DNA synthesis). During this phase, the genetic material will be reproduced, and the total number of chromosomes will grow by two. When cells enter the G2 phase (gap 2 of cell growth) of their life cycle, this marks the beginning of the process of cell division. During this phase, metabolic changes take place in the cells, preparing them for the future processes of mitosis and cytokinesis. When tuber meristem cells go into dormancy, they become stuck in a phase of the cell cycle known as G0 (resting phase). During this phase, the normally smooth transition from G1 to S-phase is halted. Once they emerge from endosomal hibernation, cells will continue to exist in the G0 phase (Gong *et al*., 2021; Sabelli & Pessarakli, 2014; Saidi & Hajibarat, 2021).

2.11. Sprouting of potatoes

Sprouting of potatoes start to occur when stored potatoes break their dormancy (Moorby, 1978). It starts to occur in the warmest region of the store and in the greenest tubers (Pringle *et al*., 2009). The dormancy period is determined by the cultivar of the potato, maturity of the tuber before harvesting, weather and soil conditions (Pinhero *et al*., 2009; Sonnewald & Sonnewald, 2014). The apical bud is the first to appear followed by lateral buds which are normally suppressed by the apical bud whose dominance is more pronounced when storage temperature is between 5 - 20ºC (Moorby, 1978: Suttle, 2007). If the apical dominance is not broken, then few large tubers are obtained, but if its broken, growth of lateral buds is favoured thus production of many small tubers. (Pringle *et al*., 2009; Sonnewald & Sonnewald, 2014). Development of sprouts as influenced by different physiological state of the tuber is shown in Figure 2.1.

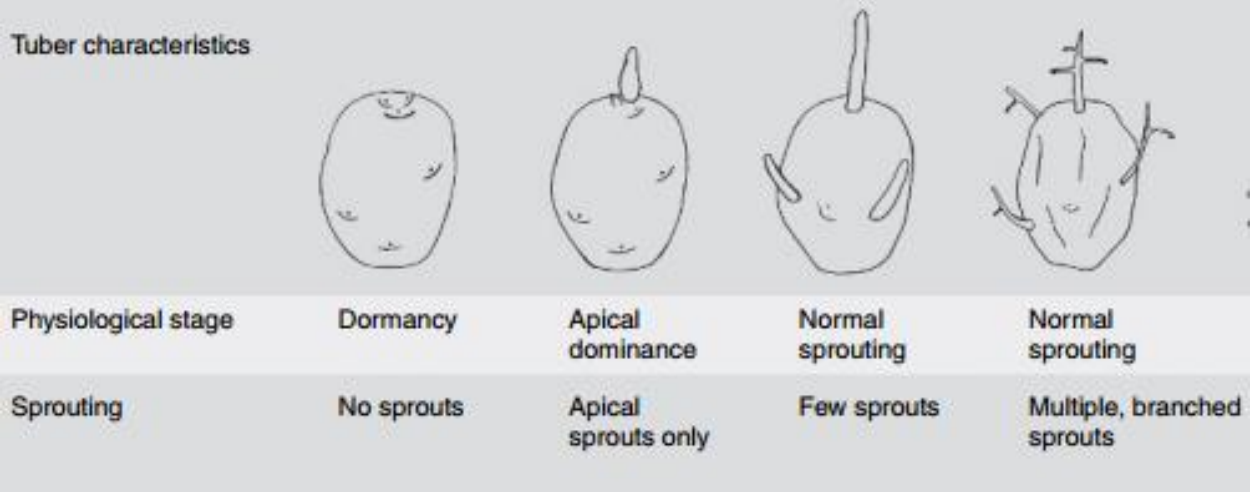

Figure 2. 1: Diffferent physiological stages of potato tuber and their effects on morphological conditions of sprout development.

Source: Struik (2007)

Sprouting is characterized by the increase in the synthesis of proteins and nucleic acid, increase in concentration of gibberellins and reduction in the amount of abscisic acid (Farre *et al*., 2011; Moorby, 1978). Other hormones that take part in regulation of dormancy and sprouting include auxin, ethylene and cytokinins, though their exact mechanisms have not been fully studied (Suttle, 2007). Proteins are hydrolysed to amino acids with proline being of particular interest as it increases rate of growth in plants (Trovato *et al*., 2008). The rate of respiration increases as the buds grow, where carbohydrates are broken down to release energy. The breakdown of starch to reducing sugars is promoted by the increased amounts of gibberellins at the end of dormancy (Moorby, 1978; Sonnewald & Sonnewald, 2014). In addition, low temperatures favour breakdown of starch into sucrose, which is again broken down by invertase to glucose and fructose leading to 'sweetening' of tubers (Farre *et al*., 2011**;** Pinhero *et al*., 2009; Zhang *et al*., 2018**)**. Some varieties are known to sprout early than others. For example, in Kenya, *shangi* is a fast sprouting variety as opposed to *Kenya karibu*, *asante* and *sherekea* varieties (Kaguongo, 2018; personal communication). Other factors that favour sprouting of potatoes include damaged tubers, high storage temperature, high relative humidity and exposure of tubers to light (Pinhero *et al*., 2009).

2.11.1. Effects of sprouts on quality of potatoes

The effects of sprouting on potatoes are catastrophic. Levels of GAs that are toxic (α-solanine and α-chaconine) increase as the number of sprouts increase in the stored potato (Sengul *et al*., 2004;

Zhang *et al*., 2018). Toxicity start to occur when the level of GAs exceeds 20mg/100g (Taylor *et al*., 2007). These toxins have been shown to give an off-flavour (bitter taste) in potato products; a burning sensation in the mouth and the throat; inhibit acetyl cholinesterase as well as transport of calcium in humans; damages nerve cells and in acute cases, they have caused deaths (Aziz *et al*., 2012; Koffi *et al*., 2017; Romanucci *et al*., 2016; Sengul *et al*., 2004). In addition, different toxins produced through potato sprouts have been linked to diseases such as dyspnea, convulsion and emesis (Zhang *et al*., 2018). In particular, solanism causes vomiting, nausea, abdominal pain, dizziness, diarrhea among other symptoms in humans (Chen *et al.*, 2018). It is worthwhile, however, to note that α-solanine has been linked to a few beneficial effects such as being anti-diabetic, anti-cancer, anti-bacterial and anti-fungal (Camire *et al*., 2009; Pringle *et al*., 2009; Zhang *et al*., 2018). It has also been reported that low levels of GAs enhance flavour of potatoes (Pringle *et al*., 2009). Nevertheless, GAs present a serious challenge both to processors and consumers because they are heat-stable and remain active even after processing (Aziz *et al*., 2012).

The appearance of the potato tuber deteriorates due to sprouting given that physiological aging is favoured by sprouts (Pringle *et al*., 2009). Sprouts increase respiration and transpiration rate that lead to weight loss. This is due to the loss of water as temperature increases in the storage house and also due to the loss of potato mass as starch and proteins are remobilized (Pringle *et al*., 2009**;** Sonnewald & Sonnewald, 2014). Weight loss reduces consumer acceptability of the potato given that potatoes that have lost weight appear to have gone shrinking, thus compromising the commercial value of potatoes (Daniels-Lake *et al*., 2005; Lysakov *et al*., 2018). With extensive sprouting, boxes with the potato may fail to empty, even with full inversion of the box, as a result of intertwined characteristic of the sprouts (Pringle *et al*., 2009). Hydrolysis of starch leads to accumulation of reducing sugars such as sucrose, glucose and fructose which leads to "sweetening" of potatoes and predisposes them to the formation of toxic acrylamide (Daniels-lake *et al*., 2005; Pinhero *et al*., 2009; Zaheer & Akhtar, 2016). The vitamin content of potato has been shown to decrease with increasing sprout development (Moorby, 1978). These changes are undesirable to potato processors because they not only decrease the quality of potatoes but also reduce their processability and eventual reduction on income, and thus sprouting of potatoes has constantly hampered the sustainable development of industries related to potato and its products all over the world (Aziz *et al*., 2012; Zaheer & Akhtar, 2016; Zhang *et al*., 2018).

2.11.2. Regulation of potato tuber dormancy and sprouting

The tuber is the organ that is responsible for the vegetative reproduction of potatoes. Tuber development and subsequent functioning are dependent on an extensive network of physiological processes and can be broken down into a number of steps that occur one after the other (Bisognin *et al*., 2018). These include the hormonal regulation during tuber formation, the development of stolons, the induction of tuberization, the beginning and growth of tubers, dormancy and sprouting.

During the period of dormancy, tubers have a high level of resistance to attacks by pathogens, which allows them to store reserves of starch and protein for future sprouts (Campbell *et al*., 2020). In the grand scheme of things, tuber dormancy is an adaptation of potato ontogeny that provides for the effective reproduction of the *Solanum tuberosum* species (Haider *et al*., 2022). After a period of dormancy, the tuber buds become active and the sprouts begin an intensive growth phase, during which roots begin to emerge at their bases. At this point in the process, the tubers transition from their role as a storage organ into that of a source of nutrients and energy to support the growth of sprouts. The process of vegetative propagation of potatoes is hereby finished, and a new young plant emerges. This new plant is a clone of the potato's original parent organism. The current language defines dormancy as a temporary pause in the growth of any plant structure that contains a meristem (Bisognin *et al*., 2018; Campbell *et al*., 2020).

There are three basic types of dormancies, which can be identified from one another based on the method that is used to limit growth. Because of the physiological processes that are taking place within the organism, growth comes to a complete halt while the organism is in a state of deep dormancy (endodormancy). When an organism is prevented from growing as a result of either external physiological processes (paradormancy) or unfavourable environmental circumstances (ecodormancy), this state is referred to as forced or induced dormancy. The term "dormancy" was initially developed to characterise vegetative buds on stems, but it has since been extended to characterise the state of potato tubers (Bisognin *et al*., 2018). Dormancy is broken for budding tubers after each of these three stages. After harvesting, the tuber buds go into a deep slumber that makes it extremely difficult for them to sprout, even in the best possible growing conditions. Once the profound dormancy phase of a tuber's life cycle has come to an end, the tuber's latent buds will not emerge unless favourable environmental circumstances exist. Temperatures ranging from 0 to 4 °C will still deter buds from sprouting (Draie & Al-Absi, 2018).

At the beginning of the sprouting process, induced dormancy can occur in lateral buds (depending on the parameters that exist within the plant's internal physiological environment) due to a correlative inhibition from the earlier sprouting apical bud. The apical meristem of the stolon transforms into an eye once tuberization has begun (Draie & Al-Absi, 2018). An eye is a central dormant bud that, like other eyes, does not outgrow until tuber dormancy release. Therefore, the early phases of growth in immature tubers are thought to be when dormancy first begins to set in (Saidi & Hajibarat, 2021). During this stage, the cells that make up the cortex and pith tissues of young tubers go through significant mitoses, which results in an increase in the size of both the individual cells and the tuber as a whole (Wang *et al*., 2020). Even in huge tubers weighing 120 grammes, there is a discernible rise in cell volume (expansion growth), as well as a discernible rise in cell number. The rise in cell number is especially noteworthy in the cortical parenchyma. There is widespread consensus among industry experts that the optimal period to harvest tubers is just before to the start of deep dormancy (Bahadir *et al*., 2020).

It is widely agreed upon that the period of deep dormancy comes to an end when the bud growth begins to become obviously larger. The conditions under which a tuber was grown and stored as well as its genotype both play a role in determining how long a tuber will remain dormant once it has been harvested. Dormancy breakdown and early bud growth can be encouraged by storing tubers in conditions with high temperatures (up to 30 °C), high humidity (up to 90% of water capacity), and various air components (hypoxia, anoxia, increased oxygen concentration). On the other hand, it is not known if or how seasonal changes in the environment come before or after the beginning of the profound dormancy of tubers (Saidi & Hajibarat, 2021; Wang *et al*., 2020).

2.12. Growth, metabolism, and egne expression

In most cases, the potato buds, sometimes known as eyes, do emerge until a number of months after the tuber is formed. This prolonged absence of eye growth is certainly adaptive because it allows vegetative buds to be preserved as tuber tissue during periods of substantial storage metabolite accumulation and the ensuing unfavourable season. Although the specific processes that impede bud growth and remove this blockage on the path to the end of tuber dormancy have not been described, their fundamental features have been uncovered. It has been demonstrated (Li *et al*., 2020b) that the transition of the cell cycle from G1 to S phase is arrested in the cells of dormant tuber buds: after completion of the G1 phase related to cell growth after the previous

division, the cells do not transition to the DNA synthesis characteristic of S phase and required for subsequent mitosis. This is necessary for the cells to be able to undergo subsequent mitosis. This shift from G1 to S phase is dependent on the presence of a large number of genes and proteins, some of which include cyclindependent kinases (CDK), Dcyclins (CYCD), histones H3 and H4, and others. The expression of genes that govern DNA replication (Zhang *et al*., 2020b) and cell cycle progression, including the gene for cyclin D3, is induced both during the transition from the tuber eye to sprouting and in response to artificial stimulation of sprout growth. This occurs both naturally and artificially. In order for dormant buds to begin the process of sprouting, these genes need to be triggered. On the other hand, the signal transduction pathways that govern cell division in buds according to the condition of tuber dormancy are not fully understood at this time (Chen *et al*., 2020; Li *et al*., 2020).

2.12.1. Ethylene

Although its specific role in these processes is not fully understood, it is known that ethylene has a role in the beginning and maintenance of dormancy in tubers. Tosetti *et al*. (2021) give the best evidence for the engagement of ethylene in the earliest steps of maintaining dormancy in the organism. The tubers that were cultivated in vitro and were going through their dormant phase contained the highest concentrations of endogenous ethylene, which then quickly dropped after that. When applied to tubers that are about to enter dormancy, the ethylene antagonists silver nitrate and norbornadiene cause premature sprouting, which can be avoided. Researchers observed that ethylene was only effective at maintaining the first few phases of dormancy (Li *et al*., 2021). There is conflicting data regarding the role that ethylene plays in the upkeep of dormancy and the release of dormancy in the future. The amount of ethylene present, the type of potato used, and the conditions in which it was stored all had an impact on how strong or fragile the dormancy of ethylene-exposed tubers and their producers was. The brief increase in ethylene synthesis that follows the breaking of dormancy through means such as wounding, treatment with bromoethane, and other methods is likely a response to the presence of stressful situations (Maltsev, 2021). The TDF profiles of sprouting and dormant tubers taken at the same time suggested that ethylene may have played a role in limiting bud growth during the most recent period of tuber hibernation (Tosetti *et al*., 2021). This was discovered by comparing the TDF profiles of the two types of tubers at the same time. The strong expression of transcripts whose sequences are identical to those

encoding components of the ethylene signalling pathways in tomato and Arabidopsis was observed in dormant buds, whereas this expression was observed to decrease after the sprouting process had begun. The expression of genes that are involved in primary and secondary responses to the ethylene signal is suppressed during the sprouting stage of plant development. In each of these experiments, ethylene signalling has been shown to have a role in the preservation of tuber bud dormancy. In addition, it has been found that the interaction between ethylene and ABA is what controls the dormancy of tubers (Maltsev, 2021; Wang *et al*., 2020). In particular, the treatment of dormant tubers with the ethylene producer 2-chloroethylphosphonic acid resulted in a prolonging of the profound dormancy phase (Li *et al*., 2021). This was accomplished by enhancing ABA production and increasing ethylene levels in the tissues. This shows that ABA may be able to assist with the increase in tuber dormancy that is caused by ethylene.

2.12.2. Brassinosteroids

Brassinosteroids, also known as BS, are active plant growth regulators; however, the understanding of how they affect the dormancy and sprouting of potato tubers is limited. There haven't been many investigations carried out in this particular field. The potato variety was handled by Wang and colleagues. After harvesting, Nevskii tubers enter a profound dormant state because they contain 24 epibrassinolide and remain in this state until used. This treatment also resulted in an increase in the production of ethylene and an accumulation of free as well as bound ABA in the tuber buds (Wang *et al*., 2020). Furthermore, the dormancy period of the tubers was lengthened, and the sprouting of the tubers was delayed by more than a month. A decrease in cell size in the central portion of the meristem, as well as an increase in the number of vacuoles in meristematic cells, and a decrease in the volume of those vacuoles, were also observed to be associated with the delay of eye outgrowth caused by BS, as observed by electron microscopy (Di *et al*., 2019; Li *et al*., 2020a). Additionally, these results could be the result of the high BS concentration's artificial suppression of tuber bud sprouting, but they could also be the result of a possible role for BS in the regulation of ethylene and ABA levels in the natural control of tuber dormancy. Either way, they suggest a possible role for BS. The role that BS plays in controlling the dormancy of potato tubers is likely to become clearer as further and more in-depth research is conducted on the topic (Wang *et al*., 2020).

2.12.3. Cytokinins

Cytokinins, often known as CK, are extremely effective dormancy breakers and growth regulators in tubers. They play an important role in the process of reversing tuber hibernation and initiating the formation of buds. The amount of CK in tubers is low during deep dormancy; it then rises and reaches its maximal levels shortly prior to sprouting and during sprout emergence, as shown by numerous analyses of CK activity and content (Cheng *et al*., 2020a). This phenomenon is evidenced by the fact that CK levels rise and reach their maximum shortly before sprouting and during sprout emergence. The function that particular forms of cytokinin perform in these processes is not yet completely understood. The total amount of CK, which comprises cis and transzeatin as well as isopentenyl type cytokinins, increased when dormancy was broken. This was seen in both the tubers and the buds. In particular, the use of benzyladenine (BA), which was applied to dormant tubers, caused the tubers to emerge from their state of dormancy and sprout (Cheng *et al*., 2020a; Raspor *et al*., 2020). When it comes to rousing potato cv. Russet Burbank minitubers from their dormant state, research has revealed that synthetic cytokinins, which are compounds of phenylurea or nitroguanidine, are more successful than natural zeatin (Lomin *et al*., 2020). It's possible that this is due to the fact that synthesised cytokinins are less susceptible to being broken down by enzymes. On potato plants treated with an arabidopsis gene encoding one of the primary enzymes responsible for CK inactivation, cytokinin oxidase/dehydrogenase, an essential function of endogenous CK inactivation for lengthening tuber dormancy time was established (Lomin *et al*., 2020). This function was found to be essential for the lengthening of tuber dormancy time. After the expression of this gene caused a delay of 5-8 weeks in the sprouting process, treatment of such tubers with BA was able to normalise the timing of the sprouting process. As a result, the shortened bud dormancy period in the discs cut from the transgenic potato tubers can be explained by the enhanced CK biosynthesis that was mediated by the agrobacterial ipt gene (Raspor *et al*., 2020).

In addition, it was found that the tuber's sensitivity to CK shifted over the dormancy period. Dormancy exit was triggered by treatment with cytokinins, but sensitivity to the phytohormone increased time-dependently during storage. Treatments with cisor transzeatin administered soon after harvest did not result in a decrease in tuber dormancy. This enhanced tuber CK sensitivity was unrelated to changes in zeatin metabolism, and instead resulted from the activation of cytokinin signalling components (Lomin *et al*., 2020). The available evidence suggests that

different forms of CK, as well as their biosynthesis and inactivation mechanisms, are involved in the regulation of tuber dormancy and sprouting. Among its many functions in plants, CK are responsible for boosting cell proliferation and expanding tissue sinks (Cheng *et al*., 2020a). It is believed that CK's role in dormancy breaking is primarily connected to the stimulation of cell division because the arrest of the G1/S phase transition in the cell cycle is removed at the time of dormancy termination. D-type cyclins are thought to play a role in unblocking this pathway. Buds that break dormancy also serve as active sinks, removing metabolites from storage in other parts of the tuber. Consequently, CK may also play a part in enhancing bud sink capacity. To date, the mechanisms by which CK controls tuber dormancy and sprouting have not been fully elucidated (Cheng *et al*., 2020a).

2.12.4. Gibberellins

Gibberellins (GA) are a type of hormone that, once the dormancy of a tuber has been broken, may induce rapid new growth in the form of sprouts. Previous research (Yan *et al*., 2021) discovered that GA is also responsible for promoting the end of hibernation as well as the commencement of bud expansion. According to these investigations, the activity of endogenous GA-like compounds is low during dormancy and increases shortly before bud growth; dormancy can be broken during tuber storage by treating the plant with GA. The GA treatment of dormant tubers was used in practise, and it was a commercially viable strategy for early potato seeding (Gong *et al*., 2021). The research that follows hints at a role for endogenous GA in boosting the growth of consecutive sprouts from a tuber that had been dormant; however, it is unable to prove that this component is responsible for breaking the dormancy of the plant. Therefore, the absence of considerable GA activity in mutants (GA1 and its immediate precursor GA20) did not result in any detectable variations in the duration of tuber dormancy or the time at which the sprouting process began in comparison to plants that had a normal phenotype (Cheng *et al*., 2020a). Antisense expression of the gene of GA biosynthesis GA20ox1 artificially decreased the quantity of endogenous GA 20 and GA 1, but it had no significant influence on the length of time the tuber could remain in a state of dormancy. However, it did slow the growth of succeeding sprouts (Haider *et al*., 2021).

2.12.5. Phytohormone Interaction

Recent research on the hormonal regulation of plants has disclosed the existence of intricate interactions between various phytohormones, and these interactions can be observed both at the

level of physiological responses and hormonal signals (Liu & Sherif, 2019; Saidi & Hajibarat, 2021). It has also been shown that the regulation of potato tuber dormancy and sprouting is affected by interactions between various phytohormones. Several studies have demonstrated that GA and CK have a close working relationship in order to regulate tuber sprouting. Therefore, the combination of GA3 and BA was able to break the dormancy of the minitubers of seed-grown potato plants substantially faster than either chemical alone was able to. Transgenic potato plants that expressed cytokinin oxidase/dehydrogenase produced tubers with significantly reduced levels of endogenous CK activity. This meant that the tubers were insensitive to GA therapy. When CK, more precisely BA, was administered to the tubers, the effect of GA that had been inhibiting the growth of the sprouts was totally abolished. The maintenance of tuber dormancy was a direct result of the interaction between ethylene and ABA (Shen *et al*., 2021). After the bud dormancy was broken, there was a decrease in the levels of ethylene signalling components, whereas there was an increase in the variables linked with IAA action activation expression (Xu *et al*., 2022). It was discovered that the hormonal regulation of tuber dormancy and the release of dormancy is under the control of a group of phytohormones, each of which performs a unique role. Multiple classes of hormones work together to make sure their interactions are coordinated over long periods of time. Dormancy in tubers is begun, sustained, and broken through a complex interaction of the dynamics and roles of phytohormones, although the mechanism by which this occurs is not fully known (Saidi & Hajibarat, 2021).

2.13. Magnetism

Magnetism is the phenomenon whereby materials exert either an attractive or a repulsive force to other materials (Ahmed & Ramaswamy, 2020). Different materials respond differently to magnetic fields in terms of permeability (μ) and thus they are classified as diamagnetic, paramagnetic, ferromagnetic or ferrites materials (Jin, 2010). Diamagmetic materials possess a weak negative susceptibility (X_m) to a magnetic field – which repels them slightly, and cannot retain magnetic properties when the magnetic field is removed. Their relative permeability (μ_r) is slightly less than 1. A negative susceptibility occurs when the magnetization intensity, M (alignment of randomly oriented magnetic dipoles when a magnetic field is plied to a medium), is in a direction opposite to that of the applied magnetic field (Jin, 2010). Paramagnetic materials possess a small positive susceptibility (X_m) to a magnetic field – thus are slightly attracted by magnetic fields but do not

retain magnetic properties when the magnetic field is removed. Their relative permeability (μ_r) is slightly greater than 1. A positive susceptibility occurs when the magnetization intensity, M is in the same direction to that of the applied magnetic field. Both diamagnetic and paramagnetic materials can generally be said to be non-magnetic as their relative permeability is often approximated to be $\mu_r \approx 1.0$ (Jin, 2010). Ferromagnetic materials however, possess huge positive susceptibility (X_m) to magnetic fields – are strongly attracted to a magnetic field, and can retain magnetic properties when the magnetic field is removed. They have large relative permeability, μ_r and high conductivity. Ferrites materials like ferromagnetic materials, have large relative permeability μ_r but with low conductivity at microwave frequencies (Jin, 2010).

The repulsive behavior by diamagnetic materials when exposed to a magnetic field is because all electrons in them are paired and examples of such materials include water, silver and gold. On the other hand, the attraction exhibited by paramagnetic and ferromagnetic materials while exposed to a magnetic field is due to the presence of unpaired electrons (Ahmed & Ramaswamy, 2020). Examples of paramagnetic materials include magnesium, lithium, molybdenum and oxygen, while examples of ferromagnetic materials are iron, nickel and cobalt (Ahmed & Ramaswamy, 2020). Ferrites are commonly used in designing microwave devices (Jin, 2010)

2.13.1. Magnetic fields

A magnetic field is defined as the field of magnetic force that is generated by a permanent magnet (Ahmed & Ramaswamy, 2020). It is the area around a magnet where attractive or repulsive effects are felt (Thirika *et al*., 2016). They are created by moving particles that are charged. For example, a coil of wire that is connected to a battery produces magnetic field by allowing electrons to move through it (Ahmed & Ramaswamy, 2020), as shown in Figure 2.2.

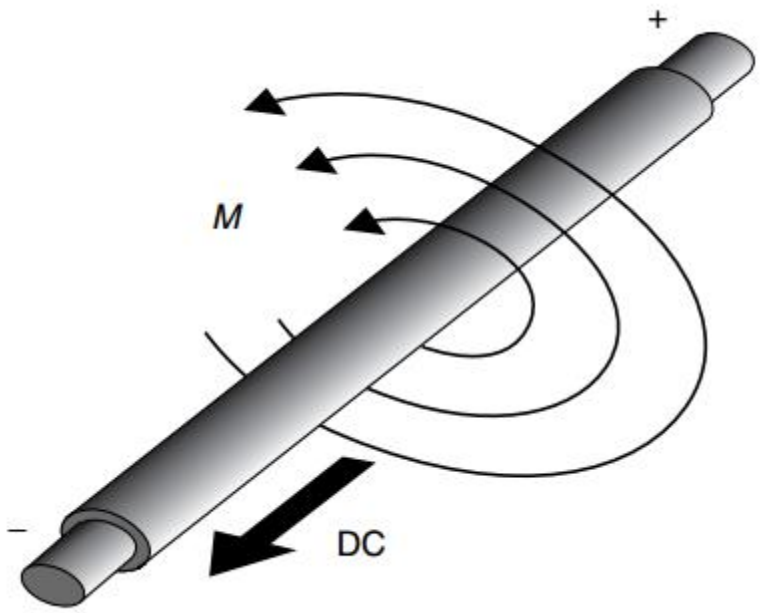

Figure 2. 2: Production of magnetic fields (M) as current flows through a wire.

Source: Ahmed and Ramaswamy (2020)

Magnetic fields are visualized by use of imaginary lines known as magnetic field lines (Figure 2.3), where the number of magnetic field lines constitutes a magnetic flux (ϕ) (Thirika, 2016), – the flow of magnetic energy, measured in Weber (Wb). The flow of magnetic flux is from the north pole of a magnet to the south pole (Figure 2.3). Magnetic flux density (***B)***, also known as magnetic induction, is the amount of magnetic flux that passes at right angles, through a unit area (***A***), to the magnetic field lines, and is measured in Tesla (T), and given as equation 1. It determines the strength of a magnetic field (***H***), through the relationship in equation 2, where μ is the magnetic permeability determined by the properties of the magnetic medium (Knoepfel, 2008).

$B = \frac{\Phi}{A}$……Equation 1

$B = \mu H$……Equation 2

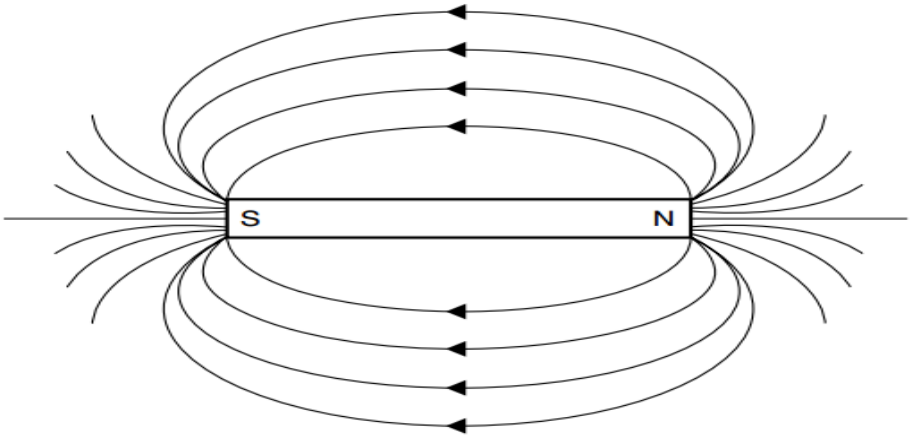

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Figure 2. 3: Magnetic field lines due to a single magnet.

Source: Ahmed and Ramaswamy (2020)

There are different types of magnetic fields based on their intensities and ranges from geomagnetic fields (GMF), super weak magnetic fields, weak magnetic fields (WMF), and high magnetic fields (Belyavskaya, 2004). Geomagnetic fields (Earth's magnetic fields) are naturally occurring from the Earth's cluster and their intensities are not static. They keep changing due to migrations of the magnetic north pole. Their intensities are approximately in the ranges of 25 μT – 65 μT. The intensities of super weak magnetic fields are below 0.1 μT, while that of WMF ranges from 0.1 μT to 500 μT (Belyavskaya, 2004; Maffei, 2014). High magnetic fields can be in the range of 30,000 μT – 100,000 μT (Miura *et al*., 1986). Magnetic fields can also be classified as either homogenous or heterogeneous, where the magnetic field strength is uniform in a homogenous field and non-uniform in a heterogeneous field.

2.13.2. Electromagnetism

Electromagnetism is the production of magnetic fields through a conductor that has current passing through it. It can be static or pulsed based on the type of current applied (Rothwell & Cloud, 2018). A direct current (DC) voltage produces a magnetic field with a fixed polarity, whereas an alternating current (AC) voltage produces a magnetic field with a pulsed polarity (Thirika, 2016).

2.13.3. Laws of electromagnetism

Laws of electromagnetism are popularly known as 'Maxwell's equations and can be in integral or in differentiated forms (Jin, 2010; Rothwell & Cloud, 2018). For purposes of simplicity, the

equations are presented in differentiated forms in this text. Unless otherwise stated, the following symbols are used in the equations

H = magnetic field strength (also known as magnetic intensity), measured in amperes per meter (A/m)

E = Electric field density, measured in volts per meter (V/m)

B = Magnetic flux density (also known as magnetic induction), measured in webers per square meter (Wb/m^2), or in Teslas (T)

D = Electric displacement, measured in coulombs per square meter (C/m^2)

J_{total} = Electric current density, measured in amperes per square meter (A/m^2), derived from the addition of j_r – the free current caused by moving charges, j_p – the polarization or bound current resulting from bound charges in dielectrics and j_m – the magnetization current.

ε_0 = permittivity of free space, measured in farads per meter (F/m), whose numerical value is given by:

$\varepsilon_0 = 8.854\times10^{-12}$ F/m »$1/36\pi\times10^{-9}$F/m .....Equation 3

μ_0 = permeability of free space, measured in henrys per meter (H/m) whose numerical value is given by:

$\mu_0 = 4\pi\times10^{-7}$H/m.....Equation 4

P_{etotal} = electric charge density measured in coulombs per cubic meter (C/m^3)

t = time, measured in seconds (s)

2.13.3.1. Faraday's law

It states that a change in magnetic flux induces an electromotive force (emf) in the coil, and is given as:

$$\nabla \times E = -\frac{\partial B}{\partial t}$$ ..... Equation 5

The negative sign implies that the magnetic field generated by induced emf is in an opposite direction to the magnetic field that produced it. This phenomenon is known as the Lenz law

Faraday's law in equation 3 can be simplified into

$$E = -\frac{N\Delta\phi}{\Delta t}$$ ..... Equation 6

Where;

E = electromotive force (V); N = number of turns in the coil; ϕ = is the magnetic flux (Wb); t = time

2.13.3.2. Maxwell-Ampere Law

This law gives the relationship between magnetic flux and electric currents, and is given as;

$$\nabla \times B = \varepsilon_0 \mu_0 \left(\frac{\partial E}{\partial t}\right) + \mu_0 J_{total} \quad \text{.....Equation 7}$$

2.13.3.3. Gauss' law

It states that the net electric flux emanating from a closed surface is proportional to the electric charge density divided by the vacuum permittivity. It is given as;

$$\nabla . E = P_{e.total} / \varepsilon_0 \quad \text{.....Equation 8}$$

2.13.3.4. Gauss' magnetic law

It states that the magnetic field has zero divergence. In other words, no magnetic monopoles exist.

$$\nabla . B = 0 \quad \text{..... Equation 9}$$

2.13.3.5. Current continuity equation

This equation shows how electric charges are conserved in any closed system as they flow as electric currents from one point to another. It retaliates that the net electric charge of a closed system can never change despite the changes in the system

$$\nabla . J_{total} = -\partial P_{e.total} / \partial t \quad \text{..... Equation 10}$$

2.13.3.6. Lorentz force law

The force a particle, which carries electric charge q, experiences due to electric and magnetic fields is known as the Lorentz force, and is as below:

$$F = q(E + v + B) \quad \text{..... Equation 11}$$

Where;

F = Force exerted by a charged particle; q = electric charge carried by a particle; E = Electric flux density; v = velocity vector of the charge, perpendicular to magnetic field; B = Magnetic flux density

This law helps us to understand the interaction between matter and electromagnetic fields and is useful in designing electrical devices such as magnetrons and electric motors (Jin, 2010). Its direction is obtained using the right-hand rule; where the thumb is pointed to the direction of the current, first finger pointed in the direction of the magnetic field and the second finger indicates the direction of the force.

2.13.4. Generation of magnetic fields

Weak magnetic fields have been produced in the laboratory through different ways with the commonly used methods being either by shielding or by compensation techniques. In shielding, the experimental zone is normally surrounded by ferromagnetic plates that possess high magnetic permeability, and this property allows for deviation and concentration of magnetic fields in the plates (Maffei, 2014). In compensating method, two or more coils are used to generate WMF when current is passed through them. They have the advantage of the ability to control both the frequency and the amplitude of the generated WMF (Milutinov *et al*., 2015). For example, Helmholtz coils – two circular coils with same radii, with radius of each coil being equal to the distance between the two coils - have extensively been used mainly due to their ability to produce a highly uniform WMF at the axial point, which is a point midway between the two coils (Restrepo-Alvarez *et al*., 2012; Thirika, 2016). In addition, Helmholtz coils produces magnetic fields in relatively low controllable volumes that are desired for experimental set up, and also offer room for repeatability of the experiment (Restrepo-Alvarez *et al*., 2012). The intensity of magnetic field produced is normally measured in Teslas (T) using a teslameter and is dependent on the current *I*, number of turns per each coil, *N* and the radius of the coil, *a*. A practical configuration of the Helmholtz coils is shown in Figure 2.4, with the expression of the magnetic field at a point of symmetry axis and at a distance z given by:

$$B(z) = \mu_0 NIa^2/2 \times \left[\left(\frac{1}{(a^2+(z+\frac{h^2}{2})^{\frac{3}{2}}}\right) + \left(\frac{1}{(a^2+(z-\frac{h^2}{2})^{\frac{3}{2}}}\right)\right] \text{..... Equation 12}$$

Where; a =radius of the coil; h/2 =distance between the coils and the center of separation; and z = distance between the center point of separation and evaluated point

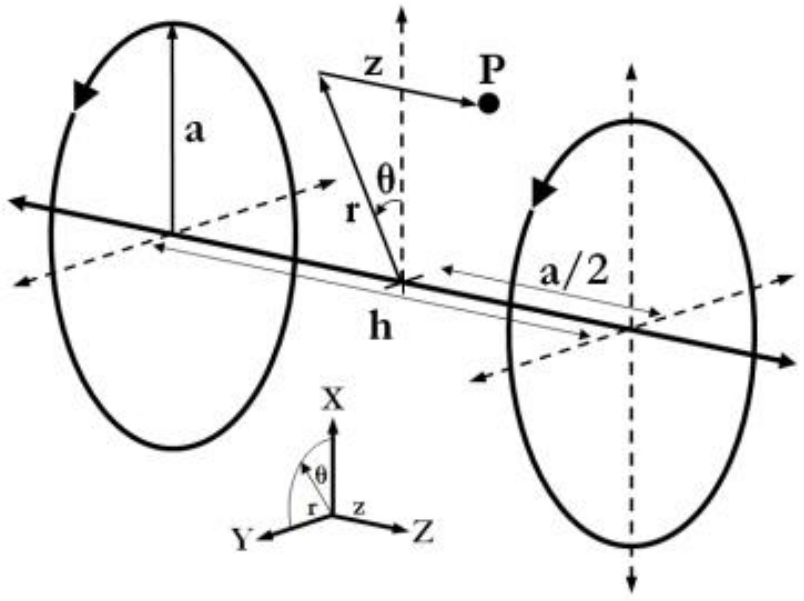

Figure 2. 4: Configuration of the circular Helmholtz coils.

Source: Restrepo-Alvarez (2012)

2.13.5. Uses of magnetism in food production and preservation

Magnetic fields have been used in production and preservation of various foods such as in pasteurization of foods (Ahmed & Ramaswamy, 2020); treatment of water (Thirika *et al*., 2016; Thirika & Onyango, 2017) inactivation and destruction of spoilage microorganosms (Piatti *et al*., 2002; Tsuchiya *et al*., 1996). Its application in food quality control processes is fast growing as 'magnetic resonance imaging (MRI)'. In particular, MRI has been used efficiently in prediction of beef eating quality (Jackman *et al*., 2008) as an in-line sensor for measuring the quality of vegetables and fruits (Lu, 2008); in quality evaluation of meat cuts (Valous *et al*., 2016); cooked meats (Du *et al*., 2016); seafood (Balaban *et al*., 2016); rice (Ogawa, 2016); maize (Symons *et al*., 2016); bakery products (Nashat & Abdullah, 2016); grading of potatoes (Pedreschi *et al*., 2016a); as well as evaluation of quality and control of French Fries and Potato Chips (Pedreschi *et al*., 2016b). It has also been used to predict the dynamics and structure of foods during and after processing (Ahmed & Ramaswamy, 2020).

CHAPTER THREE
DC AND AC MAGNETIC FIELDS EFFECTS ON PHYSICOCHEMICAL PROPERTIES OF STORED POTATOES

Abstract

Production of potatoes in the developing countries has been on the rise. This reinforces the growing importance of potatoes throughout Africa, Asia, and Latin America as a source of food and livelihood. However, this crop continues to experience major postharvest losses that are associated with a lack of effective storage facilities in these regions. This study used magnetic fields as an innovative technology to reduce potato losses while under storage. The effects of test variables; sources of magnetic fields intensity and exposure time on physicochemical properties of stored shangi potatoes were investigated. Double Helmholtz coils were used to generate MF. The coils were supplied with either direct current (DC) or alternating current (AC). Potatoes were then exposed to MF and stored in either the control or the commercial store. At the end of storage, physicochemical analyses were done following standard methods. AC MF resulted in significant ($\rho < 0.05$) higher specific gravity, dry matter, starch, and the number of sprouts per tuber but lower weight reduction, total sugars, reducing sugars, and non-reducing sugars than DC MF. Exposing potatoes to 3.00 mT of both DC and AC MF resulted in significant ($\rho < 0.05$) lower weight reduction, internal and external greening, sprouting, and the number of sprouts per tuber than in potatoes that were not exposed to MF. The current work has shown that it is possible to extend the shelf-life of the shangi potato variety by about 1 month, by use of MF, without compromising on quality parameters.

3.1. Introduction

Potato is currently the world's third most important food crop in terms of human consumption, after wheat and rice (FAOSTAT, 2020). However, Potatoes incur substantial postharvest losses during storage, with up to 30% of the crop being lost. This is because potato tubers are live organisms that continue to respire long after they have been harvested. As a result, they lose a significant amount of weight and quality as a result of matter loss during respiration (Ozturk & Polat, 2016). Excessive moisture loss, deterioration caused by microorganism infection, and sprouting are the main causes of losses (Lysakov *et al*., 2018; Sonnewald & Sonnewald, 2014). Because starch is hydrolyzed to enable sprout growth, the commercial value of sprouted potatoes

diminishes dramatically due to unfavourable changes in morphological properties of the potato, loss of dry matter, decrease in potato torgur pressure, and higher sugar concentrations (Daniels-Lake *et al*., 2005; Kirkman, 2007). These losses have a negative impact on potato prices, the processability of the potatoes, and ultimately on consumer desirability.

There are over 50 approved potato varieties in Kenya, with varied attributes. The shangi potato variety matures fast, is relatively disease resistant, and has relatively high productivity per unit area with yields of 30,000 – 40,000 kg per acre. This variety has multiple uses, especially in the table and industrial processing. Thus, it is preferred by most Kenyan potato farmers. This has led to the variety controlling more than 80% of the potato market share in the country. However, it has a short shelf life of less than 1 month. (National Potato Council of Kenya, 2019: Sophie, 2019). The major losses affecting this variety after harvest include sprouting, weight loss, and greening (Kaguongo 2018; Personal Communication). Shangi potatoes are harvested in Kenya's key potato-producing regions during the warmer months of January-March and August-September. Due to insufficient post-harvest storage infrastructure and a lack of alternate markets, market excess often occurs, resulting in significant price reductions during peak harvesting months. Potato prices are then significantly raised after 2-3 months owing to scarcity (National Potato Council of Kenya, 2019). Due to the prevailing losses, most farmers are unable to keep their harvested potatoes for long periods of time for price speculation, especially up to times of scarcity, and thus they are predisposed to unscrupulous buyers who buy the potato at a very low price. There is therefore the need to identify mechanisms that can reduce postharvest losses and thus prolong the shelf life of shangi potatoes without compromising on quality aspects.

In food crops, MF have been employed to induce or repress favourable or undesirable characteristics (Radhakrishnan, 2019). Different strengths of electromagnetic fields, for example, have been shown to increase the germination rate in beans (Odhiambo *et al*., 2009), maize (Aladjadjiyan, 2002; Florez *et al*., 2007), tomato (De Souza *et al*., 2006), oaks (Celestino *et al*., 2000), onions (Hozayn *et al*., 2015), and oil palm (Sudsiri *et al*., 2016). It is reported that prolonged exposure of barley seeds to DC MF, with an intensity of 7.00 mT, slowed organ development in barley seedlings by slowing the creation of shoots and roots, (Shabrangy *et al*., 2021). Studies on the effects of DC MF on potatoes have yielded positive results, including increased growth rate, when potatoes were exposed to the intensity of 0.00 – 0.0005 mT (Rakosy-Tican *et al*., 2005), and

reduced storage mass loss, after exposure to the intensity of 1.27 mT (Lysakov *et al*., 2018). Similarly, the use of AC MF on potatoes resulted in increased yield upon exposure to 115.00 mT (Pittman, 1972), reduction of spoilage micro-organisms after exposure to 5,000.00 – 20,000.00 mT (Lipiec *et al*., 2004), and low storage weight loss, with an intensity of 0.35 mT (Lysakov *et al*., 2018). Success in the use of MF was anticipated following promising reports on the applicability of other novel physical methods to reduce postharvest losses in stored potatoes. These methods include the use of ultraviolet radiation in the C band of light (UV-C) (Jakubowski & Krolcyzk, 2020; Jakubowski, 2018), impulse electric fields, and microwave radiation (Jakubowski, 2019).

There is limited research on the effects of MF on post-harvest storage of potatoes, Lysakov and Tarasov (2019) and Lysakov *et al*. (2018) reported the impacts of MF on sprouting, the internal structure of stored potatoes, and weight loss. Jakubowski (2019) reported on the effects of MF on starch and simple sugars of stored potatoes. There is therefore the need to investigate how MF affects other key quality parameters of potatoes while under storage. It is also imperative to explore the impacts of MF on other potato varieties and from other regions. In addition, there is a lack of information on the use of MF on potatoes that are destined for processing. Hence, the primary objective of this study was to assess the possibility of using MF to extend the shelf-life of shangi potatoes during storage. The effects of source of magnetic fields (DC or AC), magnetic field intensities, and holding time of exposure to MF were investigated. A secondary objective was to assess the impacts of two storage protocols (a dark room, herein referred to as the control store, and a commercial store with varying light intensities) on the quality of potatoes. The effects of MF on key attributes that determine the quality of potatoes after storage including specific gravity, dry matter, weight loss, starch, greening, sprouting, and sugars were evaluated.

3.2. Materials and Methods

3.2.1. Collection of potatoes

A registered potato farmer in Nakuru County, Kenya, supplied flesh, clean and disease-free potatoes of the shangi variety for this study.

3.2.2. Sample collection protocols

During the growth and harvesting of the potatoes, extra care was taken to guarantee that sound agricultural practices were followed (National Potato Council of Kenya, 2018). The potatoes were sorted by size, with tubers measuring above 60 mm in diameter being chosen (Kenya Plant Health Inspectorate Service, 2016). These were cured at room temperature (16 - 20 °C) for 5 days. After that, the tubers were exposed to varied magnetic field strengths before storage.

3.2.3. Application of magnetic fields

Magnetic fields were created by placing two Helmholtz coils (154 turns, 20 cm in radius) at a distance equal to their radii apart. The coils were fed either direct current by a variable power supply (UNILAB, Blackburn England; output: 0 -25 V; 8.5 A) or alternating current by a variable power supply (Dimmerstat, Automatic Electric Limited, Bombay, India; output: 2.16 KVA; 8 A), respectively. By adjusting the direct and alternating currents, different magnetic strengths of 1.00, 2.00, and 3.00 mT were achieved. The maximum magnetic field variations while using DC were 6%, 4%, and 4% for the 1.00, 2.00, and 3.00 mT respectively. For the AC MF, the maximum variations were 5%, 7%, and 4%. The choice of magnetic strengths was based on findings by Lysakov *et al*. (2018) and pre-experimental trials. The current and voltage were measured using a multimeter (2010 Dmm; PeakTech, Ahrensburg, Germany) (measurement error = ± 0.01 A). The amount of magnetic flux was measured using a tesla meter (S/N: 360500184889; Phywe Systems GmbH & Co. Gottingen, Germany) equipped with a Hall Effect sensor (S/N: 256500176195; Phywe Systems GmbH & Co. Gottingen, Germany) (measurement error = ± 0.01 mT). Using an electronic weighing scale (TXB6201L; Shimadzu Kyoto, Japan) (measurement error = ± 0.1 g), ten tubers were weighed and placed in a mesh net fabric with 12.5 mm diameter holes. The tuber net was hung in the centre of the Helmholtz coils by a thread linked to a wooden blackboard ruler, which was held in place by two stands on the far ends of the coils (Figure 3.1). The hanging tuber net with potatoes formed a circular shape with a diameter of 180 - 185 mm and a height of 60-65 mm. Thereafter, tubers were exposed to varied magnetic strengths for 20, 40, and 80 seconds.

3.2.4. Estimation of exposure dose

The dose of magnetic induction that was exposed to potato tubers was estimated as described by Jakubowski *et al*. (2022), using the formula;

$$D = \left(\frac{10^7}{4\pi}\right) B^2 . t_e \ [J . m^{-3}]$$

Where D = exposure dose (J m^{-3}), B = magnetic induction (T), and t_e is the exposure time (s)

For tubers that were exposed to 1.00, 2.00, and 3.00 mT, exposure dose, D ranged from 15.92 – 63.66, 63.66 – 254.65, and 143.24 – 572.96 J m^{-3} respectively.

Figure 3. 1: Experimental setup

3.2.5. Storage conditions

After exposure to MF, the potatoes were stored in two different locations (Control and commercial stores). Within the stores, tuber nets containing potatoes were placed onto plastic racks, while ensuring no contact among the nets. The control store was a pitch-black chamber with a light intensity of 0 lux, whereas the commercial store is a community store where many small-scale farmers in Molo, a sub-county in Nakuru county, store their harvested potatoes. The light intensity in the commercial store ranged from 0 to 4.2 lux with an average of 3.5 lux, as shown in Table 3.1. A data logger (EL-USB-2; Lascar Electronics Inc. Pennsylvania, USA) (measurement error = ±

0.3 °C and ± 2.2.5% for temperature and relative humidity respectively) was used to track temperature, relative humidity, and dew point in the two stores, while a digital lux meter (S/N: H20233288, Shenzhen Yowexa Sensor System Co., Ltd, Guangdong, China) (measurement error = ± 0.1 lux) was used to assess light intensities. The storage conditions of the two stores are given in Table 3.1. After two months of storage, physicochemical analyses were performed.

Table 3. 1: Temperature, dew point, relative humidity and light conditions of the stores

Store	Temperature (°C)			Dew point (°C)			Relative humidity (%)			Light (lux)			
										Daytime			Night
	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	
Control	18.0	30.0	20.0	7.2	20.8	11.7	43.5	73.5	59.1	0.0	0.0	0.0	0.0
Commercial	9.5	32.5	18.4	2.4	21.2	10.3	22.3	85.3	61.1	2.5	4.2	3.5	0.0

3.2.6. Experimental design

A 2 × 2 × 3 × 3 factorial arrangement in a completely randomized design was used. The factors investigated were the type of store (two levels; control and commercial), source of magnetic fields (two levels; DC and AC), magnetic field intensity (three levels; 1.00, 2.00, and 3.00 mT), and holding time of exposure to magnetic fields (three levels; 20, 40 and 80 seconds). However, for the sugars, only one level of holding time (80 seconds) was used. This is because, at 80 seconds of holding time, potatoes exhibited better quality characteristics such as significantly lower weight reduction and sprouting. The experiment was replicated thrice.

3.2.7. Physicochemical analyses

3.2.7.1. Specific gravity, dry matter, and starch content

The method outlined by Jarén *et al*. (2016) was used to determine specific gravity. Mass of tubers in air and in water was measured and specific gravity was expressed as:

$$Specific\ gravity = \frac{Mass\ of\ tubers\ in\ air}{Mass\ of\ tubers\ in\ air - Mass\ of\ tubers\ in\ water}$$

For the determination of the dry matter, three potatoes were randomly selected from each sample, cut into small pieces of 1 - 2 mm, and mixed thoroughly. Dry matter was then determined by

drying replicates of 10 g samples in a forced-air oven for 72 hours at a temperature of 80 °C. Starch content was obtained as described by Hassanpanah *et al*. (2011) using the equation:

$$\%\ Starch\ content = 17.546 + 119.07 \times (specific\ gravity - 1.0988)$$

Where 17.546, 119.07, and 1.0988 are constants developed after numerous experimental trials

3.2.7.2. Weight reduction, sprouting, and number of sprouts per tuber

For the evaluation of weight reduction, the final weight of tubers was measured and expressed as a percentage of the initial weight of tubers at the beginning of storage, as follows:

$$\%\ Weight\ reduction = \frac{initial\ weight\ of\ tubers - final\ weight\ of\ tubers}{initial\ weight\ of\ tubers} \times 100$$

Gachango *et al*. (2008) reported on how to determine the sprouting characteristics of potatoes. Each lot's sprouted tubers were counted and reported as a percentage proportion of the sample's total tubers. If a tuber had one visible sprout of at least 3 mm in length, it was regarded to have sprouted. To determine the number of sprouts per tuber (NST), all sprouted tubers from each lot were selected, sprouts in each tuber were counted, and the number of sprouts was averaged per the number of sprouted tubers.

$$\%\ Sprouting = \frac{No.of\ sprouted\ tubers\ in\ a\ sample}{Total\ No.of\ tubers\ in\ the\ sample} \times 100$$

$$NST = \frac{\Sigma(No.of\ sprouts\ in\ each\ sprouted\ tuber\ per\ sample)}{No.of\ sprouted\ tubers\ in\ a\ sample}$$

3.2.7.3. External and internal greening

The method outlined by Plich *et al.* (2020) was used for the evaluation of tuber greening. External tuber greening was graded on a 0 - 5 scale, with 0 indicating no greening and 5 indicating extensive greening. Internal depth of greening (hence referred to as internal greening) was measured in tubers cut longitudinally into halves on a 0 - 5 scale, with 0 indicating no greening, 1 indicating greening just below the skin, 2 indicating greening up to 2 mm, 3 indicating greening up to 5 mm, 4 indicating greening up to 10 mm, and 5 indicating greening of more than 10 mm deep.

3.2.7.4. Total sugars, reducing sugars, and non-reducing sugars

The Lane - Eynon titration methods (Lane & Eynon, 1923) were used in the determination of sugars with slight modifications. For the reducing sugars, accurately 40 – 50 g of sample was weighed and transferred into a 500 mL volumetric flask. About 100 mL of distilled water was added, followed by 10 mL of neutral lead acetate (0.527 M) solution. The solution was shaken and allowed to stand for 10 min. Potassium oxalate (0.543 M) solution was added in small amounts until there was no further precipitation and made up to volume. The solution was mixed thoroughly, filtered through Whatman No. 1 filter, and the filtrate was transferred to a 50 mL burette with an offset tip. Thereafter, titration was done against boiling Fehling's solution using methylene blue as the indicator. The reducing sugars were calculated as follows:

$$\%\ reducing\ sugars = \frac{0.25 \times V1 \times V2}{V3 \times W}$$

Where 0.25 = factor for Ferlings' solution (mg of invert sugar), V1 = titre volume of sucrose used in the standardization of the Fehling's solution, V2 = dilution volume of the sample, V3 = titre volume of the clarified sample solution required for the Fehling's solution, and W = weight of the sample

For the total sugars, an aliquot of 50 mL of the clarified, de-leaded filtrate was pipetted to a 100 mL volumetric flask. Exactly 5 mL of conc. HCL was added and allowed to stand at room temperature, after which, the solution was neutralised with conc. NaOH followed by 0.1 N NaOH with phenolphthalein used as the end point indicator. This was made up to volume and transferred to a 50 mL burette with an offset tip, after which titration was done against boiling Fehling's solution. Total sugars were then calculated using the formula;

$$\%\ total\ sugars = \frac{0.5 \times V1 \times V2}{V4 \times W}$$

Where 0.5 = factor for Ferlings' solution (mg of invert sugar) with double dilution, V4 = titre volume of the acid hydrolyzed sample solution required for Fehling's solution

Non-reducing sugars were obtained as the difference between total sugars and non-reducing sugars

$$\%\ non\ reducing\ sugars = \%\ total\ sugars - \%\ reducing\ sugars$$

3.2.8 Statistical analyses

Data were subjected to the Kolmogorov-Smirnov test to check for normality of distribution, using PROC UNIVARIATE procedure of the Statistical Analysis System (SAS) software version 9.4 (SAS Institute Inc., Cary, NC, USA). Analysis of variance (ANOVA) was carried out to investigate the effect of type of store, source of magnetic fields, magnetic field intensity and holding time on the physical chemical properties using the General Linear Model (PROC GLM) procedure. Homogeneity of variance was checked using the HOVTEST = LEVENE procedure. Separation of means was done using the Tukey's HSD (honestly significant difference) test at $\rho < 0.05$ level of significance.

3.3. Results and Discussion

3.3.1. Normality test and homogeneity of variance

The results from Kolmogorov-Smirnov and Levene tests showed normality of data distribution and variances that were homogeneous respectively at $\rho < 0.05$ level of significance. These results allowed for the data to be subjected to analysis of variance

3.3.2. Specific gravity, dry matter, starch, and weight reduction

Effects of the type of store on specific gravity, dry matter, starch content and weight reduction are shown in Figure 3.2. Type of store did not have a significant effect on specific gravity and starch, although the potatoes that were stored in the control store had a relatively higher specific gravity and starch than those that were stored in the commercial store. Storing potatoes in the control store resulted in significantly ($F_{1,19} = 203.47$, $\rho < 0.0001$) higher dry matter content than those that were stored in the commercial store. However, significant ($F_{1,19} = 7.63$, $\rho = 0.0079$) higher weight reduction was recorded for the potatoes that were stored in the commercial store. Exposing tubers to AC MF gave significant higher specific gravity ($F_{1,19} = 11.80$, $\rho = 0.0012$), dry matter ($F_{1,19} = 163.19$, $\rho < 0.0001$) and starch ($F_{1,19} = 11.81$, $\rho = 0.0012$), but lower weight reduction ($F_{1,19} = 42.94$, $\rho < 0.0001$) than DC MF (Figure 3.2). Magnetic intensity of 3.00 mT resulted into significant lower specific gravity ($F_{2,19} = 5.89$, $\rho = 0.0050$) and starch ($F_{2,19} = 5.86$, $\rho = 0.0051$) than intensities of 0.00, 1.00. and 2.00 mT. The 0.00 mT was the un-exposed treatment that was stored for the same period as the exposed treatments. Increasing the magnetic field intensity to 3.00 mT did not show a significant difference in dry matter with the 0.00 and 1.00 mT, but resulted

into a weight reduction that was significantly lower ($F_{2,19}$ = 8.52, ρ = 0.0006) than all other intensities. Increasing the holding time from 20 to 80 seconds resulted in a significant reduction in specific gravity, starch, and weight reduction, but higher dry matter at a 95% confidence level.

An ideal *ware* potato store is one that prolongs the dormancy of tubers while maintaining the quality of potatoes as desired by the processor. In this study, MF either initiated or suppressed physiological, metabolic, and chemical pathways of potatoes under storage, thus impacting their dormancy and quality. It is plausible that MF hindered the metabolic activities of the tubers thereby reducing their rates of respiration. When potatoes respire, sugars are broken down to liberate energy, carbon dioxide, and water. As a result, relative proportions of dry matter of the tuber decrease with a subsequent decrease in the mass of tubers. (Singh *et al*., 2020). This indicates why there was a remarkable increase in relative dry matter and subsequently lower weight reduction in potatoes that were exposed to higher magnetic intensities of 2.00 and 3.00 mT than potatoes that were not exposed to any MF. According to Suttle (2007), dormancy in potatoes is accompanied by low net synthesis of ribonucleic acid (RNA), which increases after the exit of dormancy and the onset of sprouting. Consequently, subjecting potatoes to MF for 80 seconds ensured more contact time, which may have reduced the rates of RNA synthesis. This maintained dormancy for a long storage time, and as a result, more dry matter and low weight reduction.

There was no significant difference between potatoes that were exposed to DC MF and those exposed to AC MF and stored in the control store on specific gravity (ρ = 0.5005), starch (ρ = 0.5003), and weight reduction (ρ = 0.9987). For the commercial store, potatoes that were exposed to DC MF differed from those that were exposed to AC MF on specific gravity (ρ = 0.0060), starch (ρ = 0.0060), and weight reduction (ρ < 0.0001) (Table 3.2). Subjecting tubers to different levels of magnetic field intensities (1.00, 2.00. and 3.00 mT) and storing them in the control store resulted in higher specific gravity, dry matter, and starch than tubers that were not subjected to any level of MF (0.00 mT) and stored in the same store at 95% level of confidence. It was noted that exposing potatoes to 3.00 mT of MF and storing them in either the control or the commercial store resulted in a significant (ρ < 0.05) lower weight reduction than potatoes that were not exposed to MF and stored in either of the two stores (Table 3.2).

The interaction effects between the source of magnetic field and magnetic field intensity on specific gravity, dry matter, starch content, and weight reduction are presented in Table 3.3.

Exposing potatoes to DC MF of 1.00 mT resulted in significantly higher specific gravity ($\rho < 0.0001$) and starch ($\rho < 0.0001$), but lower dry matter ($\rho < 0.0001$) than with 3.00 mT of the same source. On the other hand, exposing potatoes to AC MF of 3.00 mT led to significantly higher specific gravity ($\rho = 0.0003$) and starch content ($\rho = 0.0015$), but lower dry matter ($\rho < 0.0001$) than with 1.00 mT.

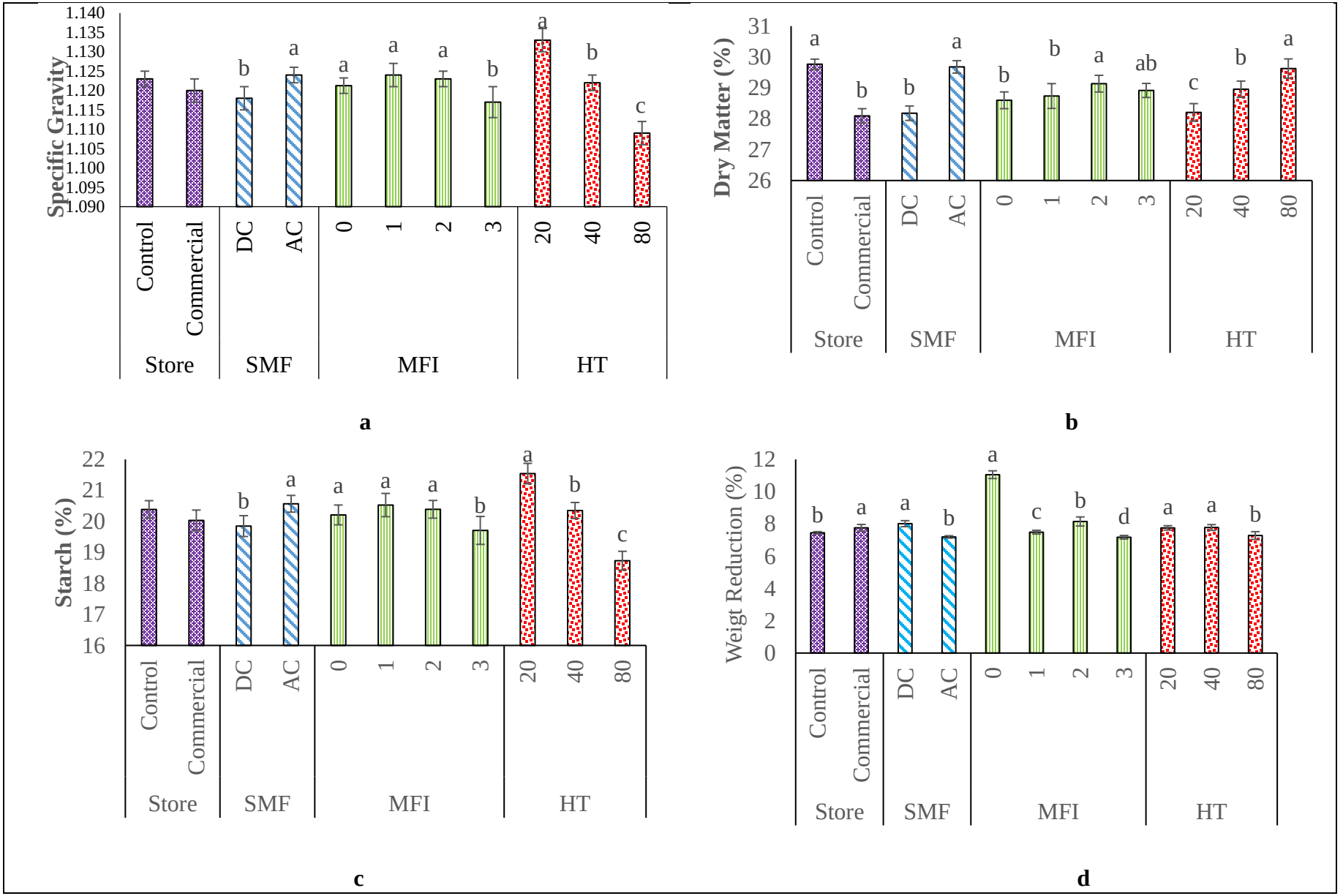
Specific Gravity
1.140
1.135
1.130
1.125
1.120
1.115
1.110
1.105
1.100
1.095
1.090
a b a a a a b a b c
Control Commercial DC AC 0 1 2 3 20 40 80
Store SMF MFI HT
a
Dry Matter (%)
31
30
29
28
27
26
a b b a b b a ab c b a
Control Commercial DC AC 0 1 2 3 20 40 80
Store SMF MFI HT
b
Starch (%)
22
21
20
19
18
17
16
b a a a a b a b c
Control Commercial DC AC 0 1 2 3 20 40 80
Store SMF MFI HT
c
Weigt Reduction (%)
12
10
8
6
4
2
0
b a a b a c b d a a b
Control Commercial DC AC 0 1 2 3 20 40 80
Store SMF MFI HT
d

Figure 3. 2: specific gravity (a), dry matter (b), starch (c), and weight reduction (d) of potatoes after 8 weeks of storage as influenced by different types of store (control and commercial), source of magnetic field (SMF) (direct current, DC, and alternating current, AC) magnetic field intensity (MFI) (0, 1, 2, and 3 mT) and holding time (HT) (20, 40 and 80 s).

Values are presented as means ± standard error of the mean. The same letters above the means within a particular group/variable show that the levels are not significantly different at $\rho < 0.05$.

Table 3. 2: Effects of store, Source and Intensity of Magnetic Fields, and the Holding Time on the Parameters of Interest.

Type of Interaction	Specific Gravity	Dry Matter	Starch (%)	Weight Reduction (%)	Internal Greening	External Greening	Sprouting (%)	No. of Sprouts per tuber
Store*SMF								
Con*DC	1.12±0.00	29.15±0.15^{b}	20.18±0.39^{ab}	7.44±0.11^{b}	0.00±0.00^{b}	0.28±0.11^{b}	77.22±2.11^{c}	4.06±0.14^{b}
Con*AC	1.12±0.00	30.38±0.23^{a}	20.59±0.41^{a}	7.47±0.09^{b}	0.06±0.06^{b}	0.28±0.11^{b}	73.33±2.29^{c}	4.68±0.12^{a}
Com*DC	1.12±0.01	27.20±0.30^{c}	19.52±0.55^{b}	8.60±0.30^{a}	1.22±0.10^{a}	2.44±0.12^{a}	83.33±2.14^{b}	2.58±0.07^{d}
Com*AC	1.12±0.00	28.98±0.24^{b}	20.54±0.36^{a}	6.92±0.09^{c}	1.22±0.10^{a}	2.67±0.11^{a}	87.78±2.37^{a}	3.05±0.08^{c}
Store*MFI								
Con*0	1.10±0.00^{c}	27.55±0.74^{b}	17.62±0.61^{c}	8.66±0.43^{b}	0.00±0.00^{d}	1.00±0.00^{c}	100.00±0.00^{a}	4.25±0.18^{b}
Con*1	1.13±0.00^{a}	29.78±0.38^{a}	21.13±0.38^{a}	7.45±0.11^{cd}	0.00±0.00^{d}	0.17±0.11^{d}	81.67±2.07^{c}	4.65±0.11^{a}
Con*2	1.12±0.00^{b}	29.86±0.23^{a}	20.18±0.37^{ab}	7.76±0.13^{c}	0.00±0.00^{d}	0.42±0.15^{d}	73.33±2.84^{de}	4.31±0.19^{ab}
Con*3	1.12±0.01^{ab}	29.66±0.27^{a}	19.85±0.64^{b}	7.15±0.11^{d}	0.08±0.08^{d}	0.25±0.13^{d}	70.83±2.29^{e}	4.16±0.21^{b}
Com*0	1.13±0.00^{a}	27.65±0.68^{b}	21.15±0.33^{a}	12.44±0.19^{a}	2.00±0.00^{a}	4.00±0.00^{a}	95.00±1.34^{b}	4.35±0.28^{ab}
Com*1	1.12±0.01^{ab}	27.69±0.58^{b}	19.93±0.61^{b}	7.53±0.20^{cd}	1.00±0.00^{c}	2.58±0.15^{b}	90.00±2.13^{c}	2.88±0.09^{c}
Com*2	1.12±0.00^{b}	28.42±0.40^{b}	20.61±0.44^{ab}	8.55±0.53^{b}	1.33±0.12^{b}	2.50±0.15^{b}	88.33±2.41^{b}	2.76±0.11^{c}
Com*3	1.12±0.01^{ab}	28.17±0.21^{b}	19.57±0.67^{b}	7.20±0.20^{d}	1.33±0.12^{b}	2.58±0.15^{b}	78.33±2.71^{cd}	2.81±0.14^{c}
Store*HT								
Con*20	1.13±0.00^{a}	29.09±0.20^{c}	21.63±0.41^{a}	7.66±0.08^{a}	0.08±0.08^{c}	0.08±0.08^{b}	81.67±1.67^{bc}	4.50±0.19^{a}
Con*40	1.12±0.00^{bc}	29.71±0.27^{b}	20.53±0.40^{bc}	7.67±0.10^{a}	0.00±0.00^{c}	0.25±0.13^{b}	76.67±2.56^{c}	4.37±0.20^{a}
Con*80	1.11±0.00^{d}	30.50±0.26^{a}	19.00±0.36^{d}	7.03±0.08^{b}	0.00±0.00^{c}	0.50±0.15^{b}	67.50±2.18^{d}	4.23±0.15^{a}
Com*20	1.13±0.00^{ab}	27.32±0.40^{e}	21.46±0.53^{ab}	7.85±0.26^{a}	1.00±0.00^{b}	2.50±0.15^{a}	93.33±1.42^{a}	2.98±0.10^{b}
Com*40	1.12±0.00^{c}	28.20±0.34^{d}	20.18±0.35^{c}	7.89±0.35^{a}	1.00±0.00^{b}	2.42±0.15^{a}	85.00±2.61^{b}	2.94±0.10^{b}

Com*80	1.11±0.00^{d}	28.75±0.45^{cd}	18.46±0.50^{d}	7.54±0.47^{ab}	1.67±0.14^{a}	2.75±0.13^{a}	78.33±2.41^{c}	2.53±0.09c

Values are presented as means ± standard error of the mean. Means followed by the same letters in a column, and for each interaction are not significantly different at ρ < 0.05. SMF; source of magnetic fields, MFI; magnetic field intensity, HT; holding time, Con; Control Store, Com; Commercial store, DC; Direct current, AC; Alternating current.

The interaction effect between the magnetic field intensity and holding time is given in Table 3.3. The least weight reduction was observed for the potatoes that were treated with 3.00 mT and held for 80 s, while the least low starch content was recorded for the potatoes that were subjected to 1.00, 2.00, and 3.00 mT for 80 seconds.

Dry matter contents recorded in the present study (27 – 30%) are higher than what Abong *et al*. (2010) and Wekesa (2014) reported (20– 23%). The influence of MF on dry matter of potato tubers has also been reported by Nassar *et al*. (2020). Specific gravity values reported in this work agree with what Gikundi *et al*. (2021) found to be the specific gravity of shangi potato variety (~ 1.12) but differ with the results of Wekesa (2014) who reported specific gravity of about 1.07 of the same potato variety. Weight reduction can also be caused by excessive water loss from the tubers. This is especially so when the periderm of the tuber is weak, coupled with the higher drying power of the surrounding air (Pinhero *et al*., 2009). This may establish why there was more weight reduction in potatoes that were stored in the commercial store than those that were stored in the control store. This is due to the fact that minimum levels of dew point and relative humidity were observed in the commercial store. This resulted in increased water loss from the tubers. In addition, exposing potatoes to MF may have stiffened the periderm of tubers thereby reducing water loss. This could explain why there was less weight reduction in tubers that were exposed to varying intensities of MF than those that were not exposed to any fields. Weight loss values reported in the present work are far much lower than what Lysakov *et al*. (2018) reported after exposure of potatoes to both DC and AC MF. This could be attributed to the higher magnetic intensities and holding times that have been used in the present study. However, the weight loss values in the current study are slightly higher than those reported by Lysakov *et al*. (2021), and this could be due to the higher storage temperatures that were used in the current research.

Dry matter is said to be the most critical factor in determining the quality of potatoes for processing, where potatoes with high dry matter are preferred. In addition, specific gravity provides a quick indicator of the quality of potatoes after storage. It also gives some insight into the process quality of potatoes for various products; where potatoes with low specific gravity are preferred for canning and boiling, while those with high specific gravity are suitable for chipping, frying, baking, and mashing (Ndunguste *et al.*, 2019). Therefore, exposing potatoes to AC MF and storing them in the control store or exposing potatoes to either DC or AC MF for 80 s and storing them in the control store would result in potatoes with the high dry matter. Additionally, exposing

potatoes to AC and DC MF would be suitable while targeting potatoes with high and low specific gravities respectively. Also, exposing potatoes to MF of 3.00 mT through either AC or DC would lead to a low specific gravity of stored potatoes, in the event that the potatoes are destined for canning.

It is desired that potatoes experience low weight reduction after storage. This will not only maximize profits but will also ensure that processed products are of good quality. The acceptable weight loss of potatoes is less than 10% (Ezekiel *et al*., 2004). Most of our study treatments had a weight loss of less than 10%. However, potatoes that were not exposed to MF had 12% weight loss after storage, which was significantly higher than potatoes that were exposed to MF of 1.00, 2.00, and 3.00 mT (7.5, 8.2, and 7.2 %). It is also worth noting that exposure to AC MF gave a significantly lower weight reduction in potatoes than the use of DC MF.

3.3.3. Internal greening, external greening, sprouting, and number of sprouts per tuber

The type of store had a remarkable influence on the greening of potatoes under storage where the commercial store resulted in potatoes with significant higher internal greening ($F_{1,19} = 775.39$, $\rho < 0.0001$), external greening ($F_{1,19} = 456.46$, $\rho < 0.0001$) as well as sprouting ($F_{1,19} = 394.17$, $\rho < 0.0001$), but lower number of sprouts per tuber ($F_{1,19} = 75.41$, $\rho < 0.0001$) than the control store (Figure 3.3). The Source of magnetic fields did not influence the greening and sprouting of potatoes. However, AC MF resulted in a significantly higher number of sprouts per tuber ($F_{1,19} = 48.69$, $\rho < 0.0001$) than DC MF (Figure 3.3). Increasing the magnetic field intensity to 3.00 mT resulted in a significant reduction in the internal and external greening, sprouting, and the number of sprouts per tuber than the control (0.00 mT) at a 95% level of confidence. Additionally, an increase in the level of magnetic field intensity from 1.00 to 3.00 mT led to a subsequent decrease in sprouting and the number of sprouts per tuber that was significant at a 95% level of significance. Exposing potatoes to MF at a higher holding time of 80 s gave significantly higher internal and external greening than holding times of 20 and 40 s. However, 80 s of holding time resulted in significantly lower sprouting and the number of sprouts per tuber than both the 20 and 40 s of holding time at a 95% confidence level.

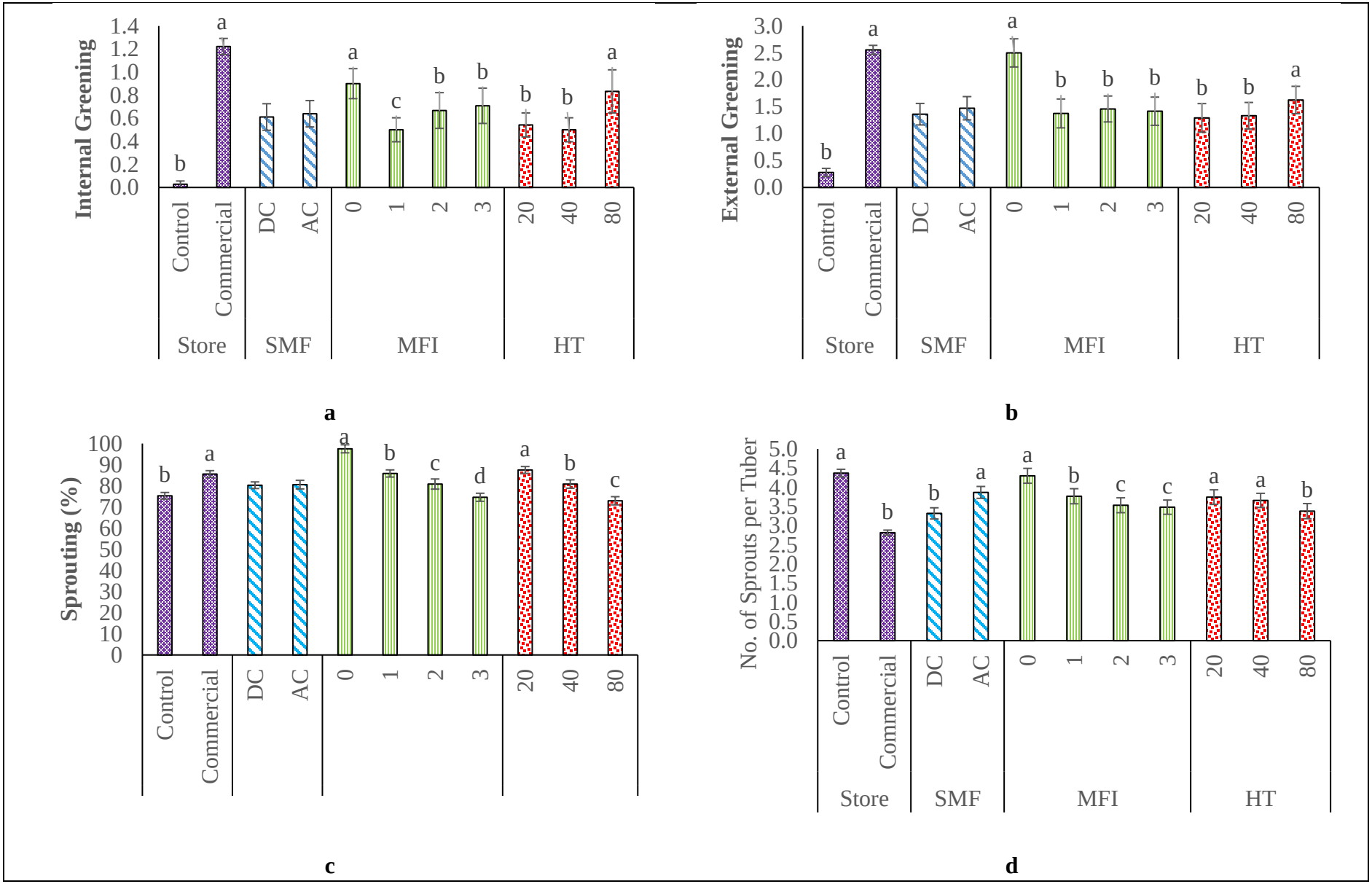
Internal Greening
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
b a b a c b b b b b a
Control Commercial DC AC 0 1 2 3 20 40 80
Store SMF MFI HT
a
External Greening
3.0
2.5
2.0
1.5
1.0
0.5
0.0
b a b a b b b b b a
Control Commercial DC AC 0 1 2 3 20 40 80
Store SMF MFI HT
b
Sprouting (%)
100
90
80
70
60
50
40
30
20
10
0
b a b a a b c d a b c
Control Commercial DC AC 0 1 2 3 20 40 80
c
No. of Sprouts per Tuber
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
a b b a a b c c a a b
Control Commercial DC AC 0 1 2 3 20 40 80
Store SMF MFI HT
d

Figure 3. 3: Internal Greening (a), external Greening (b), sprouting (c) and number of Sprouts per tuber (d) of potatoes after 8 weeks of storage as influenced by different types of store (control and commercial), source of magnetic field (SMF) (direct current, DC, and alternating current, AC) magnetic field intensity (MFI) (0, 1, 2, and 3 mT), and holding time (HT) (20, 40 and 80 s).
Values are presented as means ± standard error of the mean. The same letters above the means within a particular group/variable show that the levels are not significantly different at $\rho < 0.05$.

Table 3. 3: Effects of Source and Intensity of Magnetic Fields, and the Holding Time on the Parameters of Interest.

Type of interaction	Specific Gravity	Dry Matter (%)	Starch (%)	Weight Reduction (%)	Internal Greening	External Greening	Sprouting (%)	No. of Sprouts per tuber
SMF*MFI								
DC*1	1.13±0.00^{a}	27.32±0.46^{d}	21.56±0.57^{a}	7.69±0.21^{b}	0.50±0.15^{b}	1.42±0.40	83.33±1.88^{ab}	3.67±0.31^{a}
DC*2	1.12±0.00^{b}	28.26±0.32^{c}	19.58±0.39^{b}	8.96±0.42^{a}	0.67±0.23^{a}	1.50±0.29	82.50±2.79^{ab}	3.27±0.21^{b}
DC*3	1.11±0.00^{c}	28.96±0.30^{b}	18.41±0.39^{c}	7.41±0.16^{bc}	0.67±0.23a	1.17±0.37	75.00±2.89^{c}	3.03±0.21^{b}
AC*1	1.12±0.00^{b}	30.16±0.32^{a}	19.49±0.27^{b}	7.29±0.09^{bc}	0.50±0.15^{b}	1.33±0.38	88.33±2.71^{a}	3.87±0.25^{a}
AC*2	1.13±0.00^{a}	30.01±0.26^{a}	21.20±0.27^{a}	7.34±0.16^{bc}	0.67±0.25^{a}	1.42±0.40	79.17±3.98^{bc}	3.80±0.32^{a}
AC*3	1.13±0.00^{a}	28.87±0.36^{b}	21.01±0.63^{a}	6.95±0.13^{c}	0.75±0.22^{a}	1.67±0.37	74.17±2.60^{c}	3.93±0.25^{a}
SMF*HT								
DC*20	1.13±0.01^{ab}	27.42±0.42^{e}	21.28±0.54^{ab}	8.19±0.18^{a}	0.50±0.15^{b}	1.67±0.37	87.50±1.79^{a}	3.45±0.23^{b}
DC*40	1.12±0.00^{cd}	28.28±0.32^{d}	20.05±0.40^{cd}	8.12±0.31^{a}	0.50±0.15^{b}	1.25±0.31	81.67±2.07^{ab}	3.32±0.24^{b}
DC*80	1.11±0.00^{e}	28.84±0.39^{cd}	18.22±0.45^{e}	7.74±0.44^{ab}	0.83±0.27^{a}	1.67±0.38	71.67±2.07^{d}	3.19±0.30^{b}
AC*20	1.14±0.00^{a}	28.99±0.22^{c}	21.81±0.39^{a}	7.31±0.11^{bc}	0.58±0.15^{b}	1.42±0.40	87.50±2.79^{a}	4.04±0.19^{a}
AC*40	1.13±0.00^{bc}	29.63±0.32^{b}	20.65±0.32^{bc}	7.44±0.12^{b}	0.50±0.15^{b}	1.42±0.40	80.00±3.48^{bc}	3.99±0.15^{a}
AC*80	1.11±0.00^{de}	30.42±0.38^{a}	19.25±0.37^{de}	6.83±0.07^{c}	0.83±0.27^{a}	1.58±0.36	74.17±3.36^{cd}	3.57±0.26^{b}
MFI*HT								
1*20	1.14±0.01^{a}	27.86±0.68^{f}	21.88±0.69^{a}	7.90±0.23^{abc}	0.50±0.19^{b}	1.38±0.53^{ab}	90.00±2.67^{a}	3.68±0.30^{ab}
1*40	1.12±0.00^{abc}	28.96±0.64^{bcde}	20.49±0.51^{abc}	7.50±0.13^{bcd}	0.50±0.19^{b}	1.25±0.49^{ab}	87.50±2.50^{abc}	3.95±0.35^{a}
1*80	1.11±0.00^{cd}	29.39±0.74^{abc}	19.21±0.37^{cd}	7.07±0.12^{de}	0.50±0.19^{b}	1.50±0.42^{ab}	80.00±2.67^{cde}	3.68±0.40^{ab}
2*20	1.13±0.00^{a}	28.45±0.45^{def}	21.53±0.25^{a}	7.90±0.27^{abc}	0.50±0.19^{b}	1.13±0.44^{b}	88.75±2.95^{ab}	3.61±0.36^{ab}
2*40	1.12±0.00^{abc}	29.17±0.41^{abcd}	20.49±0.32^{abc}	8.55±0.51^{a}	0.50±0.19^{b}	1.38±0.38^{ab}	81.25±3.98^{bc}	3.74±0.34^{ab}
2*80	1.11±0.00^{cd}	29.79±0.43^{a}	19.15±0.47^{cd}	8.01±0.67^{ab}	1.00±0.38^{a}	1.88±0.44^{a}	72.50±3.66^{ef}	3.25±0.34^{b}
3*20	1.13±0.01^{ab}	28.86±0.24^{f}	21.21±0.71^{ab}	7.47±0.23^{bcde}	0.63±0.18^{b}	1.38±0.46^{ab}	83.75±2.63^{abc}	3.95±0.37^{a}

3*40	1.12±0.00^{bc}	28.74±0.30^{cde}	20.07±0.53^{bc}	7.29±0.10^{cde}	0.50±0.19^{b}	1.38±0.46^{ab}	73.75±1.83^{def}	3.28±0.27^{b}
3*80	1.10±0.01^{d}	29.69±0.47^{ab}	17.84±0.62^{d}	6.77±0.09^{e}	1.00±0.38^{a}	1.50±0.50^{ab}	66.25±1.83^{f}	3.21±0.30^{b}

Values are presented as means ± standard error of the mean. Means followed by the same letters in a column, and for each interaction are not significantly different at ρ < 0.05. SMF; source of magnetic fields, MFI; magnetic field intensity, HT; holding time; DC; direct current, AC; Alternating current

There was no significant difference in internal greening, external greening, and sprouting between potatoes that were exposed to DC and AC MF and stored in the control store (Table 3.2). However, storing potatoes in the control store after exposing them to AC MF resulted in a significantly higher number of sprouts per tuber ($\rho < 0.0001$) than those that were exposed to DC MF. Similarly, there was no difference between exposing potatoes to DC MF and AC MF and storing them in the commercial store on internal and external greening (Table 3.2). Additionally, potatoes that were exposed to AC MF and stored in the commercial store had significantly higher sprouting ($\rho = 0.0499$) and the number of sprouts per tuber ($\rho = 0.0006$) than those exposed to DC MF and stored in the commercial store. Exposing tubers to different levels of magnetic intensities (1.00, 2.00, and 3.00 mT) and storing them in the commercial store resulted in significant lower degrees of internal and external greening, sprouting, and the number of sprouts per tuber than those tubers that were not exposed to MF and stored in the commercial store at a 95% level of confidence. However, the trend was not definite for those tubers that were stored in the control store. The interaction effects between the source of magnetic fields and magnetic field intensity on internal greening, external greening, sprouting, and the number of sprouts per tuber are given in Table 3.3. A major observation was made on the sprouting, where for each source of magnetic fields, increasing the magnetic intensity from 1.00 to 3.00 mT led to a significant decrease in sprouting at a 95% level of confidence. However, there was no notable difference in external greening. The interaction effect between the magnetic field intensity and holding time on sprouting is given in Table 3.3. The least sprouting was observed for the potatoes that were treated with 3.00 mT of MF for 80 seconds.

Potato greening occurs when chlorophyll pigments develop in chloroplasts, more so when tubers are exposed to light (Plich *et al*., 2020). This could explain why potatoes that were stored in the commercial store developed greening (both internal and external greening) to a greater extent, given that this store had exposure to light during the daytime to the tune of 3.5 lux. In plants, cryptochrome – which regulates light-controlled genes and thus greening in potatoes, is believed to be the magnetosensor (Maffei, 2014). Thus, exposing tubers to magnetic fields may have degraded protein of the light-activated form of the cryptochrome, which slowed down the circadian clock of the tubers. As a result, there was significantly less greening in tubers that were exposed to MF than those that were not magnetized. However, there was no difference in both internal and external greening as a result of exposure to either DC or AC MF. This could imply that the potato

photo-receptor was excited to the same magnitude by both DC and AC magnetic fields. In addition to cryptochrome, plants have another photoreceptor known as phytochrome that is actively involved in the regulation of chlorophyll, which is a green colouring pigment. (Okamoto *et al*., 2020). Phytochrome has also been shown to influence the circadian clock in potatoes and thus altering its activity will have an impact on the physiological and metabolic activities of the potato tuber (Yanovsky *et al*., 2000). It is therefore plausible that exposing potatoes to magnetic fields slowed down the production of chlorophyll by altering the sensitivity of phytochromes, which in effect slowed down the circadian clock, and as a result, these potatoes experienced reduced internal and external greening.

Greening of potatoes reduces their market value. It is also believed that harmful toxins known as glycoalkaloids develop in greened tubers (Okamoto *et al*., 2020). Thus, it is desired to reduce potato greening as much as possible. Findings from this study have demonstrated that both internal and external greening can be reduced to a significant level when potatoes are exposed to either DC or AC MF for 40 seconds before storage. This is because, at 80 seconds of holding time, tubers experienced significantly higher internal and external greening than both the 20 and 40 seconds, with the 40 seconds recording relatively lower levels of greening than at 20 seconds. However, to achieve near nil greening, potatoes should be stored in a dark store with a light intensity of 0 lux.

Sprouting of potatoes occurs with the onset of cell division within the tuber (Suttle, 2007). In the current study, an increase in magnetic field intensity is attributed to a subsequent increase in arresting of cell division, as a result of the inactivity of the meristems. This could therefore demonstrate why there was a significant decrease in the sprouting of potatoes, and the number of sprouts per tuber, as magnetic field intensity was increased linearly from 0.00 to 3.00 mT. Plant hormones play a key role in the activation or suppression of sprouting in potatoes. Increasing magnetic field intensity (0.00 – 3.00 mT) and holding time (20 – 80 s) could have favoured the production and sustenance of abscisic acid, which promotes dormancy (Alamar *et al*., 2017), leading to a reduction in sprouting as well as the number of sprouts per tuber. According to Mani and Hannachi (2015), auxin and gibberellins promote vascular development that favours the growth of sprouts. Thus, it is likely that potatoes that were exposed to AC MF had their gibberellins and auxin hormones excited more than those that were exposed to DC MF, and thus the higher number of sprouts per tuber in the tubers that were exposed to AC MF. The influence of MF on the development of sprouts in a potato tuber has also been documented by Jakubowski (2020),

who reported that the number of shoots in a potato plant is modified by MF. In addition, Bahadir *et al*. (2020) reported that the emergence of potato sprouts was slowed by the use of MF. Sprouting of potatoes has serious implications such as reduced market prices, higher weight loss, reduced nutritional value, and development of toxins (Zhang *et al*., 2018). Therefore, delaying sprouting while maintaining the quality of potatoes is the utmost goal of storing ware potatoes. Exposing potatoes to MF of 3.00 mT for 80 seconds before storage has shown a remarkable reduction in the spouting of potatoes as well as the number of sprouts per tuber. These findings contribute to the recent identification of MF as one of the greatest solutions for potato storage (Gong *et al*., 2021).

3.3.4. Total sugars, reducing sugars, and non-reducing sugars

The type of store did not have a significant influence on total sugars but affected reducing sugars and non-reducing sugars. The potatoes that were stored in the commercial store exhibited significantly higher reducing sugars ($F_{1,9}$ = 485.57, ρ = 0.0021) and lower non-reducing sugars ($F_{1,9}$ = 26.60, ρ = 0.0356) than those that were stored in the control store (Figure 3.4a). Exposing potatoes to DC MF resulted into higher levels of total sugars ($F_{1,9}$ = 333.26, ρ = 0.0030), reducing sugars ($F_{1,9}$ = 38.12, ρ = 0.0252) and non-reducing sugars ($F_{1,9}$ = 505.03, ρ = 0.0020) than those that were exposed to AC MF (Figure 3.4b). Effects of magnetic field intensities on sugars are given in Figure 3.4c. There was no significant difference in total sugars and reducing sugars between potatoes that were exposed to 1.00 and 2.00 mT and those that were not exposed to any magnetic fields (0.00 mT) and stored in either the control or commercial store at a 95% level of confidence. Low amount of reducing sugars was observed in potatoes that were exposed to 3.00 mT (RS = 0.33 %) and this was significant (ρ < 0.05) than in those that were not exposed to any MF and stored in either the control (RS = 0.42 %) or the commercial store (RS = 0.45 %), as well as those that were exposed to 1.00 (RS = 0.43%) and 2.00 mT (RS = 0.39 %). Low values of non-reducing sugars were reported in potatoes that were not exposed to MF and stored either in the control (NRS = 1.49 %) or the commercial store (NRS = 1.44 %) and these were significant at a 95% level of confidence.

The interaction effects of main factors on sugars are shown in Table 3.4. Potatoes that were exposed to AC MF and stored in either the control or the commercial store had significantly lower total sugars and non-reducing sugars than those that were exposed to DC MF and stored in either of the stores ρ < 0.05. Notably, exposing potatoes with either DC or AC MF, and storing them in

the control store gave lower amounts of reducing sugars than those that were stored in the commercial store with the same treatments.

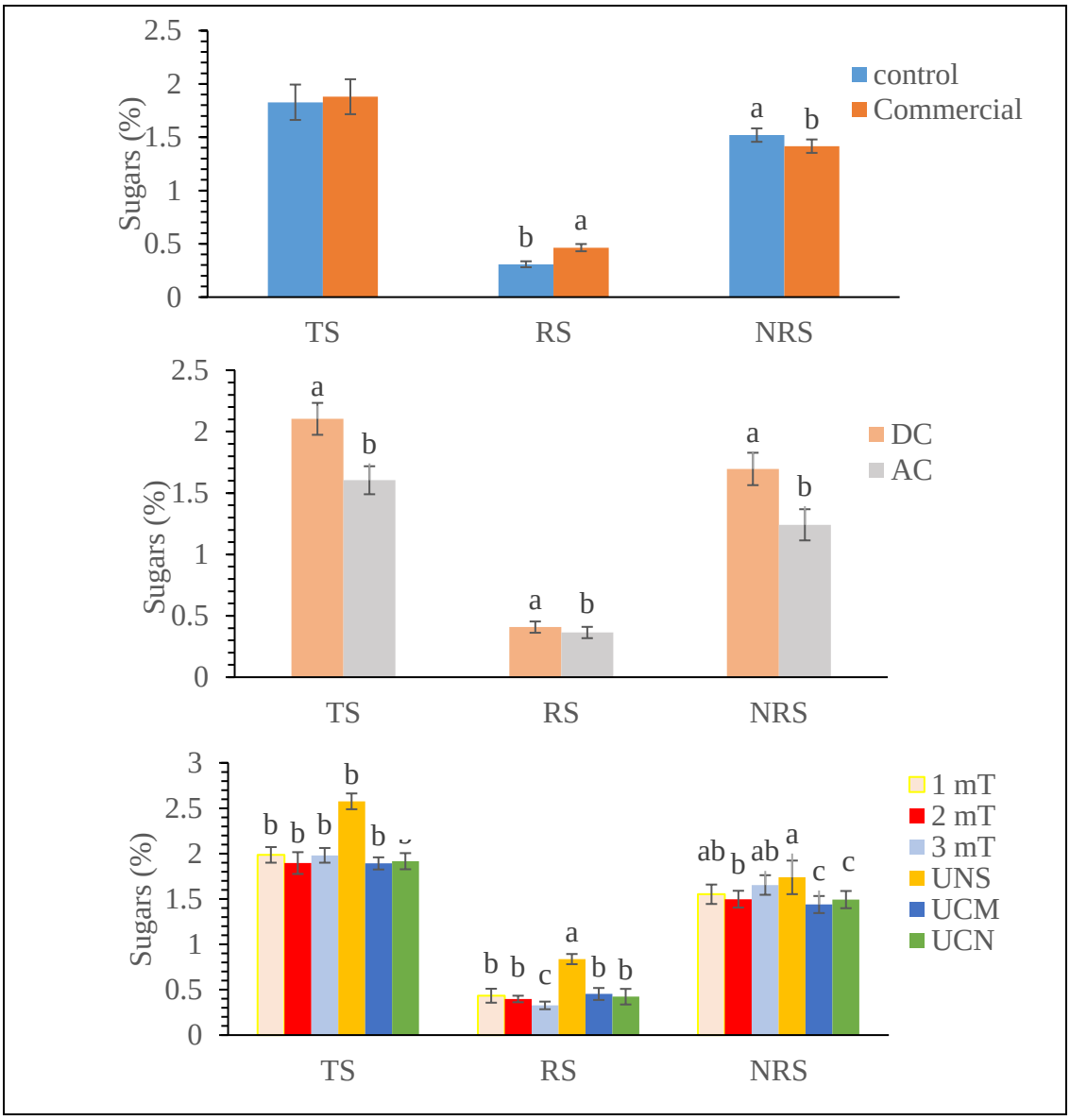

Figure 3. 4: Total sugars (TS), reducing sugars (RS) and non-reducing sugars (NRS) of potatoes as influenced by the type of store (control and commercial) (a), source of magnetic field (direct current, DC and alternating current, AC) (b) and magnetic field intensity (1, 2 and 3 mT) (c). UNS = Un-exposed to magnetic fields and not stored; UCM = Un-exposed to magnetic fields and stored in commercial store; UCN = Un-exposed to magnetic fields and stored in the control store. Values are presented as means ± standard error of the mean. The same letters above the means within a particular group of sugars show that the levels are not significantly different at $\rho < 0.05$.

Table 3. 4: Effects of two-level interactions; type of store vs source of magnetic field (store*SMF), type of store vs magnetic field intensity (store*MFI), and source of magnetic field vs magnetic field intensity (SMF*MFI) on total sugars, reducing sugars and non-reducing sugars

Two-factor interaction	Total Sugars (%)	Reducing Sugars (%)	Non-Reducing Sugars (%)
Store*SMF			
Control*DC	2.09±0.10^{a}	0.34±0.04^{b}	1.75±0.07^{a}
Control*AC	1.56±0.24^{b}	0.27±0.04^{b}	1.29±0.27^{b}
Commercial*DC	2.11±0.27^{a}	0.47±0.07^{a}	1.64±0.28^{a}
Commercial*AC	1.65±0.08^{b}	0.46±0.03^{a}	1.19±0.06^{b}
Store*MFI			
Control*0	1.92±0.09^{ab}	0.42±0.09^{bc}	1.49±0.35^{ab}
Control*1	2.06±0.13^{a}	0.33±0.09^{cd}	1.73±0.04^{a}
Control*2	1.66±0.55^{b}	0.34±0.01^{cd}	1.32±0.55^{bc}
Control*3	1.77±0.13^{ab}	0.26±0.02^{d}	1.52±0.11^{ab}
Commercial*0	1.29±0.07^{c}	0.45±0.07^{ab}	0.84±0.09^{d}
Commercial*1	1.92±0.14^{ab}	0.54±0.07^{a}	1.38±0.07^{bc}
Commercial*2	2.13±0.48^{a}	0.45±0.04^{ab}	1.68±0.52^{a}
Commercial*3	1.59±0.08^{b}	0.397±0.01^{c}	1.19±0.08c
SMF*MFI			
DC*1	2.12±0.06^{ab}	0.51±0.10^{a}	1.61±0.16^{b}
DC*2	2.41±0.20^{a}	0.38±0.04^{bc}	2.03±0.16^{a}
DC*3	1.78±0.12^{bc}	0.34±0.06^{bc}	1.45±0.17^{bc}
AC*1	1.85±0.08^{bc}	0.36±0.11^{bc}	1.50±0.19^{bc}
AC*2	1.38±0.27^{d}	0.42±0.08^{ab}	0.96±0.20^{d}
AC*3	1.58±0.07^{cd}	0.32±0.09^{c}	1.26±0.15^{c}

Values are presented as means ± standard error of the mean. Means followed by the same letters in a column, and for each interaction are not significantly different at $\rho < 0.05$. SMF; source of magnetic fields, MFI; magnetic field intensity, DC; Direct current, AC; Alternating current

There was no definite trend in the interaction effects of the type of store and magnetic field intensity on sugars. However, the observations were as follows: the highest total sugars (2.13 %) were obtained from the potatoes that were stored in the commercial store after being exposed to

2.00 mT; significant low amounts of reducing sugars were recorded for the samples that were exposed to 3.00 mT and stored in the control store; significant low amounts of non-reducing sugars were obtained from the tubers that were not exposed to MF and stored in the commercial store. Generally, exposing potatoes to AC MF gave low sugars than exposing them to DC MF across the three levels of magnetic field intensity (1.00, 2.00, and 3.00 mT). Notably, low levels of reducing sugars (0.317 %) were recorded for the potatoes that were exposed to 3.00 mT of AC MF, while the highest values were observed for the potatoes that were exposed to 1.00 mT of DC MF.

Senescence causes an increase in the sugar content of potatoes during storage. This is especially so when the membranes leak the products of starch breakdown into the cell sap (Marecek *et al*., 2013). It is therefore argued that exposing potato tubers to 3.00 mT caused the cell membrane to stiffen thereby inhibiting glucose and fructose from entering the cell sap. As a result, there was less senescent sweetening as evidenced by low reducing sugars in samples that were exposed to 3.00 mT of MF. There is a correlation between sprouting capacity and sugar content where the sugar content is higher in tubers with higher sprouting capacity (Rastovski & van Es. 1981). This may explain why there was higher sugar contents in samples that were exposed to 1.00 and 2.00 mT of MF than those that were treated to 3.00 mT, as those samples also had higher sprouting potential. The untreated sample that was not stored had significantly higher reducing sugars than other samples because with other samples that were stored, there was some sprouting which caused some sugars to be transported to the sprouts. During analyses of sugars, potatoes were de-sprouted and thus the amount of sugars in the sprouts was not accounted for. In addition, the amount of non-reducing sugars was high in the untreated and not stored sample because with sprouting, sucrose – a non-reducing sugar is used to transport carbohydrates to the sprouts. However, there was no sprouting in this sample and thus no sucrose was moved out of the tuber, and as a result, high amounts of non-reducing sugars. This phenomenon could also explain why there were high amounts of non-reducing sugars in samples that were exposed to 3.00 mT of MF, given that these samples had low sprouting capacity. Similarly, the untreated samples that were stored in either the control or the commercial store gave the lowest amounts of non-reducing sugars probably due to the fact that more sprouting was noticed in those samples. The amount of reducing sugars in potatoes should not be more than 0.5% for the effectiveness of processing into various products (Ndunguste *et al*., 2019). All our study treatments had less than 0.5% reducing sugars. However, it is the interaction effects of exposing potatoes to 3.00 mT with either DC or AC MF and storing

potatoes in either the control or commercial store after exposing them to 3.00 mT that gave the lowest values of reducing sugars.

The amount of reducing sugars in potatoes is very critical in the event that the potatoes are to be used for crisping and chipping. This is because their interaction with amino acids leads to a Maillard reaction that causes darkening, bitter taste, and reduced nutritional value of the end product (Abong *et al*., 2010). Thus, it is desired to keep the level of reducing sugars in stored potatoes as minimum as possible. From this study, the treatment combination of AC MF and 3.00 mT resulted in significantly low amounts of reducing sugars than other combinations. In addition, the study has shown that it is better to store potatoes in a dark store after exposing them to AC MF while targeting low amounts of reducing sugars. The conventional preferred potato store for ware potatoes is cold storage. However, this system is expensive for small scale potato farmers within sub-Saharan region. In addition, cold storage causes unwanted sweetening of potatoes due to increased sugar content. This study has however, provided an alternative cheap treatment of potatoes that does not lead to more sugars than necessary.

3.4. Conclusion

A significant impact of potato tuber exposure to MF on the postharvest quality of the shangi potato variety was observed. A reduction in weight loss, greening and sprouting was shown in tubers exposed to MF in comparison to the control. An increase in specific gravity, dry matter and starch was observed in tubers exposed to AC MF in comparison to tubers exposed to DC MF. Results of the experimental study indicate that MF can be applied to reduce losses of stored potatoes, thereby improving on their quality. The findings obtained will be useful in developing policies geared at improving the quality of ware potatoes after harvest. We recommend more work to assess the effects of MF on other potato varieties and in other regions.

CHAPTER FOUR

THE NUTRITIONAL QUALITY OF POTATOES (*SOLANUM TUBEROSUM* L) IS AFFECTED BY MAGNETIC FIELDS PRIOR TO THEIR POSTHARVEST STORAGE.

Abstract

Given their rapid development, adaptability, high yield, and response to low-cost inputs, potatoes are an especially potential crop alternative for developing countries. However, the enormous losses that potatoes experience during post-harvest storage limit their ability to provide food and nutritional security. Potato post-harvest losses are estimated to range from 10% to 15% annually worldwide. However, losses due to insufficient storage methods might be as high as 30% in developing countries. The main goal of this research was to evaluate how magnetic fields (MF) affected the nutrient content of potatoes during their postharvest storage. Studying how the store type affected potatoes' mineral and proximate composition was a secondary objective. Exposure of potatoes to MF had a major impact on ether extract, ash, crude fibre, and total energy, where specific MF intensities either resulted in significantly ($p < 0.05$) higher or lower elements than the unexposed tubers. However, MF did not have a major influence on crude protein and nitrogen-free extract. Exposure of tubers to MF that were produced by direct current (DC) seemed to have a major positive impact on both major and minor minerals while using alternating current (AC) to produce MF impacted minerals negatively. In particular, exposing potatoes to 2 mT of DC MF with subsequent storage in the control store resulted in significantly ($p < 0.05$) higher quantities of potassium, magnesium, copper, manganese, chromium, cobalt, and boron. Findings from this study have shown that MF can be used to innovatively influence the nutritional composition of potatoes during their postharvest storage while reducing losses associated with prolonged storage of potatoes.

4.1. Introduction

The world's most significant crop that is not a grain is now the potato. With an annual 369 million metric tonnes of production, it is grown extensively in more than 130 countries (FAOSTAT, 2021). Depending on the geography, the development of the nation, and historical factors, potatoes are now farmed for food, animal feed, industrial applications, and the generation of seed tubers (Dolničar, 2021). Potatoes are a particularly alluring crop alternative for underdeveloped nations due to their quick growth, adaptability, high yield, and responsiveness to cheap inputs (Wijesinha-

Bettoni & Mouillé, 2019). Additionally, potatoes have demonstrated positive health-promoting qualities in humans, including anticancer, hypocholesterolemic, anti-inflammatory, anti-obesity, and antidiabetic properties. Phenolics, anthocyanins, fiber, resistant starch, and carotenoids all contribute to potatoes' health advantages (Campos & Ortiz, 2020). However, during postharvest storage, potatoes incur significant losses which hamper their potential in contributing to food and nutritional security. Worldwide, the average post-harvest loss of potatoes is thought to be between 10% and 15% per year. However, losses linked to inadequate storage techniques can reach as high as 30% in developing nations (Gikundi *et al*., 2023; Tadesse *et al*., 2018). Every harvest season, in Kenya, over 19% of the crop of potatoes per acre is lost. At the national level, this amounts to over 815,000 tonnes of damaged produce per year, which has a worth of nearly 108 million dollars (Kaguongo *et al*., 2014).

Potatoes can be preserved after harvest via refrigeration storage. The process quality of potatoes exposed to freezing temperatures is frequently jeopardized, nevertheless, because of the significant accumulation of reducing sugars that result in the darkening of the potatoes' colour, which is accentuated while frying by the creation of acrylamide (Amjad *et al*., 2020). Additionally, installing such a facility is expensive, which prevents many smallholder farmers in sub-Saharan Africa and other developing nations from doing so (Akello *et al*., 2022). Another approach to sustainable storage of potatoes has been the use of sprout suppressants, the most effective being the synthetic chlorpropham, CIPC (Campbell *et al*., 2020; Murigi *et al*., 2021). However, most of these inhibitors have sparked a number of consumer and environmental concerns, leading to their ban in many nations (Vijay *et al*., 2018). It is thus imperative to identify better storage strategies that are not only affordable but also consumer and environmentally friendly, and also do not adversely impact the nutritional quality of the potato tuber. The use of magnetic fields presents that potential.

In chapter three, magnetic fields were reported to have the potential of reducing potato postharvest losses by impacting key quality parameters of potatoes during their storage. Exposing potatoes to either DC or AC MF was reported to reduce the formation of sprouts. In comparison to potatoes not exposed to MF, potatoes treated to 3.00 mT of both DC and AC MF showed significantly less weight loss, internal and external greening, and reducing sugars. However, even though MF have been shown to reduce key postharvest losses on potatoes, it is imperative to understand how the nutritional profile of the tuber is affected upon exposure to MF. The objective of this work,

therefore, was to assess the effects of DC and AC MF on the nutritional quality of potato during their postharvest storage. A secondary aim was to study the effect of type of store on proximate and minerals composition of potatoes.

4.2. Materials and Methods

Sample collection protocols, application of magnetic fields, estimation of MF exposure dose, and storage conditions are as outlined in chapter three. Shangi was the variety that was used in this study, given that it is the most popular among Kenyan potato farmers, yet it has the shortest postharvest shelf life (Gikundi *et al*., 2023). In summary, clean and disease-free potatoes were obtained from a registered potato farmer in Nakuru County, Kenya. The potatoes were sorted by size, and tubers with a diameter of at least 60 mm were chosen. These underwent a five-day cure at room temperature (16 - 20 °C). Ten tubers were then treated to a range of magnetic field intensities (1, 2, and 3 mT) by placing them at the centre of double Helmholtz coils, each with 154 turns, and placed 20 cm apart. The coils were then supplied either direct or alternating current to produce static and varied MF, herein referred to as DC MF and AC MF respectively. A tesla meter (S/N: 360500184889; Phywe Systems GmbH & Co. Gottingen, Germany) coupled with a Hall Effect sensor (S/N: 256500176195; Phywe Systems GmbH & Co. Gottingen, Germany) was used to measure the quantity of magnetic flux. Tubers were then subjected to various magnetic fields for 20, 40, and 80 seconds, and stored in either the control or the commercial store. The control store was a completely dark store while the commercial store had varying light intensities. Detailed information about the stores is described in chapter three. A flow chart that summarizes how the experiment was carried out is given in Figure 4.1.

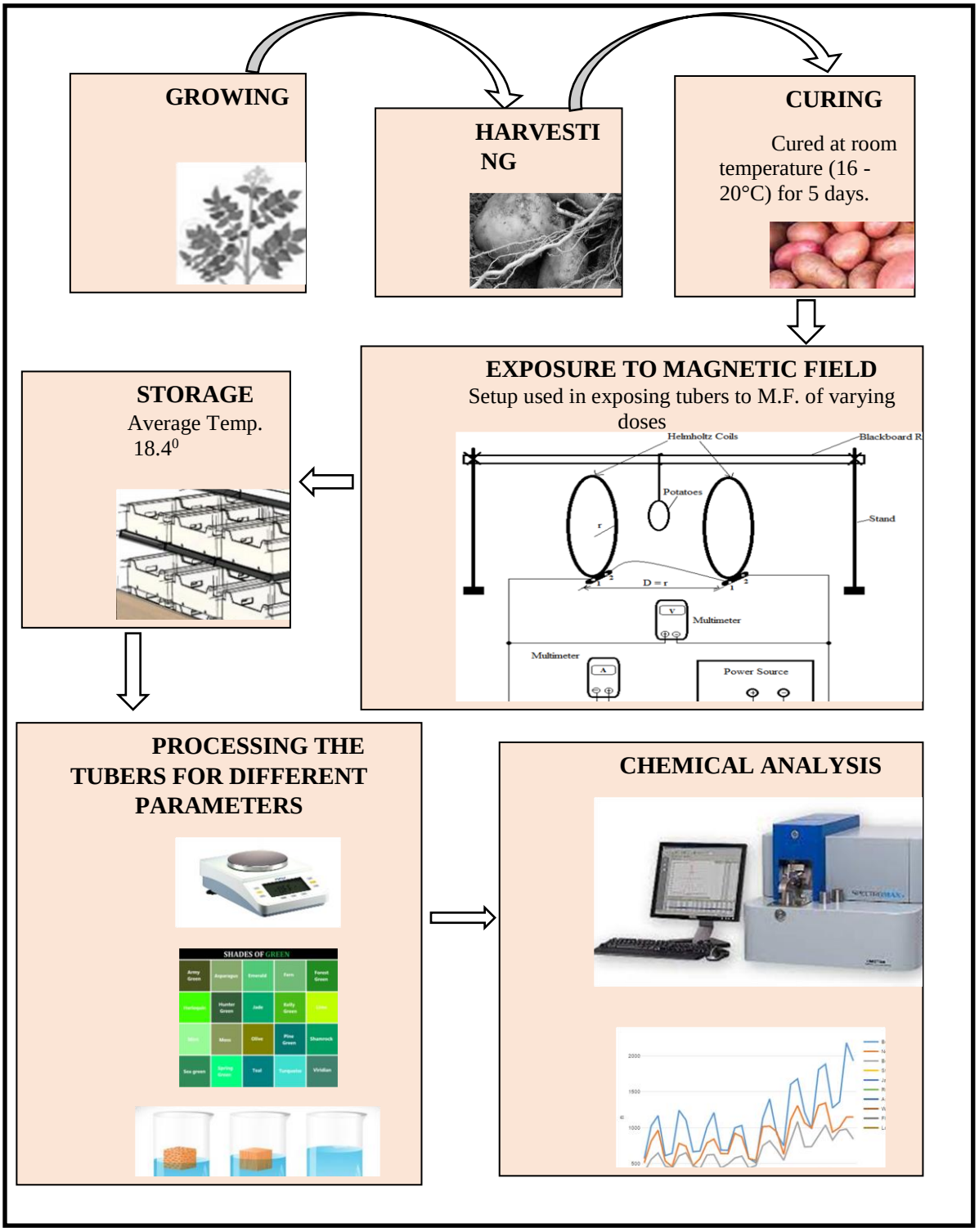

Figure 4. 1: Schematic representation of research activities

4.2.1. Experimental design

A completely randomized design was used with a 2×2×3×3 factorial setup. The following variables were examined: store type (two levels; control and commercial), magnetic field source (two levels;

DC and AC), magnetic field intensity (three levels; 1, 2, and 3 mT), and exposure holding duration (three levels; 20, 40 and 80 seconds). The holding time was only employed at one level (80 seconds) for the minerals, though. The experiment was replicated three times.

4.2.2. Dry matter determination

According to AOAC 930.15, the dry matter content was calculated gravimetrically (Association of Official Analytical Chemists, 2007). A pre-weighed plate was filled with around 2 g of ground sample, which was then weighed (*W1*). The dish's weight, including the sample, was noted (*W2*). The dish was dried at 105 °C for three hours in a drying oven (Memmert, Schwabach, Germany). It was then cooled in a desiccator and reweighed (*W3*). Dry matter (%) was calculated as follows; $100 \times (W_3 - W_2)/(W_2 - W_1)$

4.2.3. Ash determination

Determination of ash was done using the AOAC 942.05 technique (Association of Official Analytical Chemists, 2007). A crucible that had previously been calcined and weighed (*W2*) was filled with about two (2) g (*W1*) of pulverized material, which was then heated in a muffle furnace (MR170; GMBH, Hanau, Germany) for 12 hours at 550 °C. After cooling in a desiccator with the ashed sample within, the crucible was reweighed (*W3*). The formula: $Ash(\%) = 100 \times (W_3 - W_1)/W_2$ was used to determine the amount of ash.

4.2.4. Ether extract (fat content) determination

According to AOAC method 920.39, ether extract was determined (Association of Official Analytical Chemists, 2007). The extraction thimble was filled with around five grams of the sample (*W1*), which was then covered with a wad of fat-free cotton wool. A clean round bottom flask that had been cleaned, dried, and weighed was then fitted with the thimble (*W2*). The extraction flask received precisely 25 mL of petroleum ether. The Electro-thermal Soxlet Apparatus (EME 6250/CF; Cole Parmer; England) was programmed to extract the sample for 6 hours. The solvent was then evaporated, the flask dried in a desiccator, and the weight was once again determined (*W3*). Crude fat content (%) was determined as follows; $100 \times (W_3 - W_2)/W_1$

4.2.5. Crude protein determination

The AOAC method 984.13 was used to calculate crude protein (Association of Official Analytical Chemists, 2007). In a digestion tube, two (2) g of pulverized material and 20 mL of concentrated sulfuric acid were combined. The material in the tube was mixed with Kjeldahl tablets, and the sample was digested for 1 hour at 420 °C in a Gerhardt Kjeldatherm digester (KB40; Gerhardt GMBH & CO. Kg; Germany). To make 80 mL of volume, distilled water was added to the digest. After adding precisely 50 mL of sodium hydroxide solution to the mixture, a 2200 Kjeltec auto distillation machine (Foss Analytical, Höganäs, Sweden) was used to distill the ammonia into concentrated boric acid. Hydrochloric acid (0.1 mol/L) was used for titration after a few drops of indicator solution were added. The formula; $N(g/100g) = (V_s - V_b) \times M_{(HCl)} \times 1 \times 14.007 / W \times 10$ was used to determine the nitrogen content. Where: Vs is the amount of HCl (in milliliters) required to titrate the sample; Vb is the amount of HCl (in milliliters) required to titrate the blank test; M(HCl) is the molarity of HCl; and 1 is the acid factor; nitrogen has a molecular weight of 14.007; W stands for the sample's weight in grams, and 10 represents conversion factor from mg/g to g/100g. By dividing the nitrogen content by 6.25, the crude protein content was calculated.

4.2.6. Crude fibre determination

Determination of crude fibre was done according to the 978.10 method (Association of Official Analytical Chemists, 2007). In a Fibertec digester (FOSS, Sweden), two (2) g of sample were weighed (*W1*), digested in sulphuric acid for 30 min, and subsequently digested in potassium hydroxide for 30 min. Each digest was then put through filtration in a crucible. Five times with 10 mL of hot distilled water, the residue was rinsed. After being dried for four hours at 105 °C in an oven, the crucible and its contents were chilled in a desiccator before being reweighed (*W2*). The dried crucible and residue were then burned at 550 °C for two hours in a muffle furnace, cooled in a desiccator, and weighed again (*W3*). Crude fibre content (%) was calculated as follows: $100 \times (W_2 - W_3) / W_1$

4.2.7. Nitrogen-free extract determination

The nitrogen-free extract (%) was computed as the weight by the difference between 100 and the sum of the other proximate characteristics and was reported as: $NFE = 100 - (\%ether\ extract + \%crude\ protein + \%ash + \%crude\ fibre$

4.2.8. Total energy determination

The following Atwater conversion factors were used to calculate the total energy as described by (Omoba *et al.*, 2020): $Total\ energy\ (\frac{Kcal}{100g}) = (4 \times crude\ protein) + (9 \times ether\ extract) + (4 \times carbohydrate)$.

4.2.9. Minerals analysis

Mineral contents were determined by inductively coupled plasma atomic emission spectrometry (ICPE 9000, Shimadzu, Kyoto, Japan) after digestion with 6 ml of HNO_3 and 2 ml of H_2O_2 in a microwave digestion system. Phosphorus, potassium, calcium, magnesium, alluminium, sodium, copper, iron, zinc, manganese, chromium, cobalt, and boron were determined at wavelengths of 213.618, 769.940, 317.993, 279.553, 396.153, 589.592, 324.754, 259.940, 213.856, 260.569, 267.716, 228.616, and 249.772 nm respectively.

4.2.10. Statistical analyses

The Kolmogorov-Smirnov test was run on the data to make sure the distribution was normal using the PROC UNIVARIATE procedure of the Statistical Analysis System (SAS) software version 9.4 (SAS Institute Inc., Cary, NC, USA). The effects of the source of magnetic fields, the intensity of the magnetic field, the amount of exposure to the magnetic field, and the kind of store on the proximate composition and minerals of potatoes were investigated using the General Linear Model (PROC GLM) technique. The homogeneity of variance was investigated using the HOVTEST = LEVENE technique. The means were separated using the Tukey's HSD (honestly significant difference) test at a significance threshold of 0.05.

4.3 Results and Discussion

4.3.1. Proximate composition

Figures 4.2 – 4.7 show the proximate composition of potatoes after exposure to various intensities of MF and storage in either the control or the commercial store. The use of DC MF had a positive significant impact on the ether extract of potatoes, while AC MF impacted negatively. This is ascertained where exposure of potatoes to DC MF of 1 and 3 mT followed by storage in the control and commercial stores respectively led to significantly higher amounts of ether extract than those tubers that were not exposed to MF and stored in respective stores (Figure 4.2). On the other hand,

exposure to all levels of AC MF resulted in significantly low contents of ether extract than the unexposed tubers.

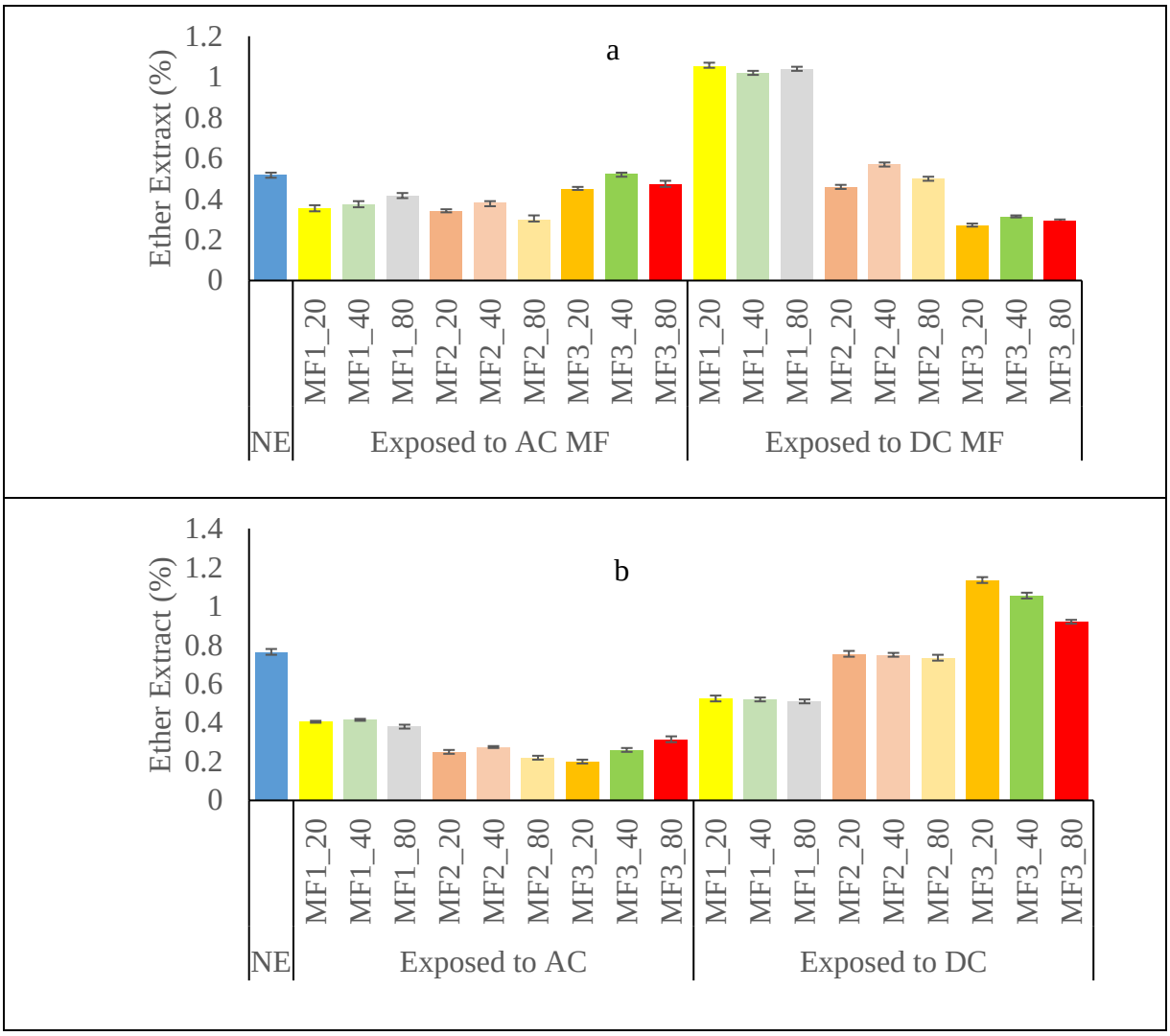

Figure 4. 2: Ether extract (%) of potatoes as influenced by magnetic fields and storage in different stores (control store (a), and commercial store (b))

MF: Magnetic field; AC: Altenating current; DC: Direct current; NE: Not exposed to MF;

MF1_20: Potatoes were exposed to 1 mT of magnetic induction for 20 seconds;

MF1_40: Potatoes were exposed to 1 mT of magnetic induction for 40 seconds;

MF1_80: Potatoes were exposed to 1 mT of magnetic induction for 80 seconds;

MF2_20: Potatoes were exposed to 2 mT of magnetic induction for 20 seconds;

MF2_40: Potatoes were exposed to 2 mT of magnetic induction for 40 seconds;

MF2_80: Potatoes were exposed to 2 mT of magnetic induction for 80 seconds;

MF3_20: Potatoes were exposed to 3 mT of magnetic induction for 20 seconds;

MF3_40: Potatoes were exposed to 3 mT of magnetic induction for 40 seconds;

MF3_80: Potatoes were exposed to 3 mT of magnetic induction for 80 seconds.

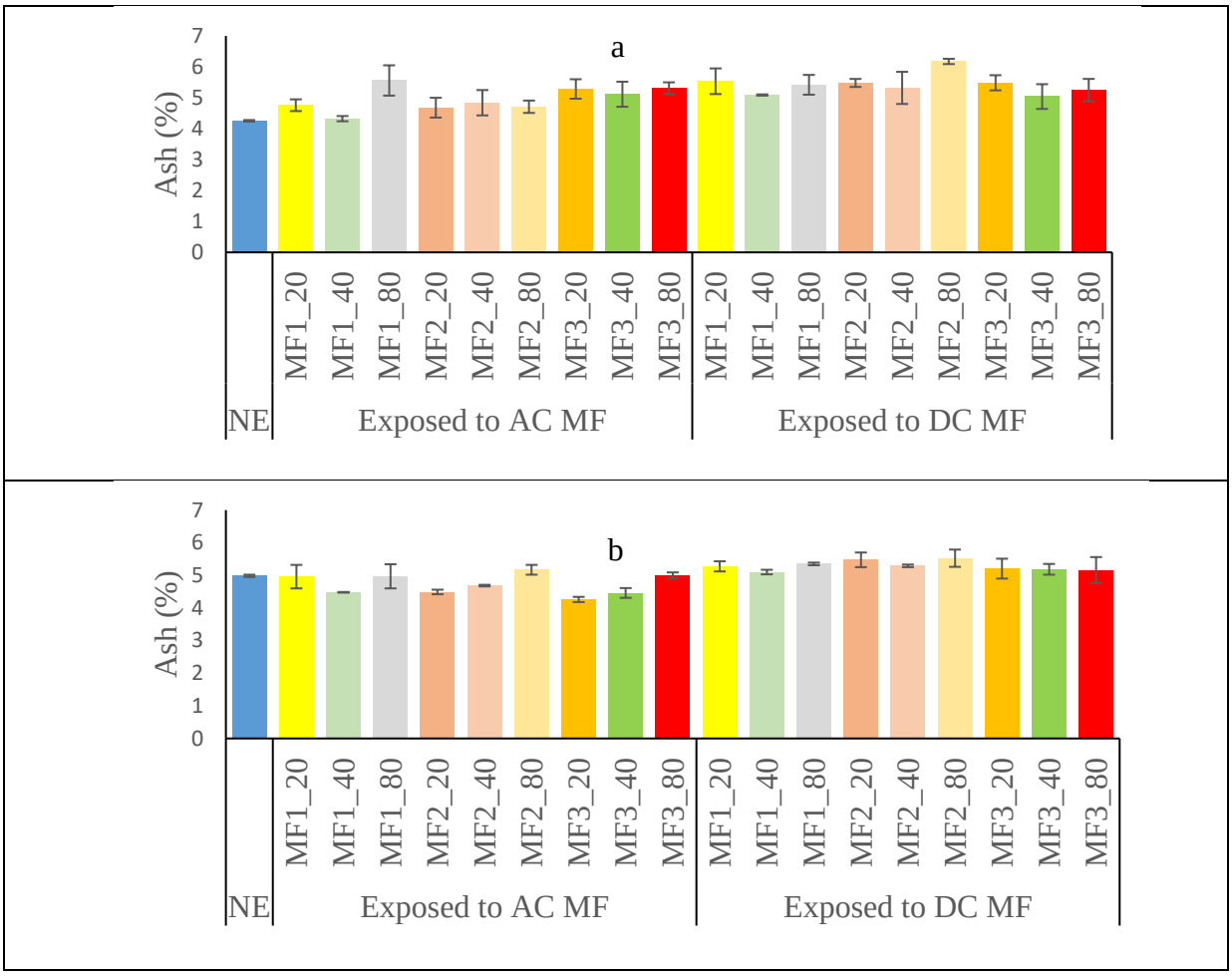

Figure 4. 3: Ash (%) of potatoes as influenced by magnetic fields and storage in different stores (control store (a), and commercial store (b))

MF: Magnetic field; AC: Altenating current; DC: Direct current; NE: Not exposed to MF;

MF1_20: Potatoes were exposed to 1 mT of magnetic induction for 20 seconds;

MF1_40: Potatoes were exposed to 1 mT of magnetic induction for 40 seconds;

MF1_80: Potatoes were exposed to 1 mT of magnetic induction for 80 seconds;

MF2_20: Potatoes were exposed to 2 mT of magnetic induction for 20 seconds;

MF2_40: Potatoes were exposed to 2 mT of magnetic induction for 40 seconds;

MF2_80: Potatoes were exposed to 2 mT of magnetic induction for 80 seconds;

MF3_20: Potatoes were exposed to 3 mT of magnetic induction for 20 seconds;

MF3_40: Potatoes were exposed to 3 mT of magnetic induction for 40 seconds;

MF3_80: Potatoes were exposed to 3 mT of magnetic induction for 80 seconds.

Although the lipid content in potatoes is quite low and makes a negligible contribution to calories, it enhances the flavor of potato products. Thus, its loss should be avoided during postharvest storage of potatoes. The ability of potato tubers to synthesize store lipids has been demonstrated, and one of the constraints on oil accumulation is malonyl-CoA, the substrate for elongation during fatty acid synthesis (Klaus *et al*., 2004; Ramadan & Oraby, 2016). It can thus be argued that the use of 1 and 3 mT of DC MF on potatoes, with further storage in the control and commercial stores respectively, favoured increased synthesis of fatty acids by overexpressing acetyl-CoA. On the other hand, exposure of tubers to AC MF may have resulted in the formation of lipid-starch-protein complexes that resist extraction during analyses, thus the low amount of ether extract in tubers that were exposed to AC MF (Wang *et al*., 2017).

Exposure of potatoes to all levels of MF (AC and DC) and storing them in the control store gave higher quantities of ash than it was found in the un-exposed potatoes, and this was significant (Figure 4.3a). For the commercial store, an interesting trend was observed, where exposing potatoes to either AC MF or DC MF and holding them for 80 seconds gave ash contents that were not significantly different from the un-exposed potatoes that were stored in the same store (Figure 4.3b). Ash represents the inorganic fractions in food material and thus is a good indicator of mineral content. As minerals are water soluble, most of them would be lost during water evaporation from tubers. In chapter three, the use of MF was shown to reduce the rates of respiration of stored potatoes. This could explain why exposure of potatoes to either AC MF or DC MF followed by storage in the control store gave higher ash content than the unexposed tubers. In the same chapter significant less evaporation was also reported in the tubers that were exposed to MF for 80 seconds than those that were exposed for 20 and 40 seconds. This demonstrates why potatoes that were exposed to either AC MF or DC MF for 80 seconds and stored in the commercial store did not differ from the unexposed potatoes.

Magnetic fields did not have a major positive impact on the crude protein of potatoes. For the control store, most of the study variables resulted in a significantly equal amount of crude protein as was found in the un-exposed sample. An exception was the exposure to 1 mT of AC MF for 20 seconds which gave a significantly higher content of crude protein than the un-exposed tubers (Figure 4.4a). On the other hand, for the commercial store, most study variables led to significantly lower quantities of crude protein than what was found in the un-exposed tubers (Figure 4.4b).

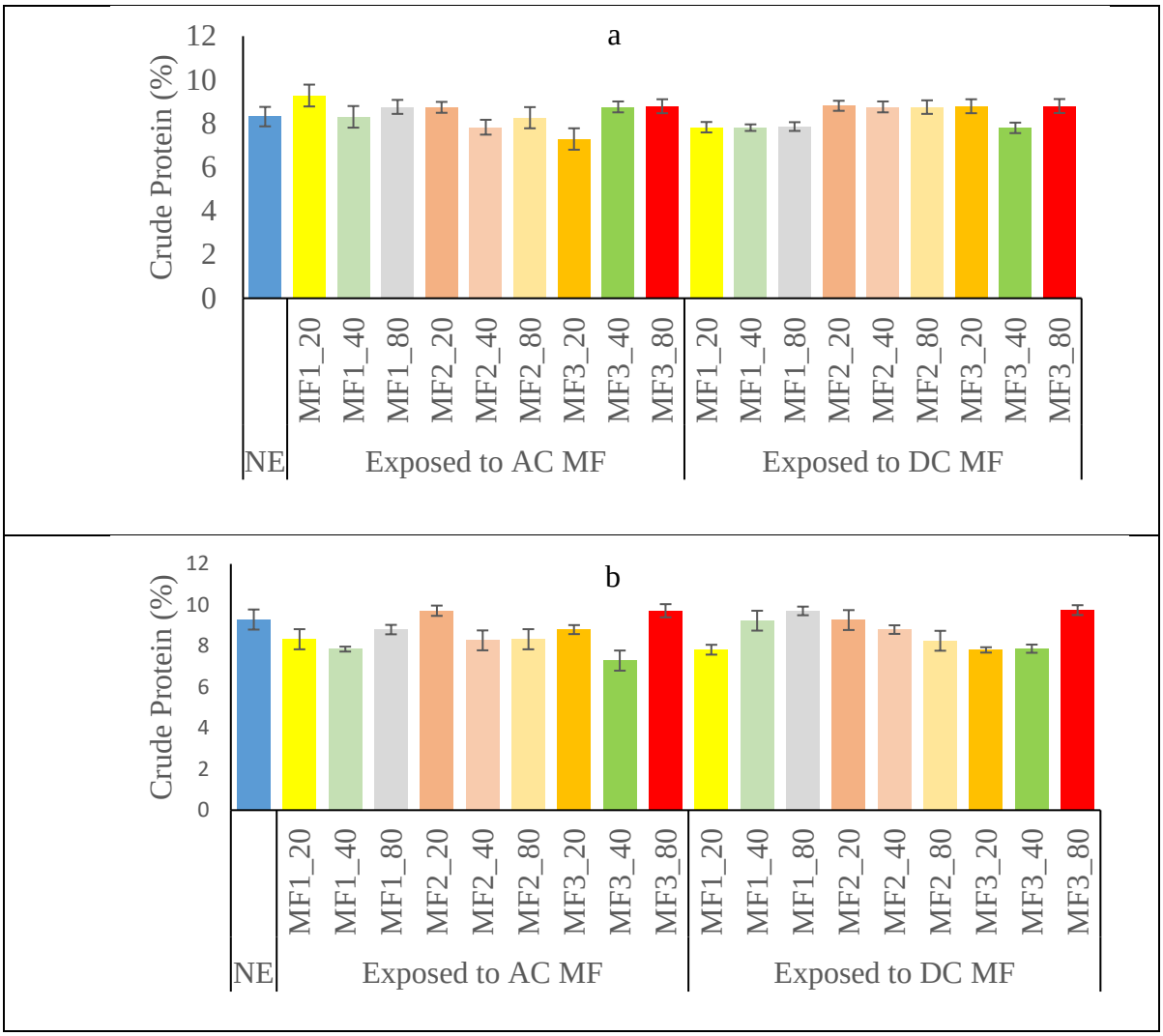

Figure 4. 4: Crude Protein (%) of potatoes as influenced by magnetic fields and storage in different stores (control store (a), and commercial store (b))

MF: Magnetic field; AC: Altenating current; DC: Direct current; NE: Not exposed to MF;

MF1_20: Potatoes were exposed to 1 mT of magnetic induction for 20 seconds;

MF1_40: Potatoes were exposed to 1 mT of magnetic induction for 40 seconds;

MF1_80: Potatoes were exposed to 1 mT of magnetic induction for 80 seconds;

MF2_20: Potatoes were exposed to 2 mT of magnetic induction for 20 seconds;

MF2_40: Potatoes were exposed to 2 mT of magnetic induction for 40 seconds;

MF2_80: Potatoes were exposed to 2 mT of magnetic induction for 80 seconds;

MF3_20: Potatoes were exposed to 3 mT of magnetic induction for 20 seconds;

MF3_40: Potatoes were exposed to 3 mT of magnetic induction for 40 seconds;

MF3_80: Potatoes were exposed to 3 mT of magnetic induction for 80 seconds.

Patatin is the major storage protein in potatoes (Fu *et al*., 2020). It is thus plausible that the use of MF did not have a major impact on the content of patatin. However, they might have induced structural modifications of patatin, that impact its functionality. Similar modifications using other non-thermal technologies have been reported (Elahi & Mu, 2017). The exposure of potatoes to 1 mT of AC MF for 20 seconds may have induced genes that encode the synthesis of proteins, resulting in increased accumulation when potatoes were exposed and stored in the control store. Protein content has been found to decrease upon prolonged storage of potatoes (Černá & Kráčmar, 2010; Pęksa *et al*., 2018). However, this study has offered promising insights into how the synthesis of proteins can be activated during storage. It is also evidenced from this study that exposure of tubers to MF with further storage in the commercial store favoured the degradation of proteins. Therefore, light promotes the reduction of proteins, and thus potatoes should be preserved in a dark store.

Exposure of tubers to 1 mT of DC MF at all levels of holding time, resulted in a significantly low amount of crude fibre than the un-exposed tubers, irrespective of the type of store (Figure 4.5). Crude fibre is mainly composed of insoluble fibre. Its reduction, therefore, implied that there was the conversion of insoluble to soluble fibre when potatoes were exposed to DC MF of 1 mT at all holding times. Other non-thermal technologies have been shown to influence the conversion of insoluble to soluble fibre (Bader Ul Ain *et al*., 2019; Elizondo-Montemayor *et al*., 2020). Interestingly, exposure time had a significant effect on crude fibre. Potatoes that were exposed to 1 and 3 mT of AC MF and 2 mT of DC MF for 80 seconds followed by storage in the control store resulted in a significantly higher amount of crude fibre than the unexposed potatoes (Figure 4.5a). For the commercial store, exposing tubers to 2 and 3 mT of either AC MF or DC MF for 40 seconds gave higher levels of crude fibre than the un-exposed tubers that were significant (Figure 4.5b). Resistant starch is classified as part of insoluble fibre (Dai & Chau, 2017). It is therefore argued that the increase in crude fibre at these specific treatment combinations could be as a result of structural modification of starch to resistant starch. Potato starch modifications to resistant starch have been reported to occur in other studies (Sawicka & das Gupta, 2018).

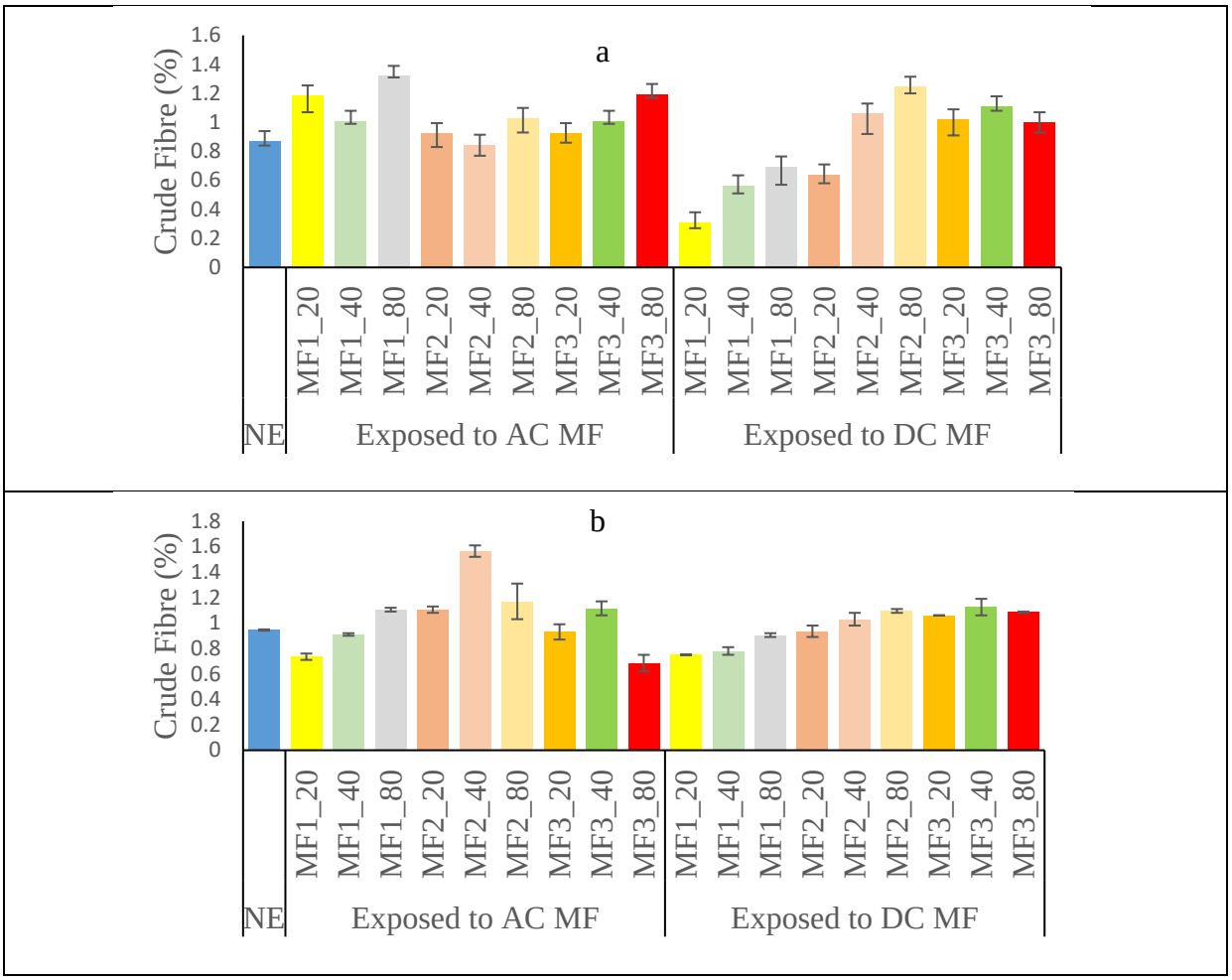

Figure 4. 5: Crude Fibre (%) of potatoes as influenced by magnetic fields and storage in different stores (control store (a), and commercial store (b))

MF: Magnetic field; AC: Altenating current; DC: Direct current; NE: Not exposed to MF;

MF1_20: Potatoes were exposed to 1 mT of magnetic induction for 20 seconds;

MF1_40: Potatoes were exposed to 1 mT of magnetic induction for 40 seconds;

MF1_80: Potatoes were exposed to 1 mT of magnetic induction for 80 seconds;

MF2_20: Potatoes were exposed to 2 mT of magnetic induction for 20 seconds;

MF2_40: Potatoes were exposed to 2 mT of magnetic induction for 40 seconds;

MF2_80: Potatoes were exposed to 2 mT of magnetic induction for 80 seconds;

MF3_20: Potatoes were exposed to 3 mT of magnetic induction for 20 seconds;

MF3_40: Potatoes were exposed to 3 mT of magnetic induction for 40 seconds;

MF3_80: Potatoes were exposed to 3 mT of magnetic induction for 80 seconds.

The nitrogen-free extract was visibly lower in most exposed potatoes stored in the control store than in the unexposed sample. The few exceptions were those that were exposed to 1 and 2 mT of

AC MF and 3 mT of DC MF for 40 seconds (Figure 4.6a). However, for the commercial store, exposing tubers to 1 and 3 mT of AC MF and 1 mT of DC MF for 20 seconds resulted in significantly higher nitrogen-free extract than the unexposed tubers (Figure 4.6b). The nitrogen-free extract is an indicator of the available starch and sugars in a tuber. During storage, sugars are formed mainly when starch is enzymatically converted to glucose (Furrer *et al*., 2018). This will not have an effect on the content of nitrogen-free extract, and as such, any increase or decrease in the nitrogen-free extract is associated with starch content. Potatoes with significant higher starch content were found to have higher activities of the enzymes ADP glucose pyrophosphorylase (AGPase), starch branching enzyme (SBE), and soluble starch synthetase (SSS) (Su *et al*., 2022). It is therefore argued that the increases in nitrogen-free extract in the aforementioned cases are a result of overexpression of genes that encode AGPase, SBE, and SSS enzymes leading to increased biosynthesis of starch. On the other hand, decreases in the content of nitrogen-free extract could be attributed to the conversion of soluble starch to insoluble resistant starch. This is ascertained by the fact that the experimental treatments that had significantly high crude fibre had a significantly low amount of nitrogen-free extract.

Exposure of potatoes to AC MF followed by storage in the control store had a positive impact on total energy. This is evident by the fact that exposure to all levels of AC MF gave significantly higher levels of total energy than the unexposed tubers. The only exception was the sample that was exposed to 3 mT of AC MF for 20 seconds which gave the same amount of energy as the unexposed tubers [Figure 4.7a). Similarly, exposure of potatoes to AC MF and storing them in the commercial store gave significantly higher or equal total energy in comparison to the unexposed tubers (Figure 4.7b). The total energy is a function of the summation of crude ether, crude protein, and carbohydrates. However, potato tubers have small quantities of protein and oil (Arshad *et al*., 2021; Gikundi *et al*., 2021). Therefore, the majority of energy is contributed by carbohydrates. This is true for this study given that the trend on how experimental treatments affected nitrogen-free extract was close to that of total energy. It is worth noting, however, that significant high energy would be achieved when potatoes are exposed to 1 mT of AC MF for 40 seconds with subsequent storage in a dark store.

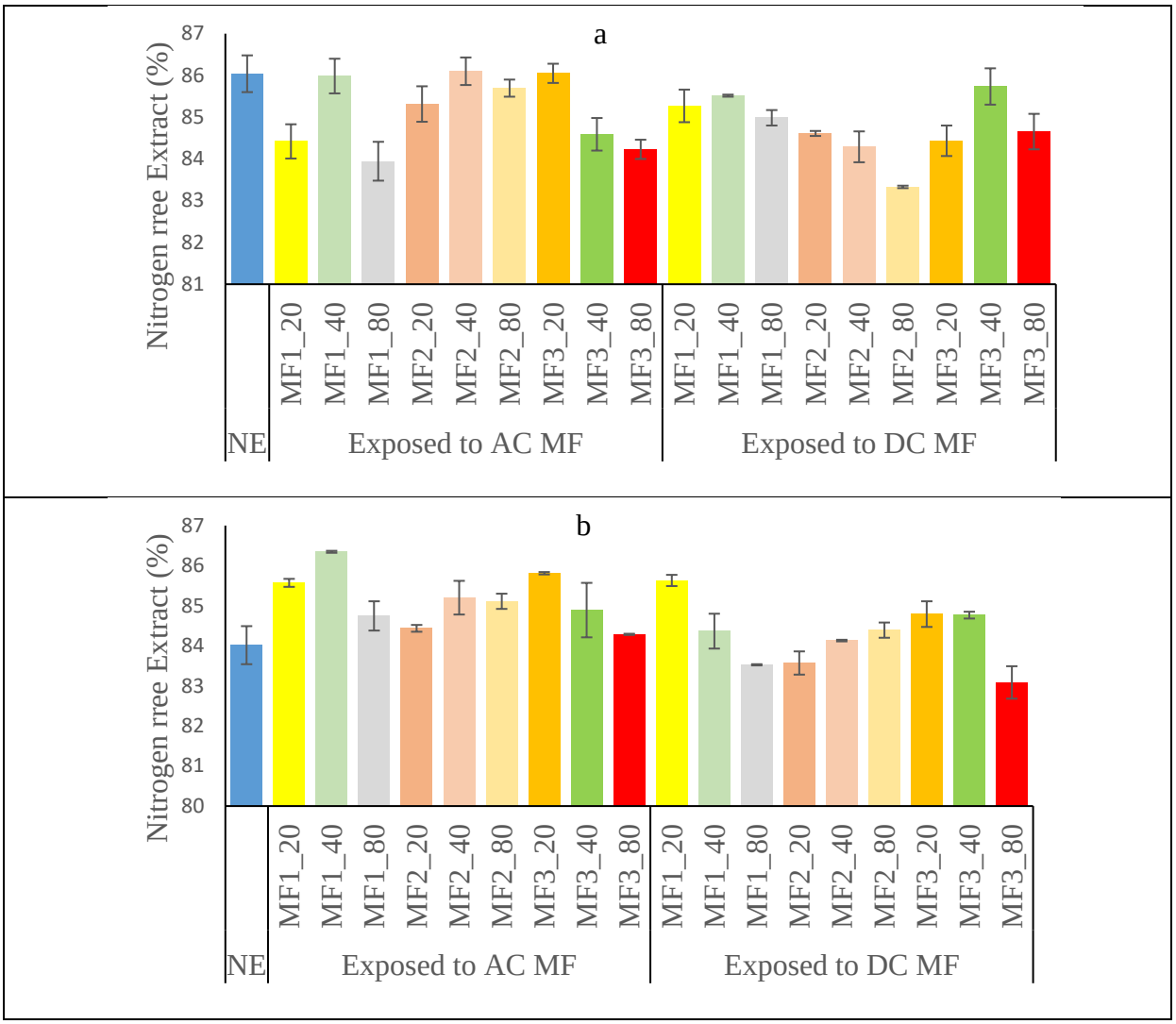

Figure 4. 6: Nitrogen Free Extract (%) of potatoes as influenced by magnetic fields and storage in different stores (control store (a), and commercial store (b))

MF: Magnetic field; AC: Altenating current; DC: Direct current; NE: Not exposed to MF;

MF1_20: Potatoes were exposed to 1 mT of magnetic induction for 20 seconds;

MF1_40: Potatoes were exposed to 1 mT of magnetic induction for 40 seconds;

MF1_80: Potatoes were exposed to 1 mT of magnetic induction for 80 seconds;

MF2_20: Potatoes were exposed to 2 mT of magnetic induction for 20 seconds;

MF2_40: Potatoes were exposed to 2 mT of magnetic induction for 40 seconds;

MF2_80: Potatoes were exposed to 2 mT of magnetic induction for 80 seconds;

MF3_20: Potatoes were exposed to 3 mT of magnetic induction for 20 seconds;

MF3_40: Potatoes were exposed to 3 mT of magnetic induction for 40 seconds;

MF3_80: Potatoes were exposed to 3 mT of magnetic induction for 80 seconds.

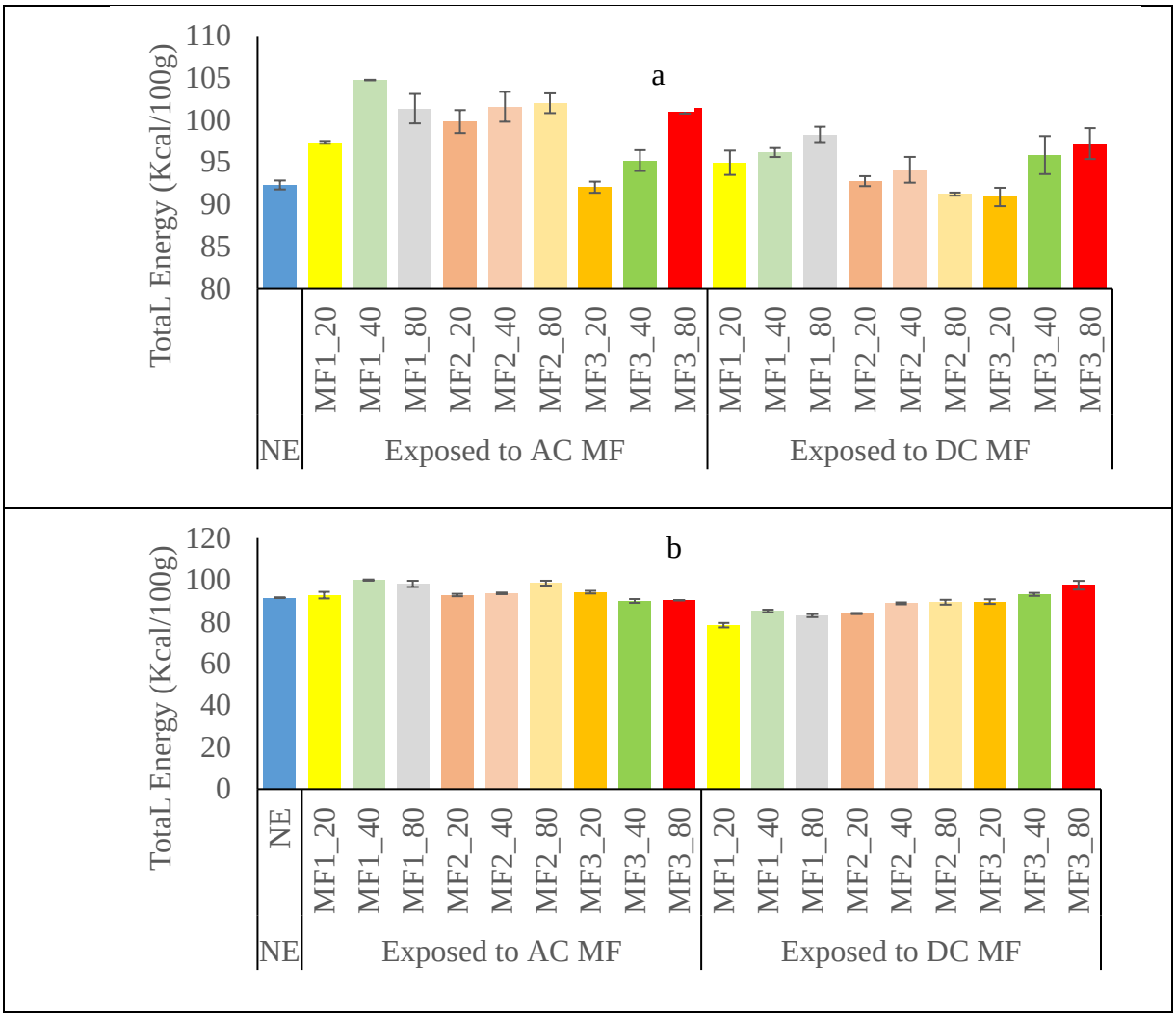

Figure 4. 7: TotaL Energy (Kcal/100g) of potatoes as influenced by magnetic fields and storage in different stores (control store (a), and commercial store (b))

MF: Magnetic field; AC: Altenating current; DC: Direct current; NE: Not exposed to MF;

MF1_20: Potatoes were exposed to 1 mT of magnetic induction for 20 seconds;

MF1_40: Potatoes were exposed to 1 mT of magnetic induction for 40 seconds;

MF1_80: Potatoes were exposed to 1 mT of magnetic induction for 80 seconds;

MF2_20: Potatoes were exposed to 2 mT of magnetic induction for 20 seconds;

MF2_40: Potatoes were exposed to 2 mT of magnetic induction for 40 seconds;

MF2_80: Potatoes were exposed to 2 mT of magnetic induction for 80 seconds;

MF3_20: Potatoes were exposed to 3 mT of magnetic induction for 20 seconds;

MF3_40: Potatoes were exposed to 3 mT of magnetic induction for 40 seconds;

MF3_80: Potatoes were exposed to 3 mT of magnetic induction for 80 seconds.

4.3.2. Minerals

The effects of study variables on major minerals are given in Table 4.1. The DC MF appeared to have a major positive impact on these elements while AC MF impacted negatively. Exposure of potatoes to 2 mT of DC MF with subsequent storage in the control store led to significantly high amounts of potassium and magnesium than all other treatments. Similarly, exposure of tubers to 1 mT of DC MF with subsequent storage in the commercial store resulted in significantly high quantities of phosphorus, calcium, and sodium. Although the highest amount of aluminium was observed for the tubers that were not exposed to MF but stored in the commercial store, exposure to all intensities of DC MF followed by storage in the commercial store resulted in significantly higher levels of aluminium than all other treatments. For calcium and aluminium, the least quantities were observed in the treatments exposed to 1 mT of AC MF.

The effects of study variables on minor minerals are given in Table 4.2. Just like in major minerals, DC MF affected minor minerals positively while AC MF appeared to affect negatively. The highest amount of copper, manganese, chromium, cobalt, and boron was achieved when potatoes were exposed to 2 mT of DC MF followed by storage in the control store. These were significant than all other treatments. Interestingly, the lowest amounts of manganese, chromium, cobalt, and boron were observed in the tubers that were exposed to 1 mT of AC MF and stored in the control store. For iron and zinc, the highest quantities were obtained when potatoes were exposed to 1 and 3 mT of DC MF with subsequent storage in the commercial store.

The effect of magnetic fields on minerals was a function of the source of MF and intensity. Exposure of tubers to DC MF may have promoted the biosynthesis of minerals by exciting key genes that encode their synthesis, resulting in their increased quantities. Other related non-thermal technologies such as the use of pulsed electric fields have been shown to positively impact the biosynthesis of minerals (Ahmed *et al*., 2020). It is also likely that the use of DC MF stiffened the tuber cells that prevented the degradation of minerals. This is supported by the documentation that magnetic fields affect the permeability of plants' cell membranes (Sarraf *et al*., 2020). In addition, MF have been shown to positively impact on minerals in the leaves of sunflower and tomato (Abdelaziz *et al*., 2015). On the contrary, the use of AC MF may have promoted the softening of the tuber stem end which resulted in the release of minerals into the perimedullary zone, given that some minerals are concentrated within the stem end of the potato tuber (Subramanian *et al*., 2011).

Table 4. 1: Effects of source of magnetic field (SMF), magnetic field intensity (MFI), and type of store on major minerals

Store type	SMF	MFI	P (%)	K (%)	Ca (ppm)	Mg (ppm)	Al (ppm)	Na (ppm)
Not stored	-	-	0.12 ± 0.01^{c}	1.26 ± 0.01^{j}	65.23 ± 0.04^{bc}	698.00 ± 1.15^{m}	13.70 ± 0.12^{d}	453.33 ± 1.45^{b}
Control	UN	-	0.15 ± 0.01^{ab}	1.38 ± 0.01^{gh}	48.63 ± 0.61^{i}	771.67 ± 0.33^{k}	14.80 ± 0.06^{c}	310.67 ± 2.60^{h}
	AC	1	0.12 ± 0.00^{bc}	1.37 ± 0.01^{hi}	47.97 ± 0.70^{j}	741.67 ± 0.88^{l}	9.40 ± 0.06^{j}	336.33 ± 0.67^{g}
		2	0.14 ± 0.01^{abc}	1.32 ± 0.01^{i}	57.17 ± 0.19^{efg}	851.67 ± 0.88^{b}	12.53 ± 0.07^{ef}	439.00 ± 0.58^{c}
		3	0.14 ± 0.01^{abc}	1.45 ± 0.01^{f}	52.53 ± 0.50^{h}	784.00 ± 1.15^{ij}	10.07 ± 0.09^{i}	379.33 ± 1.76^{f}
	DC	1	0.13 ± 0.01^{bc}	1.65 ± 0.01^{b}	53.57 ± 0.84^{h}	845.67 ± 0.33^{c}	10.53 ± 0.09^{h}	330.67 ± 1.76^{g}
		2	0.14 ± 0.00^{bc}	1.72 ± 0.01^{a}	63.40 ± 0.82^{c}	877.33 ± 0.88^{a}	12.60 ± 0.08^{e}	396.00 ± 1.15^{e}
		3	0.14 ± 0.01^{abc}	1.63 ± 0.01^{b}	57.73 ± 0.74^{def}	840.33 ± 0.88^{d}	12.17 ± 0.09^{f}	373.67 ± 1.20^{f}
Commercial	UN	-	0.11 ± 0.00^{c}	1.43 ± 0.01^{fg}	66.93 ± 0.15^{b}	787.33 ± 1.20^{i}	16.70 ± 0.06^{a}	306.33 ± 0.88^{h}
	AC	1	0.14 ± 0.01^{abc}	1.56 ± 0.01^{c}	55.30 ± 0.35^{fgh}	782.67±0.88j	11.40 ± 0.06^{g}	381.00 ± 1.73^{f}
		2	0.13 ± 0.01^{bc}	1.57 ± 0.01^{cd}	59.17 ± 0.50^{de}	820.00 ± 0.58^{g}	11.47 ± 0.15^{g}	399.67 ± 1.45^{e}
		3	0.13 ± 0.01^{bc}	1.51 ± 0.01^{e}	54.50 ± 0.46^{gh}	782.00 ± 0.58^{j}	10.33 ± 0.03^{hi}	396.00 ± 1.15^{e}
	DC	1	0.16 ± 0.01^{a}	1.53 ± 0.01^{de}	70.00 ± 0.26^{a}	823.00 ± 0.58^{g}	15.13 ± 0.09^{bc}	493.33 ± 1.45^{a}
		2	0.15 ± 0.01^{ab}	1.56 ± 0.01^{cde}	60.27 ± 0.58^{d}	813.00 ± 0.58^{h}	15.23 ± 0.09^{b}	443.67 ± 0.67^{c}
		3	0.14 ± 0.01^{abc}	1.66 ± 0.01^{b}	66.50 ± 0.06^{b}	834.33 ± 1.20^{f}	17.07 ± 0.09^{a}	418.00 ± 1.15^{d}

UN = Unexposed to magnetic fields; AC = Exposed to magnetic fields that were generated through alternating current; DC = Exposed to magnetic fields that were generated through direct current. Means with the same letter along the column are not significantly different at $p < 0.05$

Table 4. 2: Effects of source of magnetic field (SMF), magnetic field intensity (MFI), and type of store on minor minerals

Store type	SMF	MFI	Cu (ppm)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cr (ppm)	Co (ppm)	B (ppm)
Not stored	-	-	1.33±0.01^{f}	23.20±0.12^{a}	4.32±0.03^{efg}	3.79±0.13^{gh}	0.41±0.02^{h}	0.48±0.02^{gh}	1.43±0.02^{f}
Control	UN	-	2.85±0.01^{b}	20.73±0.07^{c}	4.18±0.04^{efg}	9.27±0.04^{b}	0.72±0.01^{b}	0.95±0.01^{b}	1.78±0.04^{d}
	AC	1	1.07±0.01^{g}	16.97±0.18^{hi}	2.20±0.01^{i}	3.23±0.07^{i}	0.32±0.01^{i}	0.45±0.01^{h}	1.05±0.02^{g}
		2	1.07±0.01^{g}	18.17±0.09^{ef}	3.61±0.66^{fgh}	6.78±0.06^{c}	0.51±0.02^{def}	0.81±0.01^{cd}	1.43±0.02^{f}
		3	0.87±0.01^{h}	18.00±0.12^{efg}	4.28±0.00^{efg}	4.44±0.06^{ef}	0.34±0.01^{i}	0.54±0.02^{g}	1.76±0.02^{d}
	DC	1	0.62±0.01^{j}	18.93±0.20^{d}	3.25±0.03^{h}	5.42±0.04^{d}	0.42±0.01^{gh}	0.68±0.01^{f}	1.60±0.02^{e}
		2	3.53±0.07^{a}	21.40±0.06^{b}	4.55±0.10^{de}	10.57±0.15^{a}	1.35±0.01^{a}	1.25±0.01^{a}	2.25±0.01^{a}
		3	1.16±0.01^{e}	18.57±0.03^{de}	5.34±0.02^{cd}	3.24±0.06^{i}	0.45±0.01^{fgh}	0.70±0.01^{ef}	1.91±0.02^{bc}
Commercial	UN	-	1.15±0.01^{e}	16.63±0.18^{i}	4.20±0.01^{efg}	9.50±0.02^{b}	0.55±0.01^{d}	0.76±0.02^{cde}	1.37±0.03^{f}
	AC	1	2.28±0.02^{c}	17.67±0.07^{fg}	6.26±0.03^{b}	4.31±0.07^{f}	0.54±0.01^{de}	0.75±0.01^{def}	1.72±0.02^{d}
		2	1.38±0.01^{d}	17.70±0.06^{fg}	4.48±0.02^{def}	4.19±0.08^{fg}	0.48±0.01^{efg}	0.78±0.02^{cd}	1.82±0.01^{cd}
		3	0.69±0.01ij	17.50±0.06^{gh}	3.52±0.09^{gh}	3.41±0.09^{hi}	0.55±0.01^{d}	0.77±0.01^{cd}	1.48±0.03^{f}
	DC	1	0.44±0.01^{k}	23.77±0.09^{a}	5.59±0.02^{bc}	4.75±0.11^{e}	0.64±0.01^{c}	0.91±0.02^{b}	2.27±0.01^{a}
		2	0.45±0.01^{k}	20.50±0.17^{c}	3.80±0.01^{efgh}	7.17±0.02^{c}	0.69±0.02^{bc}	0.93±0.01^{b}	1.95±0.01^{b}
		3	0.74±0.01^{i}	18.07±0.12^{efg}	7.18±0.02^{a}	3.62±0.03^{hi}	0.53±0.01^{de}	0.82±0.01^{c}	1.80±0.01^{cd}

UN = Unexposed to magnetic fields; AC = Exposed to magnetic fields that were generated through alternating current; DC = Exposed to magnetic fields that were generated through direct current. Means with the same letter along the column are not significantly different at $p < 0.05$

This then allowed more loss of minerals as the water was evaporated from the tubers. Electric fields, such as pulsed electric fields, have been shown to reduce the hardness of potato tubers (Moens *et al*., 2021).

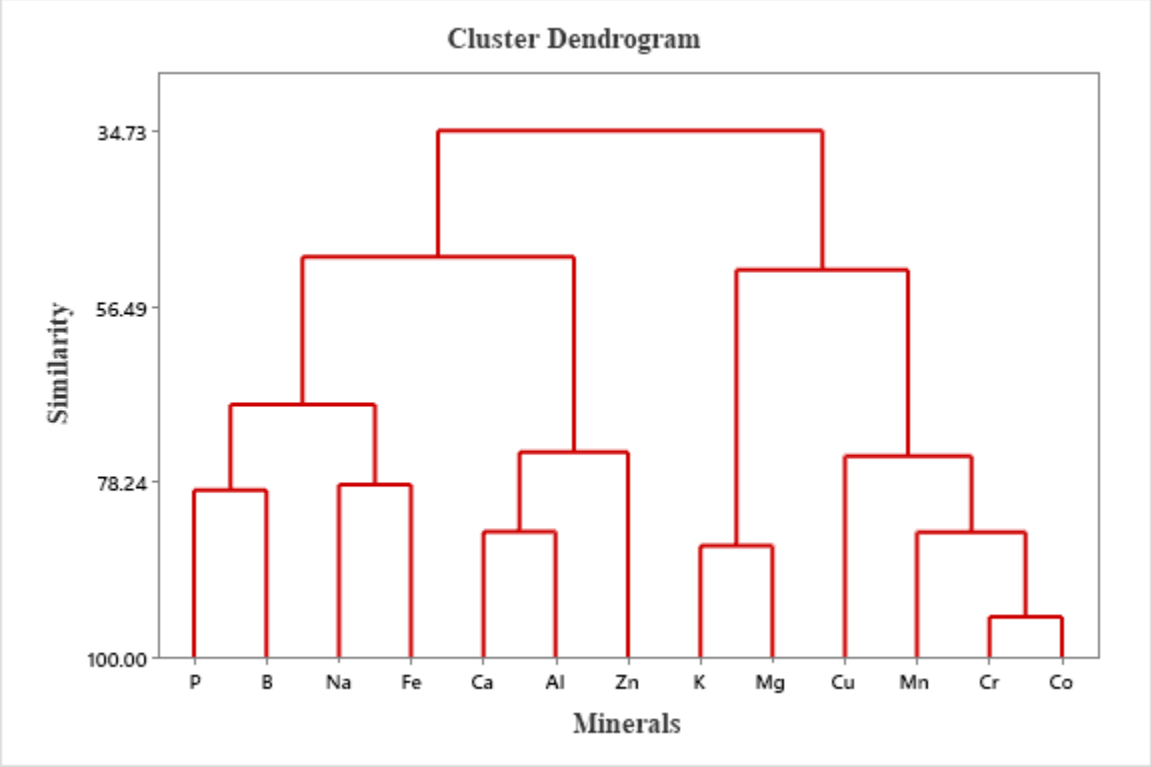

Figure 4. 8: Cluster groups of minerals based on their Pearson's correlation

Cluster groups of minerals based on their Pearson's correlation are given in Figure 4.8. Results from the similarity dendrogram support the findings from Tables 4.1 and 4.2. It helps us to understand groups of minerals that were influenced in the same manner by the MF. Minerals were grouped into five clusters. Cluster one was composed of phosphorus and boron, both of which significantly higher quantities were recorded after exposure of potatoes to 1 mT of DC MF and storage in the commercial store (Tables 4.1 and 4.2). Cluster two had sodium and iron, and again, the highest quantities of these two minerals were observed in the potatoes that were exposed to 1 mT of DC MF and further stored in the commercial store. In addition, the lowest quantities of them both were observed in the tubers that were not exposed to MF but stored in the commercial store. Cluster three consisted of calcium, aluminium, and zinc. These three had a relatable response to MF exposure. For instance, the least quantities of all the three were recorded after potatoes were exposed to 1 mT of AC MF and stored in the control store. In cluster four, potassium and magnesium were grouped together, while cluster five comprised copper, manganese, chromium,

and cobalt. All these had their highest quantities after exposure of potatoes to 2 mT of DC MF with subsequent storage in the control store.

It is evident from the dendrogram that there are two distinct sections, Section one had the first three clusters, while section two had the remaining two clusters. Section one shows the minerals whose highest quantities were recorded when potatoes were exposed to DC MF and stored in the commercial store, while section two gives the elements whose highest quantities were recorded when potatoes were exposed to 2 mT of DC MF and stored in the control store (Tables 4.1 and 4.2). In a similarity dendrogram, the shorter the joining bars, the higher the similarity (Forina *et al*., 2002). Chromium and cobalt had the shortest joining bars, and the two had a strong correlation of $r(10) = .90$, $p = .000$. On the other hand, the bar that joined zinc with calcium and aluminium was the longest. This is justified by the fact that the correlation between zinc and calcium was $r(10) = .52$, $p = .00$, while that of zinc and aluminium was $r(10) = .49$, $p = .001$.

4.4. Conclusion

Exposure of potatoes to MF impacted the proximate and mineral composition of stored potatoes. The use of AC MF led to a significantly low ether extract than potatoes that were not exposed to MF. Exposure of potatoes to MF with subsequent storage in the control store resulted in significantly higher ash content than the unexposed potatoes. Exposing potatoes to AC MF and storing them in the control store positively impacted on their total energy. Both major and minor minerals were positively influenced by DC MF and negatively impacted by AC MF. Findings from this work have provided a basis for manipulating MF to extend the shelf of potatoes during storage.

CHAPTER FIVE

USE OF MAGNETIC FIELDS REDUCES A-CHACONINE, A-SOLANINE, AND TOTAL GLYCOALKALOIDS IN STORED POTATOES (*SOLANUM TUBEROSUM* L.)

Abstract

Glycoalkaloids (GAs) are toxic, heat-resistant compounds that remain active even after the potato has been cooked. Postharvest management of potatoes has a great influence on the accumulation of GAs. This work aimed to assess the suitability of magnetic fields (MF) for the reduction of GAs in potatoes during storage. The effects of source of magnetic fields (2 levels; direct current and alternating current), magnetic field intensity (3 levels; 1, 2, and 3 mT), and storage type (2 levels; dark store – herein referred to as the control store and a commercial store with varying light intensity) on quantities of GAs were investigated. Magnetic fields were produced by the use of twin Helmholtz coils that were powered by either direct current (DC) or alternating current (AC). Potatoes of the *shangi* variety were subjected to varying strengths of MF by placing them at the centre of the coils for 80 seconds, after which they were stored in either of the stores for 2 months. At the end of storage, α-chaconine, α-solanine, and total glycoalkaloids (TG) were determined by the use of high-performance liquid chromatography. Treating potatoes to AC MF and storing them in the commercial store resulted in significant ($\rho < 0.05$) low levels of α-chaconine than potatoes that were not exposed to MF and those that were treated with DC MF. Subjecting tubers to increasing levels of MF intensities and placing them in the control store led to a significant ($\rho < 0.05$) decrease in α-chaconine and an increase in α-solanine. On the contrary, storage of potatoes in the commercial store after treatment to increasing MF intensities led to decreasing quantities of α-solanine and increasing levels of α-chaconine that were significant at a 95% level of confidence. The use of AC MF with an intensity of 2 mT resulted in a significant ($\rho < 0.05$) reduction in α-chaconine, α-solanine, and TG. These observations are associated with interference of biosynthesis pathways of GAs by the MF. The findings in the current work have shown that MF can be used to reduce quantities of toxic GAs in potatoes and thus improve on postharvest quality of potatoes

5.1. Introduction

Potato is the world's most widely consumed non-grain crop and the world's largest tuber food crop in terms of human consumption (Okamoto *et al*., 2020). In Kenya, its production is 2 million metric tonnes per year, contributing 31.82 kg of food per capita per year and providing 62 kcal of energy, 1.31 g of protein, and 0.09 g of fat per capita per day, respectively (FAOSTAT, 2020). It is a resilient crop that can protect vulnerable lifestyles under the effects of climate change and changing market situations because of its comparably short maturity time, nutritive properties, employment**,** and income opportunities (Singh *et al*., 2020; Wijesinha-Bettoni & Mouille, 2019). Potato tubers, on the other hand, are one of the most perishable types of fresh produce, with as much as 30% of the produce being lost after harvest (Stathers *et al*., 2020). The development of glycoalkaloids (GAs) is a major quality loss during the storage of potatoes. Glycoalkaloids are nitrogen-containing steroidal glycosides that are derivatives of the aglycone solanidine and their main constituents are α-chaconine and α -solanine. The glycosidic chain of α-solanine consists of glucose, galactose, and rhamnose units, whereas the chain of α -chaconine consists of one glucose unit and two rhamnose units (Nepal & Stine, 2019). The ratio of α-chaconine to α-solanine varies widely among potato varieties due to differences in genotypes and growing conditions (Ginzberg *et al*., 2009). However, α-chaconine is the most toxic of the two toxins, having twice as much toxicity as α-solanine (Friedman, 2006).

Glycoalkaloids are poisonous, heat-stable chemicals that remain active even after the potato has been cooked (Romanucci *et al*., 2016). Gastroenteritis, gastrointestinal pain, vomiting, diarrhea, fever, high pulse rate, low blood pressure, neurological and occasional deaths in humans have all been linked to their intake-induced poisoning (Koffi *et al*., 2017). Both α-chaconine and α -solanine have been shown to block human acetylcholinesterase, a neurotransmitter, and have been shown to affect the digestive system and other human organs by disrupting their cell membranes (Benkeblia, 2020). These toxins are capable of damaging nerve cells even at low concentrations. As a result, there is a set consumption limit for glycoalkaloids in potatoes, which must be less than 200 mg/kg fresh weight or 1000 mg/kg dry weight (Salem *et al*., 2021). When the concentration of GAs in potatoes is higher than 100 mg/kg fresh weight, bitter taste, and throat, and mouth burning is reported. Furthermore, the highest safe level of GAs for human consumption is about 1 mg/kg body weight; acute toxicity is caused by a level of about 1.75 mg/kg body weight; while the lethal dose is 3 to 6 mg/kg body weight (Schrenk *et al*., 2020; Tilahun *et al*., 2020).

Glycoalkaloids are thus becoming a public health concern as a result of the increased consumption of potatoes and potato products. Therefore, there is a need to ensure that they do not accumulate to toxic levels during storage.

Many studies have been conducted on GAs in potatoes during storage. These studies reported on the content, distribution, and changes of glycoalkaloids (Chen *et al.*, 2018; Deng *et al*., 2021; Dusza *et al.*, 2020; Wszelaczynska *et al*., 2020). Efforts have also been made to understand how light manipulation can be used to reduce levels of GAs during the storage of potatoes (Dickie *et al*., 2019; Nie *et al*., 2019; Okamoto *et al*., 2020; Rymuza *et al*., 2020). Zhang and co-researchers (2018) used hydrophobic nano-silica in an attempt to decrease the amount of α-solanine in potatoes under storage. Other non-thermal technologies with potential application in the reduction of GAs in stored potatoes include a combination of ethanol fumigation and nitrogen gas (Dong *et al*., 2017), pulsed electric fields (Hossain *et al*., 2015), treatment with ozone (Öztekin, 2018), and UV-C radiation (Rocha *et al*., 2015). However, to the best of my knowledge, no research has reported on the use of magnetic fields to reduce the levels of GAs in potatoes.

Magnetic fields are an emerging non-thermal green technology that has received special attention for its use in food preservation. The main benefit of magnetic fields is the way they interact with food, which includes both thermodynamic and quantum effects (Minano *et al*., 2020). They also have the benefit of reducing the impact of unwanted food changes caused by heat treatment, such as negative effects on nutrition, colour, flavor, texture, and aesthetics of food and food products. (Guo *et al*., 2021). In particular, MF has been used to improve the freezing of potatoes (Chen *et al*., 2021; Otero & Pozo, 2022; Purnell *et al*., 2017). They have also been used to reduce weight reduction on potatoes under storage (Lysakov *et al*., 2018). The aim of this work was therefore to investigate how magnetic fields can be used to reduce the formation of GAs on potatoes during two-month storage. *Shangi* potato variety was used in this study due to its popularity among Kenyan potato farmers and its short shelf life of less than one month. The effects of the source of magnetic fields and intensity on the contents of α-chaconine, α-solanine, and total glycoalkaloids were studied. Additionally, the effect of the type of storage (a commercial store with varying light intensities and a dark store) on GAs was investigated. This knowledge will inform on the suitability of MF in the reduction of postharvest losses of potatoes.

5.2. Materials and Methods

The research site, collection of potatoes, application of magnetic fields, and storage of treated tubers were as outlined in chapter three. Briefly, a registered potato farmer in Nakuru County, Kenya, provided fleshly harvested, clean, and disease-free *shangi* potatoes. Extra care was taken to ensure that sound agricultural techniques were followed during the cultivation and harvesting of the potatoes. Physiological maturity of harvested potatoes was assured by making sure that all the upper parts of the potato plant had withered. The potatoes were sorted by diameter, with tubers larger than 60 mm being picked (Kenya Plant Health Inspectorate Service, 2016). These were then cured for 5 days at ambient temperature (18±2 °C), after which they were treated to varying magnetic field strengths before being stored. Generation of MF was done by use of double Helmholtz coils (154 turns, 20 cm in radius) that were placed at a distance apart equal to their radii. These were supplied with either direct or alternating currents whose variations resulted in different magnetic field strengths of 1, 2, and 3 mT. Direct and alternating currents produced static and alternating MF respectively. Potatoes were then exposed to the different magnetic fields by hanging them at the centre of the coils for 80 seconds. Thereafter, potatoes were stored in different stores (a commercial store with varying light intensities and a dark store) for 8 weeks, before analyses of GAs. Conditions of the stores (temperature, dew point, and relative humidity) were monitored by use of a data logger (EL-USB-1; Lascar Electronics Inc. Pennsylvania, USA), and are as given in Figure 5.1.

5.2.1. Experimental design

A 2 × 4 × 2 factorial arrangement in a completely randomized design was used. The factors investigated were the source of magnetic fields (two levels; DC and AC), magnetic field intensity (four levels; 0, 1, 2, and 3 mT), and type of store (two levels; control and commercial store). The experiment was replicated thrice.

5.2.2. Determination of glycoalkaloids

The contents of α-solanine and α-chaconine were determined by the use of the high-performance liquid chromatography (HPLC) method using a Waters HPLC (Waters 2695, Waters Corporation, 34 Maple St, Milford, MA 01757-3696, USA), as described by Tomoskozi-Farkas *et al*. (2006).

Total glycoalkaloids were estimated by adding the individual amounts of α-solanine and α-chaconine.

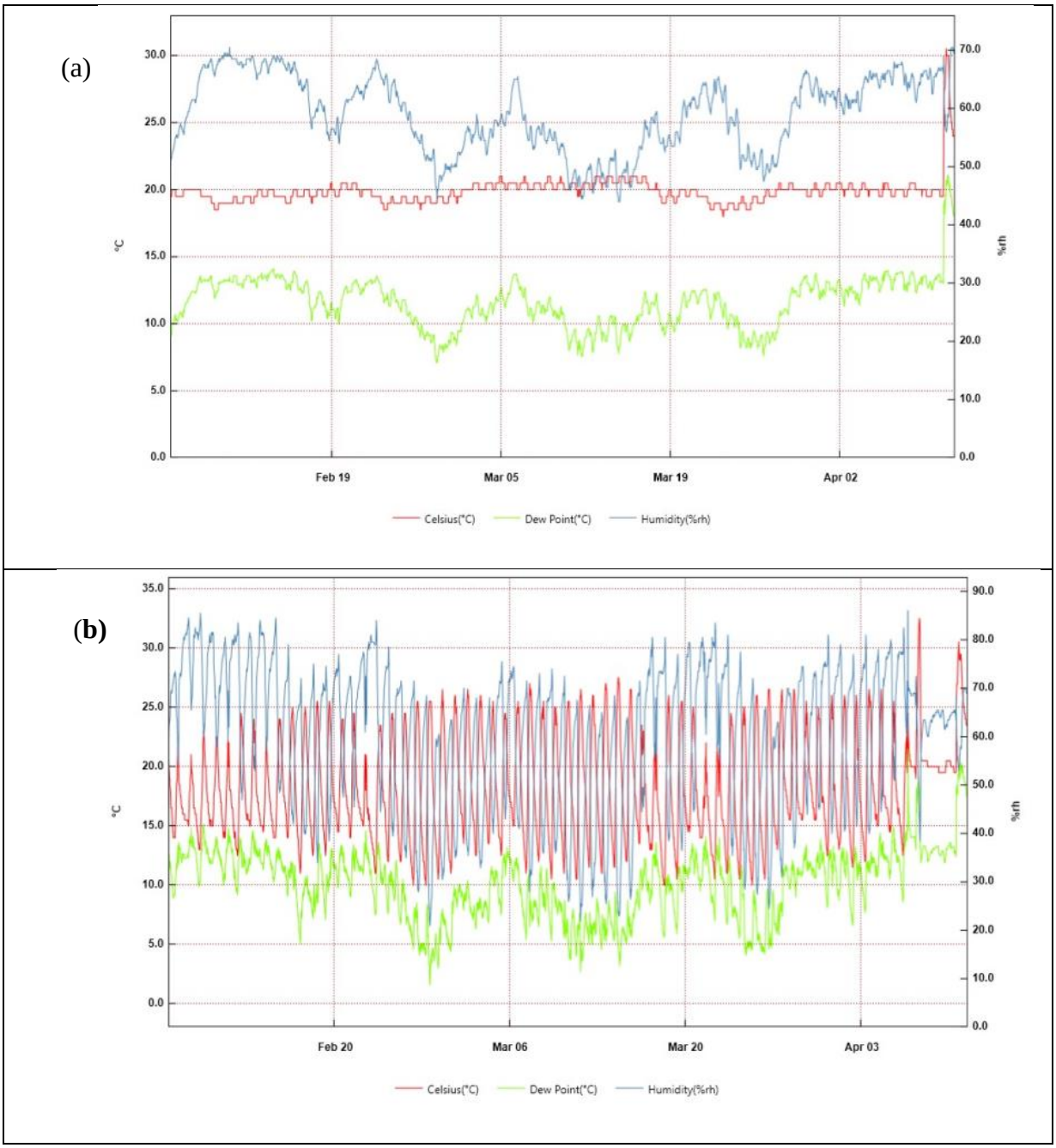

Figure 5. 1: Graphical print-out of storage conditions [temperature (°C), dew point (°C), and relative humidity (%)] of the two stores; control store (a) and commercial store (b) during the 8 weeks of storage.

5.2.3. Sample preparation

Tubers from each sample were washed, peeled, sliced into 5 mm strips, and blanched for 3 minutes in boiling water at 95 °C. They were then oven-dried at 80 °C for 72 hours, after which they were milled into powder, packaged into sealed plastic bottles, and stored at 4 °C awaiting analysis.

5.2.4. Extraction of Alkaloids

Five grams of lyophilized sample were weighed into a 50 mL-Falcon tube and 20 mL extraction solution (H_2O–acetic acid–$NaHSO_3$ (100 + 5 + 0.5, v/v/w)) was added. The mixture was homogenized using a vortex and centrifuged at 3,000 rpm for 20 min. The supernatant was collected. A solid-phase extraction (SPE) column (Sep-Pak C18 solid-phase disposable extraction cartridges with 360 mg packing material from Waters Corp., 34 Maple St, Milford, MA 01757-3696, USA) was placed on the vacuum manifold (SPE Vacuum-manifold for multiple solid-phase extractors) and conditioned with 5 mL acetonitrile followed by 5 mL extraction solution. This was followed by passing 10 mL of the extract through the column. The column was then washed with 4 mL SPE wash solution (15% acetonitrile). For the elution, 4 mL LC mobile phase (60% acetonitrile in 0.01M phosphate buffer) was used. The volume of the eluate was then adjusted to 5 mL with LC mobile phase. Each eluate was transferred to an HPLC vial ready for loading onto the HPLC.

5.2.5. High performance liquid chromatographic analysis

Both α-solanine and α-chaconine were separated and quantified using a Waters HPLC system that was equipped with an autosampler and a photodiode array detector. The HPLC instrument was fitted with a reverse phase C 18 (250 × 4.6 mm, 5 µm) column for the separation of GAs. The mobile phase was composed of acetonitrile: phosphate buffer of 0.01M (60:40, v/v) flowing at a rate of 1.5 mL/min. Detection of GAs was done at 202 nm with the ultraviolet detector by injecting 50 µL of the prepared sample after adjustment of the column temperature to 40 °C. Standard reference materials from Sigma Aldrich (α-solanine-from potato sprouts - CAS Number 20562-02-1, and α-chaconine - CAS number 20562-03-2) were also analyzed to certify the quality of the GAs detection in the potato samples. Glycoalkaloids were then calculated based on calibration curves that were generated from stock solutions and expressed as mg/kg on a dry weight basis.

5.2.6. Statistical analysis

The data obtained was first subjected to a normality test using the PROC UNIVARIATE procedure of the SAS software (SAS Institute Inc., Cary, NC, USA. Version 9). Analysis of variance was then carried out to investigate the effect of study variables on contents of GAs, using the General Linear Model procedure. Means were separated using Tukey's honestly significant difference test at a 95% confidence level.

5.3. Results and Discussion

5.3.1. Effects of the sources of magnetic fields under different types of store

The effects of the source of magnetic fields and type of store on potatoes are shown in Figure 5.2. There was a significant ($\rho < 0.05$) increase in α-chaconine, α-solanine, and TG (Total Glycoalkaloids) in potatoes that were stored in either the commercial or the control store than those that were not stored. During storage, potatoes respire to produce heat, and this favours the formation of GAs. In addition, at the end of dormancy, potatoes sprouted while under storage. It has been reported that sprouted potatoes accumulate more GAs than un-sprouted tubers (Friedman, 2006). This explains why there was more GAs in tubers that were stored for 2 months than those that were not stored. However, the few levels of the GAs present in the potatoes that were not stored are attributed to the inherent levels of GAs in the tubers that were accumulated while in the field. Potatoes are known to develop some GAs to act as a defense mechanism against nematodes, insects, bacteria, fungi, and viruses (Sanchez-Maldonado *et al*., 2016). The levels of these inherent GAs are dependent on species, environmental conditions, and management practices. Thus, the GAs found in the untreated tubers that were not stored are characteristics of the *shangi* potato variety (Musita *et al*., 2020).

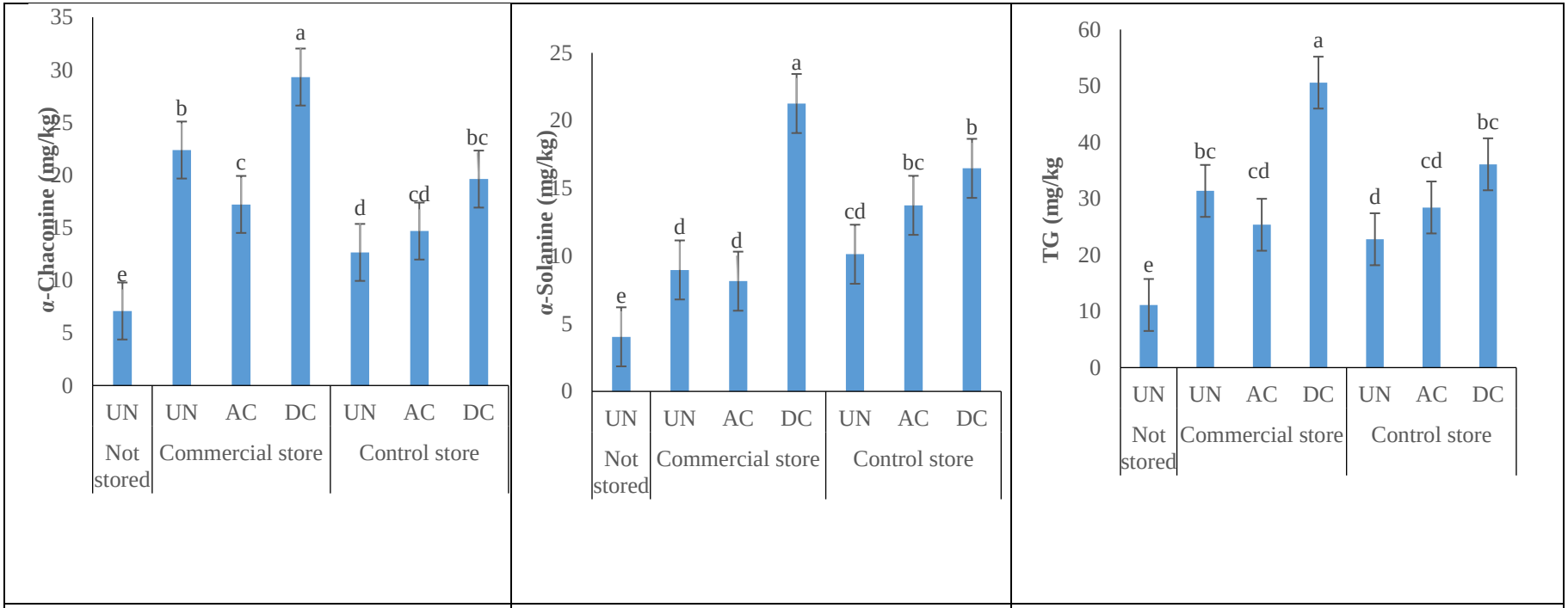

Figure 5. 2: Glycoalkaloids as affected by the source of magnetic fields under different stores.

UN: Unexposed to magnetic fields,

AC; Alternating current as a source of magnetic fields,

DC; Direct current as a source of magnetic fields,

TG; Total glycoalkaloids

For the commercial store, exposing potatoes to AC MF resulted in significant low amounts of α-chaconine (Figure 5.2a) than the potatoes that were not exposed to any magnetic fields as well as tubers that were subjected to DC MF and stored in the commercial store, at 95% level of confidence. In addition, treating tubers with AC MF and storing them in the commercial store resulted in low levels of α-solanine (Figure 5.2b) and TG (Figure 5.3c), which were significant ($p < 0.05$), in comparison to tubers that were exposed to DC MF and stored in the commercial store. For the control store, the untreated tubers had the lowest levels of α-chaconine, α-solanine, and TG (Figure 5.2). These were not significantly different from tubers that were treated with AC MF but were significantly different from those that were exposed to DC MF and stored in the control store at a 95% level of confidence.

In plants' biological systems, MF act through many models including the parametric resonance model, ion cyclotron resonance model, quantum excitations, and the radical pair model (Sarraf *et al*., 2020). These models explain how MF interferes with cell division and metabolism of various pathways. It has also been documented that MF affects cell division in food and plants (Jin *et al*., 2019; Maffei, 2014; Minano *et al*., 2020). According to Itkin *et al*. (2013), interfering with RNA (ribonucleic acid) silenced the metabolism of GAs resulting in their reduced levels in potatoes. The use of AC MF in the current study could therefore be said to have interfered with RNA which slowed down glycoalkaloids metabolism leading to low levels of α-chaconine, α-solanine, and TG in potatoes that were subjected to AC MF and stored in the commercial store. Itkin *et al*. (2013), further reported that silencing of RNA had the same effect on GAs concentration in potatoes that were stored in darkness and under exposure to light. This is also true in this study, where levels of GAs did not vary when potatoes were treated to AC MF and stored in either the control (dark store) or the commercial store (store with varying intensities of light), further solidifying the assumption that use of AC MF indeed interfered with the synthesis of RNA within the tuber cytoplasm.

When comparing the stores, potatoes that were under various sources of MF and stored in the control store, had significant ($\rho < 0.05$) lower amounts of α-chaconine than their corresponding treatments that were stored in the commercial store (Figure 5.2a). Subjecting tubers to different AC MF and storing them in the commercial store resulted in significant ($\rho < 0.05$) lower amounts of α-solanine than potatoes that were treated with AC MF and stored in the control store (Figure 5.2b). However, exposing potatoes to DC MF and storing them in the commercial store gave higher levels of α-solanine than the corresponding tubers that were stored in the control store, and this

was significant ($\rho < 0.05$). Similarly, significant ($p < 0.05$) higher values of TG were observed for the potatoes that were treated with DC MF and stored in the commercial store than those that were exposed to DC MF and stored in the control store (Figure 5.2c).

The high levels of GAs that were reported in potatoes that were stored in the commercial store are attributed to the light intensity that varied between 0 and 3.5 lux during night and day respectively. Light has been shown to stimulate the development of both α-solanine and α-chaconine. In particular, light excited key genes that encode enzymes necessary for the biosynthesis of GAs (Okamoto *et al*., 2020). In addition, MF has been shown to activate photoreceptors in plants especially cryptochromes which are flavoproteins that absorb blue light (Agliassa *et al*., 2018; Pooam *et al*., 2019). Given that potatoes that were subjected to DC MF and stored in the commercial store had significantly high levels of α-chaconine, α-solanine, and TG than all other treatments, it is probable that DC MF activated cryptochrome that resulted in increased biosynthesis of GAs. According to Siddique and Brunton (2019), the blue spectral region (< 500 nm) of light and infrared light (1000 nm) are the active elicitors of GAs synthesis. The light in the commercial store was from sunlight, which is mainly composed of both visible light (400 – 700 nm) and infrared light. We thus argue that this light source contained the active elicitors of GAs synthesis, whose activity was enhanced by the use of DC MF and thus the high levels of GAs in potatoes that were stored in the commercial store. Mekapogu *et al*. (2016) reported that exposure of potatoes to light elevated the expression of *Hmg1*, *Pss1*, *Sgt1*, *Sgt2*, and *Sgt3* genes that are actively involved in the synthesis of GAs. Thus, exposing potatoes to DC MF and storing them in the commercial store could have favoured more expression of these genes, leading to higher levels of GAs.

5.3.2. Effects of magnetic field intensity under store types

Figure 5.3 shows the effects of subjecting tubers to varying magnetic field intensities and storing them in either the control or the commercial store. The α-chaconine was visibly low in potatoes that were stored in the control store than in the commercial store for all the levels of MF. This was however significantly low ($\rho < 0.05$) when potatoes were subjected to 2 and 3 mT of MF (Figure 5.3a).

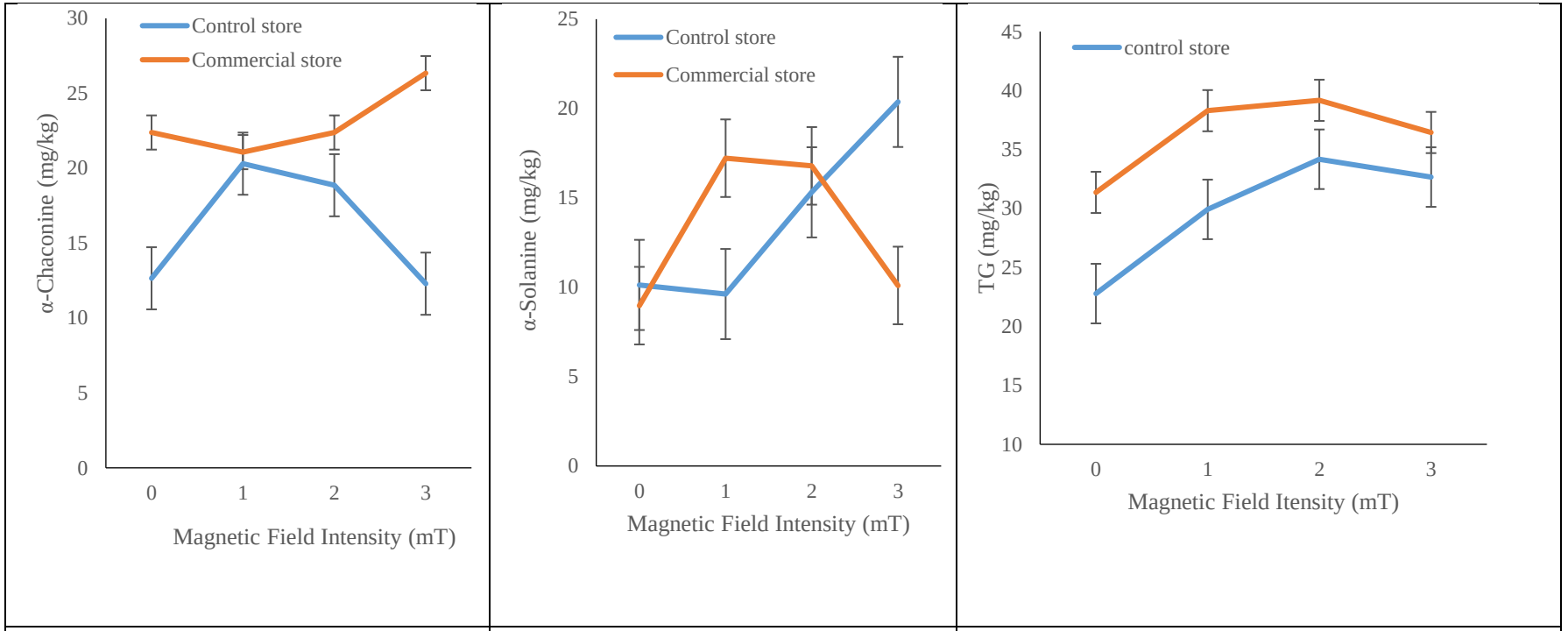

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Figure 5. 3: Glycoalkaloids as influenced by magnetic field intensities under different stores

TG = Total glycoalkaloids

Interestingly, α-chaconine increased ($\rho < 0.05$) when tubers were subjected to increasing strengths of MF (1 – 3 mT) and stored in the commercial store while it reduced ($p < 0.05$) during storage in the control store. On the contrary, α-solanine decreased ($\rho < 0.05$) when tubers were exposed to increased levels of MF and stored in the commercial store while they increased ($\rho < 0.05$ when tubers were

stored in the control store (Figure 5.3b). A different scenario was observed for TG where increasing MF intensity to 2 mT resulted in increased TG while storing tubers in either the control or the commercial store, with further increase in MF intensity to 3 mT resulting in a decrease in levels of TG (Figure 5.3c).

Synthesis of α-chaconine and α-solanine stem from the same steroidal aglycone solanidine. However, the glycosylation pathway is different for the two alkaloids due to the differences in their carbohydrate side chains (chacotriose for α-chaconine and solatriose for α-solanine). (Baur *et al*., 2021). Steroidal α-chaconine has one glucose and two rhamnose sugar units, whereas α-solanine has one galactose, one glucose, and one rhamnose sugar units. The first derivatives of solanidine glycosylation are the γ-solanine and γ-chaconine for the biosynthesis of α-solanine and α-chaconine respectively. These are mediated by *Sgt1* (solanidine galactosyltransferase) and *Sgt2* (solanidine glucosyltransferase) genes respectively (Mekapogu *et al*., 2016). The use of MF to regulate gene expression in plants has been documented (Agliassa *et al*., 2018; Dhiman & Galland, 2018; Paul *et al*., 2006). It can thus be argued that exposing potato tubers to different strengths of MF and storing them in the commercial store overexpressed the activity of *Sgt2* due to silencing of *Sgt1* leading to increased levels of α-chaconine and decreased levels of α-solanine as the intensity was increased from 1 to 3 mT. On the other hand, subjecting potatoes to MF and storing them in the control store favoured overexpression of *Sgt1* over *Sgt2* and this resulted in increasing quantities of α-solanine and decreasing amounts of α-chaconine as MF intensity was increased linearly from 1 to 3 mT. Similar findings have been reported by McCue *et al*. (2006) and McCue *et al*. (2005) who reported that suppressing *Sgt1* in potato tubers, through the use of an antisense transgene, inhibited the synthesis of α-solanine leading to increased levels of α-chaconine. Another key finding from this work is that a dark store enhanced the production of α-solanine while a lighted store favoured the synthesis of α-chaconine only. This is because α-solanine and α-chaconine were significantly higher in control and commercial store respectively at 3 mT of MF intensity. Therefore, the expression of *Sgt1* is optimized in a dark store while the expression of *Sgt2* is optimized in a store with varying light intensity. This could explain why Musita *et al*. (2020) reported a higher α-chaconine to the α-solanine ratio in *shangi* potatoes that were exposed to long periods of *light*.

The final step in the synthesis of α-solanine and α-chaconine is the conversion of β-solanine and β-chaconine, through the addition of L-rhamnosyl sugar moiety that are both mediated by *Sgt3* (rhamnosyl transferase) gene (Kalinowska *et al*., 2005; McCue *et al*., 2007). Therefore, increasing MF intensity to 2 mT resulted in linear overexpression of *Sgt3* leading to increased levels of TG. However, 2 mT was the optimum intensity for the expression of this gene where further increase in intensity to 3 mT suppressed its expression and thus the reduction in TG. It is documented that a positive correlation between *HMGR* (3-hydroxy-3-methylglutarl coenzyme A reductase), *SQS* (squalene synthase), and *Smt1* (S-adenosyl- L –methionine: sterol C24-methyl transferases type 1) genes with steroidal GAs in potatoes exists (Cardenas *et al*., 2015). Thus, it is possible that increasing magnetic field intensity to 2 mT led to an overexpression of *HMGR*, *SQS*, and *Smt1* genes leading to a linear increase in the level of TG. However, further increase of magnetic intensity to 3 mT led to inhibition of their expression and as result, the quantities of TG were reduced.

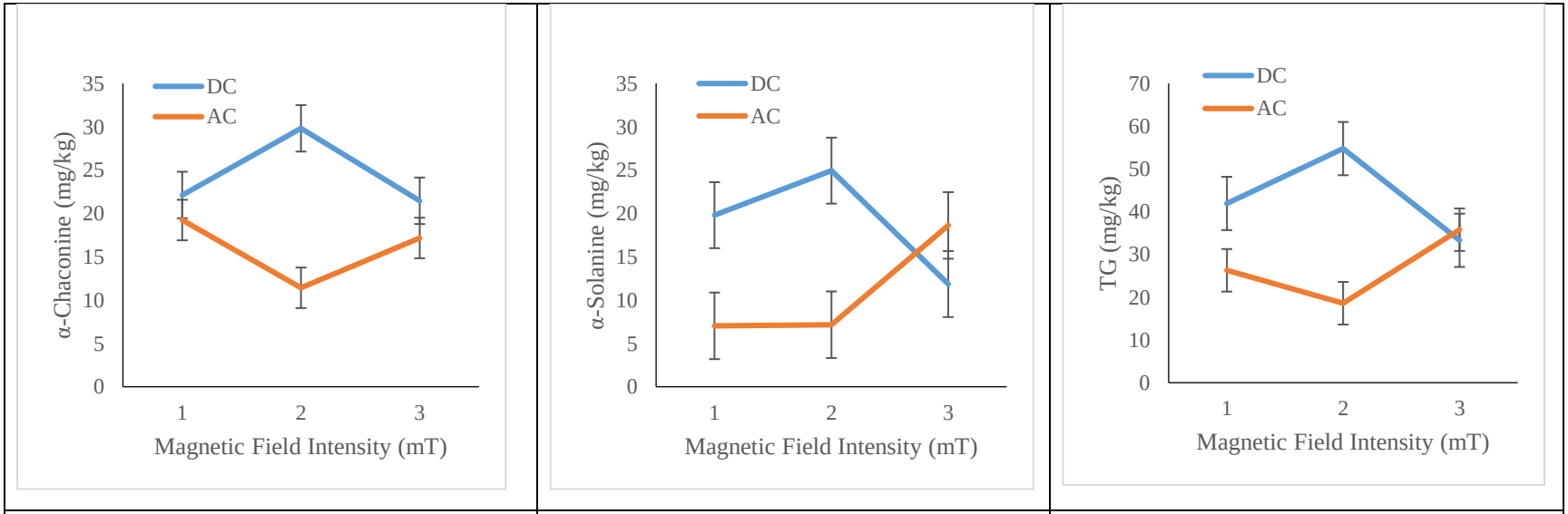

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Figure 5. 4: Glycoalkaloids as influenced by magnetic field intensities produced either through direct current (DC) or alternating current (AC), TG = Total glycoalkaloids

5.3.3. Effects of sources of magnetic fields and magnetic field intensity

The effects of magnetic field intensities as produced by either DC or AC on GAs are shown in Figure 5.4. Subjecting potatoes to DC MF resulted in significant ($\rho < 0.05$) higher levels of α-chaconine, α-solanine, and TG, than exposing them to AC MF for 1 and 2 mT. However, for the 3 mT, there was no significant ($p < 0.05$) difference between using DC or AC in the generation of MF on GAs. Subjecting tubers to 2 mT of MF appeared to be the optimum intensity for the formation of GAs. This is because α-chaconine, α-solanine, and TG increased from 1 to 2 mT when potatoes were subjected to DC magnetic fields but decreased sharply when MF was further increased to 3 mT (Figure 5.4). On the contrary, increasing magnetic field intensity from 1 to 2 mT through AC resulted in a decrease in α-chaconine, α-solanine, and TG, but a further increase of intensity to 3 mT resulted in a sharp increase in the GAs. These changes were significant for α-chaconine and TG, but not α-solanine.

During storage, potatoes can accumulate GAs due to the excitation of key enzymes that favour glycosylation. Quantities of GAs can also reduce when enzymes that catalyse the hydrolysis of glycosides are stimulated (Friedman *et al*., 1997; Friedman, 2006; Ginzberg *et al*.**,** 2009). Models on the use of MF on enzyme kinetics are explained (Letuta *et al*., 2017). Some studies have also documented the effects of MF on enzyme activities in plants (Asghar *et al*., 2016; Podlesny *et al*., 2021). Therefore, it is plausible that exposing tubers to DC MF and increasing the magnetic field intensity to 2 mT favoured glycosyltransferase enzyme to catalyse the glycosylation of the soladine aglycone to form GAs. This led to the increase in the contents of α-chaconine, α-solanine, and TG. However, 2 mT seemed to be the optimum intensity of the activity of glycosyltransferase. Further increase of intensity to 3 mT suppressed its activity resulting in a decrease in levels of GAs. On the contrary, treating potatoes with AC MF with intensities of up to 2 mT activated hydrolytic enzymes galactosidase, glucosidase, and rhamnosidase that gradually cleaved galactose, glucose, and rhamnose side chains respectively, of the aglycon solanidine. Hydrolysis could either be to β_1, β_2, or γ intermediates of chaconine and solanine glycosides (Friedman, 2006). As a result, α-chaconine, α-solanine, and TGs reduced in potato tubers. The MF value of 2 mT was the optimum intensity for the action of the hydrolytic enzymes However, an increase to 3 mT resulted in their suppression and thus an increase in quantities of GAs.

During the biosynthesis of steroidal glycoalkaloids, cholesterol acts as a common precursor. Several hydroxylation, oxidation, and transamination processes are required to convert cholesterol to the unsaturated aglycone solanidine (Friedman *et al*., 1997; Itkin *et al*., 2013). Glycoalkaloid levels can be reduced when the steroidal GA biosynthesis pathway is altered by targeting potato genes encoding these processes. (Sawai *et al*., 2014). According to Umemoto *et al*. (2016), two cytochrome P450 monooxygenase genes (*PGA1* and *PGA2*) mediate oxidation steps during the synthesis of GAs. Therefore, silencing those results in low levels of GAs. We thus claim that exposing tubers to AC MF at 2 mT of MF intensity silenced these cytochrome P450 genes leading to significantly low levels of α-chaconine, α-solanine, and total glycoalkaloids. Another possible explanation as to why exposing potato tubers to AC MF for 2 mT resulted in significantly low levels of α-chaconine, α-solanine, and TG is that the *SSR2* (sterol side-chain reductase 2) gene was silenced with this treatment. This follows findings by Sawai *et al*., (2014) who reported that *SSR2* is key in the biosynthesis of cholesterol and that when it is silenced, then the quantities of GAs reduce.

5.3.4. Effects of type of store, source of magnetic field, and magnetic field intensity

The effects of treating potatoes to different MF intensities from different sources of MF and storing them in different stores are shown in Table 5.1. As expected, the lowest levels of GAs were recorded for the potatoes that were not subjected to any treatment (not stored). However, exposing potato tubers to AC MF at intensities of 2 mT and storing them in either the control or the commercial store resulted in low levels of α-chaconine, α-solanine, and TG than those tubers that were not exposed to any MF and stored in either the control or the commercial store, as well as those tubers that were exposed to DC MF at all levels of MF intensities. Thus, it can be concluded that a significant reduction in quantities of GAs in stored potatoes can be achieved by exposing them to AC MF at 2 mT for 80 seconds before storage. This is a breakthrough, given that no previous research has reported on the use of MF to reduce levels of GAs in potatoes. This study has therefore provided a basis for more research on the use of MF to improve the postharvest quality of potatoes.

Table 5. 1: Effects of type of store, source of magnetic field, and magnetic field intensity on glycoalkaloids

Store type	SMF	MFI	α-Chaconine (mg/kg)	α-Solanine (mg/kg)	TG (mg/kg)
Not stored	-	-	7.08 ± 0.17^{h}	4.03 ± 0.58^{d}	11.11 ± 0.60^{f}
Control	UN	-	12.65 ± 0.78^{fgh}	10.13 ± 0.69^{bcd}	22.78 ± 0.56^{de}
	AC	1	20.97 ± 1.67^{cd}	9.21 ± 0.21^{cd}	30.18 ± 1.65^{c}
		2	13.07 ± 1.07^{fg}	7.11 ± 0.09^{cd}	20.18 ± 1.04^{e}
		3	10.00 ± 0.98^{gh}	24.89 ± 3.07^{a}	34.89 ± 2.09^{c}
	DC	1	19.62 ± 0.72^{cde}	10.04 ± 0.98^{bcd}	29.66 ± 0.74^{cd}
		2	24.65 ± 0.78^{bc}	23.50 ± 0.97^{a}	48.16 ± 0.69^{b}
		3	14.58 ± 0.94^{efg}	15.89 ± 2.89^{b}	30.43 ± 2.07^{c}
Commercial	UN	-	22.38 ± 0.91^{cd}	8.97 ± 0.83^{cd}	31.36 ± 0.86^{c}
	AC	1	17.51 ± 1.16^{def}	4.87 ± 0.33^{d}	22.38 ± 1.26^{e}
		2	9.77 ± 1.29^{gh}	7.21 ± 0.55^{cd}	16.98 ± 1.23^{ef}
		3	24.34 ± 0.89^{bc}	12.36 ± 0.33^{bc}	36.70 ± 0.57^{c}
	DC	1	24.63 ± 0.76^{bc}	29.57 ± 0.79^{a}	54.20 ± 1.55^{b}
		2	35.00 ± 1.51^{a}	26.37 ± 0.44^{a}	61.37 ± 1.95^{a}
		3	28.34 ± 2.13^{b}	7.84 ± 0.80^{cd}	36.18 ± 1.68^{c}

SMF= Source of Magnetic Field; MFI= Magnetic Force Intensity; UN= Unexosed to magnetic fields; AC= Alternating Current; DC= Direct Current; TG= Total Glycoalkaloids; Means with the same letter along the column are not significantly different at $p < 0.05$

5.4. Conclusion

Glycoalkaloid content in potatoes is of importance to the potato business and policymakers to ensure consumer safety. Investigation of the effects of magnetic fields on the reduction of glycoalkaloids in potatoes during 2-month storage was done in this study. Subjecting potato tubers to magnetic fields with intensities of 2 mT, that were generated by the use of an alternating current showed a significant reduction in quantities of α-chaconine, α-solanine, and total glycoalkaloids. This study has provided useful information that can be used to optimize the storage of potatoes and ultimately improve food and nutritional security. The action of magnetic fields on the biosynthetic pathway of glycoalkaloids is hypothesized in this study. Future studies should examine how magnetic fields interfere with genes that encode various enzymes that mediate specific steps in the synthesis of potato glycoalkaloids.

CHAPTER SIX

ANTIOXIDANT LEVELS AND ACTIVITY IN POTATOES DURING STORAGE ARE AFFECTED BY POSTHARVEST EXPOSURE TO MAGNETIC FIELDS.

Abstract

A novel technique for preserving potatoes using magnetic fields (MF) was developed. The effects of sources of magnetic fields (direct current (DC) and alternating current (AC)) and magnetic field intensity (1. 2, and 3 mT) on the antioxidants of potatoes after storage were investigated. Exposing potatoes to 3 mT of AC MF and storing them in the control store (dark store) significantly increased the content of ascorbic acid by 37% in comparison to the fresh tubers. Potatoes that were exposed to both DC MF and AC MF recorded significantly higher chlorophyll b than fresh tubers. Exposing potatoes to 3 mT of DC MF with storage in the control store and 3 mT of AC MF with storage in the commercial store (store with varying light intensities) resulted in an 11% and 21% increase in carotenoids, respectively. Total polyphenols decreased with storage apart from the samples that were exposed to 1 mT of AC MF and 1 mT of DC MF and stored in the control and commercial stores respectively, whose contents were comparable to the fresh samples. The antioxidant activities of potatoes that were exposed to DC MF were comparable to that of fresh tubers. The results revealed that the use of MF may be a promising approach for the increased production and preservation of antioxidants in potatoes during their postharvest storage.

6.1. Introduction

The importance of antioxidants in the human diet is gaining popularity, thanks to epidemiological studies that have shown that eating vegetables can protect human beings from a number of chronic diseases such as diabetes, obesity, a variety of cancers, and cardiovascular diseases (Deledda *et al*., 2021). Potatoes are a good source of antioxidants (Hellmann *et al*., 2021). The most prevalent antioxidants in potatoes are anthocyanins, polyphenols, phenolics, ascorbic acid, and carotenoids (Brown, 2005). Different potato market types with different tuber flesh and skin colours have different antioxidant activity and compounds that function as antioxidants. Purple-skinned cultivars have the highest antioxidant activity, followed by red-skinned cultivars, and yellow-skinned cultivars (Lachman & Hamouz, 2005). The amount and activity of antioxidants are also dependent on genetic makeup and environmental conditions under which potatoes are grown (Keutgen *et al*., 2019). The activity of antioxidants is higher in potatoes than most vegetables (Blessington *et al*., 2010). This is good news given that potato is the most worldwide consumed non-grain crop (Singh *et al*., 2021). Therefore, it helps in not only alleviating food malnutrition but also chronic ailments through its great contribution to dietary phytochemical concentrations.

The contents and activity of antioxidants are influenced by the storage conditions of harvested potatoes. A review by Ezekiel *et al*. (2013) found that the use of irradiation to inhibit sprouting in stored potatoes resulted in increased amounts of total phenols after storage of tubers both at cold and ambient temperatures. The content of ascorbic acid and carotenoids have been found to decrease during cold storage (Davies *et al*., 2002; Morris *et al*., 2004). On the other hand, phenolic acid was shown to increase upon storage at 4 °C (Lewis *et al*., 1999). Studies by Rosenthal and Jansky (2008) and Blessington *et al*. (2010) reported higher antioxidant activities in potatoes that had been stored at 5.6 °C and 4 °C respectively than tubers that were not stored. However, postharvest storage of potatoes in developing countries is mainly done under ambient temperatures through rudimentary technologies (Akello *et al*., 2022; Degebasa, 2020; Singha & Maezawa, 2019). This is because the majority of farmers are small-scale producers who lack the capacity to install cold stores. This has resulted in the inability of these farmers to safely store their produce for long enough until when prices are more favourable (Allen & de Brauw, 2018). This is mainly contributed by storage losses such as sprouting, greening, nutritional and phytochemical losses. Cold storage is also not ideal for potatoes that are destined for processing due to its association with increased tuber sweetening (Tai *et al*., 2020). Additionally, there is limited research on how

ambient storage of potatoes can be optimized for the retention of antioxidants. Thus, there is the need to innovatively improve the quality of potatoes that are stored at ambient temperatures. The use of magnetic fields (MF) presents that potential.

Magnetic fields are clean, safe, and environmentally friendly, whose use has shown promising applications in food preservation. A review by Ahmed and Ramaswamy (2020) revealed that MF have been used in food pasteurization, sterilization, freezing of foods, microbial and biological systems, and in isolation and separation of protein. The effects of MF on the antioxidant activity of plants have been reported (Sarraf *et al*., 2020). They include regulation of antioxidant defence mechanism in soybean against alkalinity stress (Kataria *et al*., 2019); increase in catalase activity and radical scavenging capacity of wheat (Ghanati & Payez, 2015); enhanced activity of ascorbate peroxidase and catalase in parsley cells (Rajabbeigi *et al*., 2013); oxidation of free radicals by reduction of proline thus protection of plants against tissue damage (Dhawi, 2014) and regulation of redox in plants through enhancement of free radical ions (Maffei, 2014). Potato tubers are living organisms that continue to respire even during storage (Alexopoulos & Petropoulos, 2021). Thus, their exposure to MF was anticipated to impact on synthesis and activity of antioxidants. In addition, there are attempts that have been made to reduce other postharvest losses during the storage of potatoes such as sprouting, weight reduction, tuber greening, formation of undesirable sugars, and formation of toxic glycoalkaloids using MF (Jakubowski, 2019; Lysakov, 2019). Hence, Potatoes are a good candidate for research using MF.

To the best of my knowledge, there is no research that has been conducted on the use of MF to avoid losses of antioxidants in potatoes during postharvest storage. There is also the need to investigate how antioxidants would be affected when potatoes are exposed to MF and stored in different stores. The objective of this work was therefore to assess the suitability of using MF in the retention of potato antioxidants during two-month storage. A further aim was to study the effects of sources of MF, the exposure period of potatoes to MF, and types of potato stores on quantities and activity of antioxidants. Findings from this study will inform on how MF can be utilized to innovatively improve on postharvest storage of potatoes to avoid losses.

6.2. Materials and Methods

The research location, potato collecting, magnetic field application, and storage of treated tubers all took place as described in chapters three, four, and five. In a nutshell, shangi potatoes that had

been cleanly harvested and free of illness were delivered by a registered potato farmer in Nakuru County, Kenya. The cultivation and harvesting of the potatoes were done with extra care to guarantee that good agricultural practices were used. The potatoes were separated according to diameter, and tubers that were greater than 60 mm were chosen (Kenya Plant Health Inspectorate Service, 2016). After being cured for 5 days at room temperature, these were then subjected to various magnetic field intensities before being stored. Double Helmholtz coils (154 turns, 20 cm in radius) were used to generate the MF, and they were positioned at a distance equal to their radii apart. These were powered by either direct or alternating currents, whose variations produced magnetic fields of 1, 2, and 3 mT. Static MF was created by direct current, while alternating MF was created by alternating current. Then, by suspending potatoes for 80 seconds at the center of the coils, varying magnetic fields were applied to them. Before antioxidant studies, potatoes were kept for 8 weeks in two separate storage facilities (a commercial facility with varying light intensities and a dark facility). Using a data logger (EL-USB-1; Lascar Electronics Inc. Pennsylvania, USA), the stores' conditions were observed for temperature, dew point, and relative humidity.

6.2.1. Experimental design

A completely randomized design with a factorial layout of 2 × 3 × 2 was employed. The sources of the magnetic fields (at two levels: DC and AC), the intensity of the magnetic fields (at three levels: 1, 2, and 3 mT), and the type of store (at two levels; control and commercial store) were all factors that were examined. The experiment was replicated thrice.

6.2.2. Determination of ascorbic acid

The concentration of ascorbic acid was evaluated following the method by Egoville *et al*. (1988). About 15 grams of potato tuber sample was extracted with oxalic acid (0.4%) and acetone solution (20%) through homogenization at 4000 rpm for 5 minutes. The extract was filtered using Whatman filter paper (No. 2) and topped up with the same extracting solution to a total volume of 100 mL. After that, 5 mL of the extracts were allowed to react for 2 minutes with 2 mL of 2, 6-dichloroindophenol (1.6%) and absorbance read at 520 nm using a spectrophotometer (UV-1800, Shimadzu, Kyoto, Japan). Oxalic acid and 2, 6-dichloroindophenol were used to make the blank. A standard curve of 0, 0.2, 0.5, 0.8, and 1 mg/100 mL of ascorbic acid was used to determine the concentration of ascorbic acid. The amount of ascorbic acid was expressed as mg/100 mL.

6.2.3. Determination of chlorophyll a, chlorophyll b, and carotenoids

Extraction of chlorophyll and carotenoids was done by placing 5 grams of sample and 80% acetone (10 mL) in a mortar and pressing with a pestle, in the dark. An adequate amount of magnesium carbonate was added into the mortar to prevent the pheophytinization of chlorophyll during extraction. Extracts were then centrifuged at 5000 rpm for 10 min. The homogenized mixture was filtered. The contents of the mortar and pestle were quantitatively transferred to the filter after being rinsed multiple times with acetone. The rest of the filter was washed with acetone until it was entirely white. The absorbance was taken at 647, 663, and 470 nm, respectively using a spectrophotometer (UV-1800, Shimadzu, Kyoto, Japan). The pigments were then determined according to the following formulae and expressed as µg/mL fresh weight, as outlined by Lichtenthaler. (1987);

$$Chlorophyll\ a = (12.25 \times A663) - (2.79 \times A647)$$

$$Chlorophyll\ b = (21.50 \times A647) - (5.10 \times A663)$$

$$Carotenoids = \frac{1000 \times A470 - 1.82 \times Chl\ a - 85.02 \times Chl\ b}{198}$$

Where A = is the absorbency at the corresponding wavelength; 12.25, 2.79, 21.50, 5.10, 1.82 and 85.02 are specific absorption coefficients

6.2.4. Determination of total polyphenols

Total polyphenols were determined using the Folin-Ciocalteu reagent method as outlined by Pourmorad *et al*. (2006). A dilute extract of each sample extract or gallic acid (standard polyphenol compound) was mixed with 5 mL of Folin-Ciocalteu reagent and 4 mL of aqueous sodium carbonate (Na_2CO_3, 1 M). The mixtures were allowed to stand for exactly 15 minutes after which total polyphenols were determined by colorimetry at 765 nm (UV-1800, Shimadzu, Kyoto, Japan). Standard stock solutions of 0, 50, 100, 150, 200 and 250 ppm in methanol:water (50:50, v/v) were used to prepare standard curve. Total polyphenols were expressed in terms of gallic acid equivalent (mg/g) and then converted into percentage

6.2.5. Determination of antioxidant activity

The DPPH (1,1-diphenyl-2-picrylhydrazyl) radical scavenging activity method as previously described by Brand-Williams *et al*. (1995) and modified by Karori *et al*. (2007) was used in the assay of antioxidant activity. Five grams of sample were infused in 100 mL of boiling double-

distilled water, stirred with a magnetic stirrer, and steeped at room temperature for 30 minutes. The extracts were strained through a nylon mesh (120 µm) before being filtered using Whatman filter paper (No. 54). The extracts were kept frozen at -1 °C until they were needed for further use. The soluble solid extract was standardized to produce stock solutions containing 50 mg of soluble solids per 100 mL of 50% methanol. In a cuvette, a methanolic solution of the antioxidant (50 µL) was added, followed by a methanolic solution of DPPH (2 mL) (DPPH solution was produced with 80 percent methanol). A UV (UV-1800, Shimadzu, Kyoto, Japan) spectrophotometer was used to measure the decrease in absorbance at 515 nm until the absorbance stabilized. Reading took place at intervals of every 15 or 30 minutes. To prevent the loss of free radical stock solution, the DPPH solution was made fresh and maintained in the dark. All of the tests were carried out thrice. The inhibition of DPPH radical (%) was calculated from the absorbance data, as follows;

$$\%\ inhibition\ against\ DPPH = \left[\frac{Ab - Aa}{Ab}\right] \times 100$$

Where Ab = absorbance of the blank sample, Aa = absorbance of the test sample after 15 min.

6.2.6. Statistical analyses

The PROC UNIVARIATE procedure of the Statistical Analysis System (SAS) software version 9.4 (SAS Institute Inc., Cary, NC, USA) was used to perform the Kolmogorov-Smirnov test on the data to ensure that the distribution was normal. Using the General Linear Model (PROC GLM) approach, analysis of variance (ANOVA) was done to look into the effects of the source of magnetic fields, the intensity of the magnetic field, and the type of store on antioxidants content and activity. The HOVTEST = LEVENE method was used to examine the homogeneity of variance. The Tukey's HSD (honestly significant difference) test was used to separate the means at $\rho < 0.05$ level of significance.

6.3. Results and Discussion

6.3.1. Normality test and homogeneity of variance

At a significance level of 0.05, the results of the Kolmogorov-Smirnov and Levene tests revealed normality in the data distribution and homogenous variances, respectively. These findings made it possible to perform an analysis of variance on the data.

6.3.2. Ascorbic acid

Figure 6.1 shows the effects of study variables on ascorbic acid. Significant higher values of ascorbic acid were observed in the control store than in the commercial store. Ascorbic acid is sensitive to light, whereupon exposure, it is oxidized to reversible dehydroascorbic acid and further to irreversible 2,3-diketogulonic acid (Yin *et al*., 2022). The commercial store had varying light intensities, where during the day, illumination was about 3.5 lux. This light degraded ascorbic acid in potatoes that were stored in this store, thus the low values of this pigment than in potatoes that were stored in the control store (control store was completely dark with constant light illumination of 0 lux). Similar findings on photodegradation of ascorbic acid in potatoes under storage have been reported in other studies (Abbasi *et al*., 2016). However, in the commercial store, tubers that were exposed to AC MF had significantly higher amounts of ascorbic acid than potatoes that were not exposed to MF and stored in the same store, at a 95% level of confidence. I argue that subjecting potatoes to AC MF created a shielding wall that protected tubers from the sensitive environment that was found in the commercial store, thereby preventing the degradation of ascorbic acid. It is also worth noting that increasing intensities of AC MF on potatoes and storing them in the commercial store resulted in a corresponding decrease in the amount of ascorbic acid. Therefore, it is plausible that increasing intensity of AC MF weakened the shielding wall resulting in decreasing amounts of ascorbic acid as a result of subsequent degradation of the acid. Shielding of ascorbic acid from harsh environments has been done through other technologies (Carvalho *et al*., 2019; Chang *et al*., 2010; Comunian *et al*., 2014; Jiménez-Fernández *et al*., 2014).

The highest content of ascorbic acid was observed for the tubers that were exposed to 3 mT of DC MF and stored in the control store. This was significantly high than all other treatments, including tubers that were not exposed to MF and not stored, as well as those that were not subjected to MF and stored in both the control and the commercial stores. In addition, exposing potato tubers to 2 and 3 mT of AC MF and storing them in the control store resulted in significantly higher amounts of ascorbic acid than tubers that were not treated with MF and not stored, although this did not

don’t differ with potatoes that were not exposed to MF and stored in the control store at a 95% level of confidence.

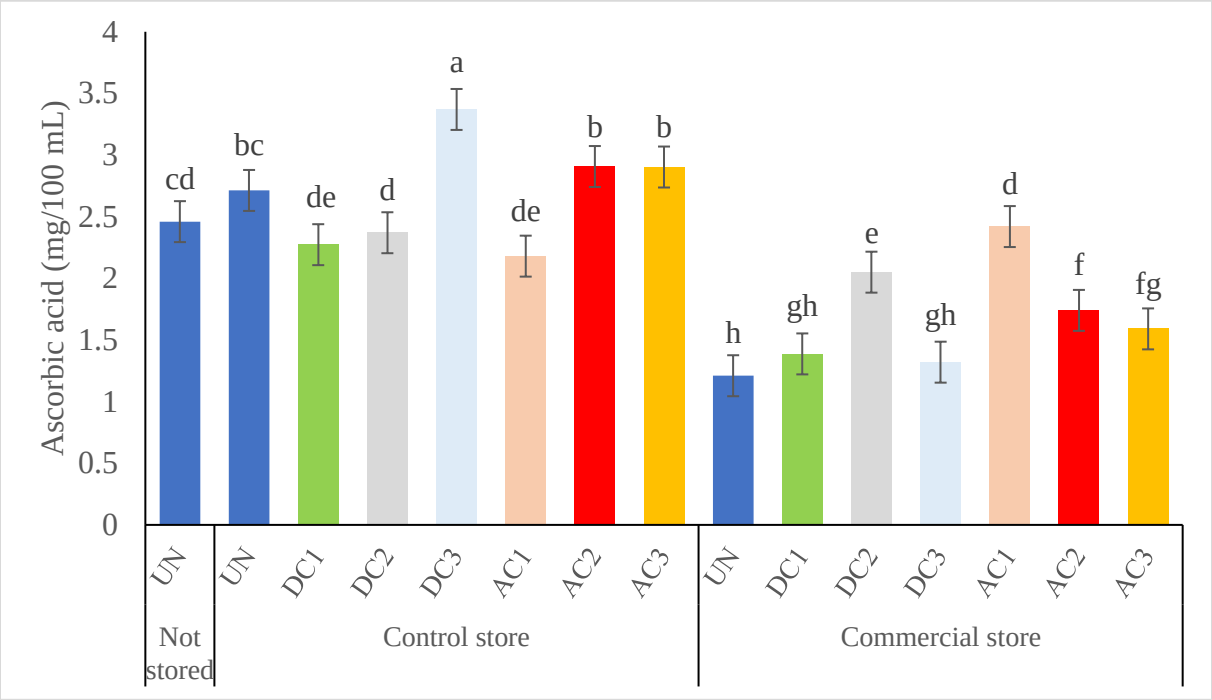

Figure 6. 1: Effects of magnetic fields’ sources and intensity on ascorbic acid of potatoes after storage in either the control or the commercial store.

UN; Un-exposed to magnetic fields,

DC1; Potatoes were exposed to 1 mT of magnetic fields supplied through direct current,

DC2; Potatoes were exposed to 2 mT of magnetic fields supplied through direct current,

DC3; Potatoes were exposed to 3 mT of magnetic fields supplied through direct current,

AC1; Potatoes were exposed to 1 mT of magnetic fields supplied through alternating current,

AC2; Potatoes were exposed to 2 mT of magnetic fields supplied through alternating current,

AC3; Potatoes were exposed to 3 mT of magnetic fields supplied through alternating current.

The majority of efforts to increase ascorbic acid in foods focus on overexpression of genes involved in various phases of ascorbic acid metabolism (Fenech *et al*., 2019). Therefore, it follows that exposing potatoes to DC MF with the intensity of 3 mT or AC MF with 2 and 3 mT and storing them in the control store favoured overexpression of key genes that encode various pathways involved in the synthesis of ascorbic acid. In particular, *GGP* (that encodes GDP-L-galactose-phosphorylase enzyme) may have been overexpressed leading to increased amounts of ascorbic acid. Overexpression of *GGP* has been shown to enhance the synthesis of ascorbic acid in tubers

and fruits as this gene is the rate-limiting in the production of ascorbic acid (Bulley *et al*., 2012; Bulley *et al*., 2009; Laing *et al*., 2007). In addition, it is possible that MF at higher intensities overexpressed *L-GalDH* (L-galactose dehydrogenase) and *GMP* (GDP-D-mannose pyrophosphorylase) genes, whose expression have also been linked to increase in ascorbic acid contents in plant tisues (Fenech *et al*., 2019; Hellmann *et al*., 2021).

When potatoes were subjected to increasing intensities of both DC MF and AC MF and stored in the control store, there was a corresponding increase in ascorbic acid content. It is plausible that exposing tubers to DC and AC MF at higher intensities and storing them in the control store favoured the activity of endogenous enzymes that disrupted cell wall structure allowing complete extraction of ascorbic acid during the assay procedure (Zee *et al*., 1991), and thus the high content of this pigment at higher MF intensities. However, the peak excitation of those enzymes was with the intensity of 3 mT, and therefore further decrease of intensity led to a corresponding decrease in the amount of ascorbic acid due to stiffening of the cell wall structure. Contents of ascorbic acid in plant tissues can increase as a result of ascorbate recycling (Fenech *et al*., 2019). It is therefore plausible that exposing tubers to low levels of MF and storing them in the control store degraded ascorbic acid leading to low levels of the acid than tubers that were not exposed to MF. However, the subsequent increases in MF intensities favoured recycling of ascorbic acid and thus the corresponding increase of the acid in potatoes that were stored in the control store.

Ascorbic acid is a necessary nutrient that functions as an antioxidant, as well as being a key co-factor and immune system pathway regulator. Our bodies need ascorbic acid for regular physiological functions and for its anti-cancer properties (Doseděl *et al*., 2021; Reang *et al*., 2021). The widely recognized sign of an ascorbic acid deficiency is scurvy, which is characterized by brittle tissues and inadequate wound healing (Yin *et al*., 2022). Despite its huge contribution, ascorbic acid cannot be synthesized by our bodies and thus has to be obtained from the diet (Padayatty & Levine, 2016). In addition to their relatively high ascorbic acid content, potatoes also have the ability to be preserved, making them a reliable source of ascorbic acid around the world. It is also reported that ascorbic acid contributes to about 13% of the total antioxidant activity of potatoes. Therefore, any increase in the amount of ascorbic acid in potatoes will be good for human nutrition (Chu *et al*., 2002; Love & Pavek, 2008). It is regarded as an essential quality indicator in fruits and vegetables during storage and food processing (Özkan *et al*., 2004). Furthermore, because depletion of ascorbic acid has been linked to reduced nutritional quality (Yin *et al*., 2022),

postharvest technologists have been concerned about ensuring their stability throughout storage. Fortunately, this study has provided promising insights on the application of MF in the retention of ascorbic acid during the storage of potatoes. In particular, the use of DC MF with the intensity of 3 mT and further storage in a dark store showed an incredible increase in the contents of this pigment. This is despite many studies reporting significant decreases in amount of ascorbic acid during the storage of potatoes (Abbasi *et al*., 2016; Brown, 2005; Burgos *et al*., 2009; Hamouz *et al*., 2018).

6.2.3. Chlorophyll a and chlorophyll b

Figure 6.2 shows the effects of magnetic fields and types of stores on chlorophyll a. In each store, potatoes that were exposed to DC MF had significantly higher quantities of chlorophyll a than potatoes that were neither exposed to MF nor stored as well as potatoes that were not exposed to MF and stored in respective stores. On the other hand, lower contents of this pigment were observed in tubers that were exposed to AC MF. The effects of study variables on chlorophyll b are given in Figure 6.3. Exposing tubers to MF (both DC and AC MF) and storing them in the control store resulted in significantly higher quantities of chlorophyll b than in tubers that were not exposed to MF and not stored as well as tubers that were not exposed to MF and stored in the same store. For the commercial store, tubers that were exposed to 3 mT of DC MF and 2 and 3 mT of AC MF recorded significantly higher levels of chlorophyll b than tubers that were not exposed to MF and stored in the same store, as well as those tubers that were neither exposed to MF nor stored. Interestingly, there was a converse accumulation of chlorophyll a and b for the same treatments. For example, exposing tubers to 1 mT of AC MF and storing them in the control store resulted in significantly low amounts of chlorophyll a (Figure 6.2) but significantly higher amounts of chlorophyll b (Figure 6.3). Similarly, tubers exposed to 2 and 3 mT of AC MF and stored in the commercial store resulted into significant low amounts of chlorophyll a (Figure 6.2) but significant higher amounts of chlorophyll b (Figure 6.3).

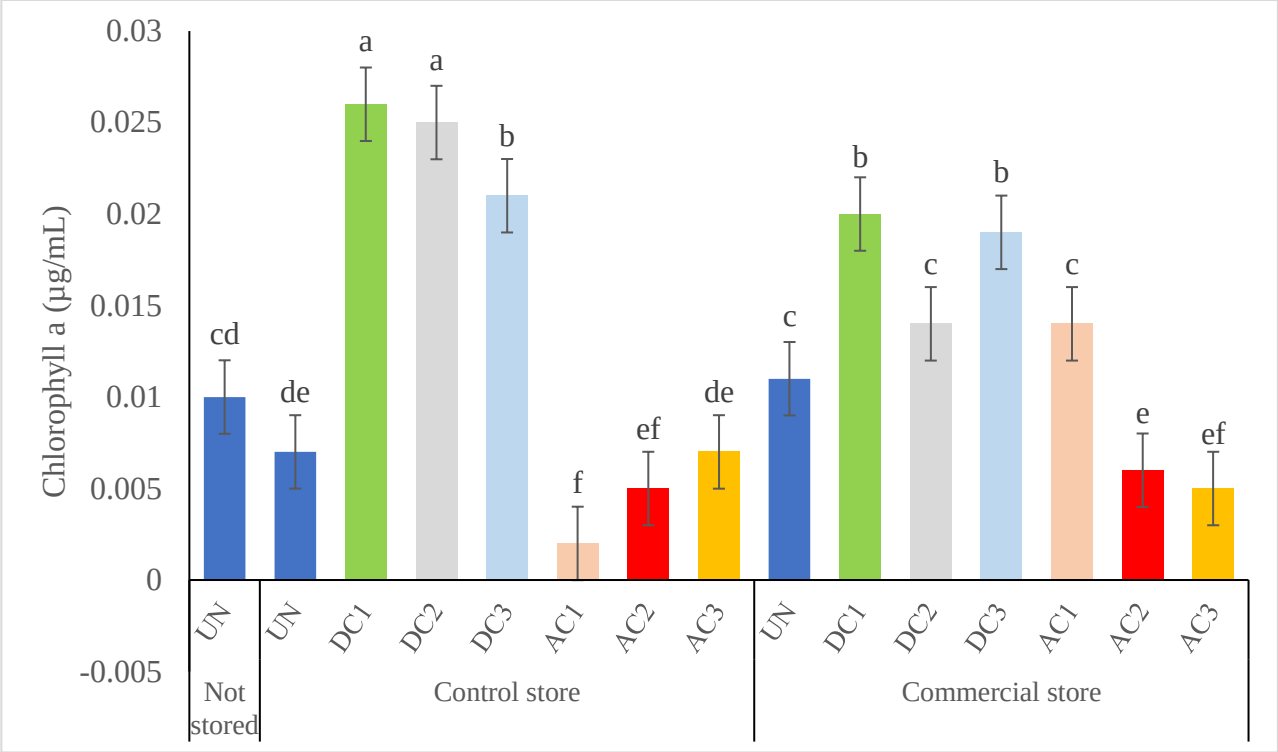

Figure 6. 2: Effects of magnetic fields' sources and intensity on chlorophyll a of potatoes after storage in either the control or the commercial store.

UN; Un-exposed to magnetic fields,

DC1; Potatoes were exposed to 1 mT of magnetic fields supplied through direct current,

DC2; Potatoes were exposed to 2 mT of magnetic fields supplied through direct current,

DC3; Potatoes were exposed to 3 mT of magnetic fields supplied through direct current,

AC1; Potatoes were exposed to 1 mT of magnetic fields supplied through alternating current,

AC2; Potatoes were exposed to 2 mT of magnetic fields supplied through alternating current,

AC3; Potatoes were exposed to 3 mT of magnetic fields supplied through alternating current.

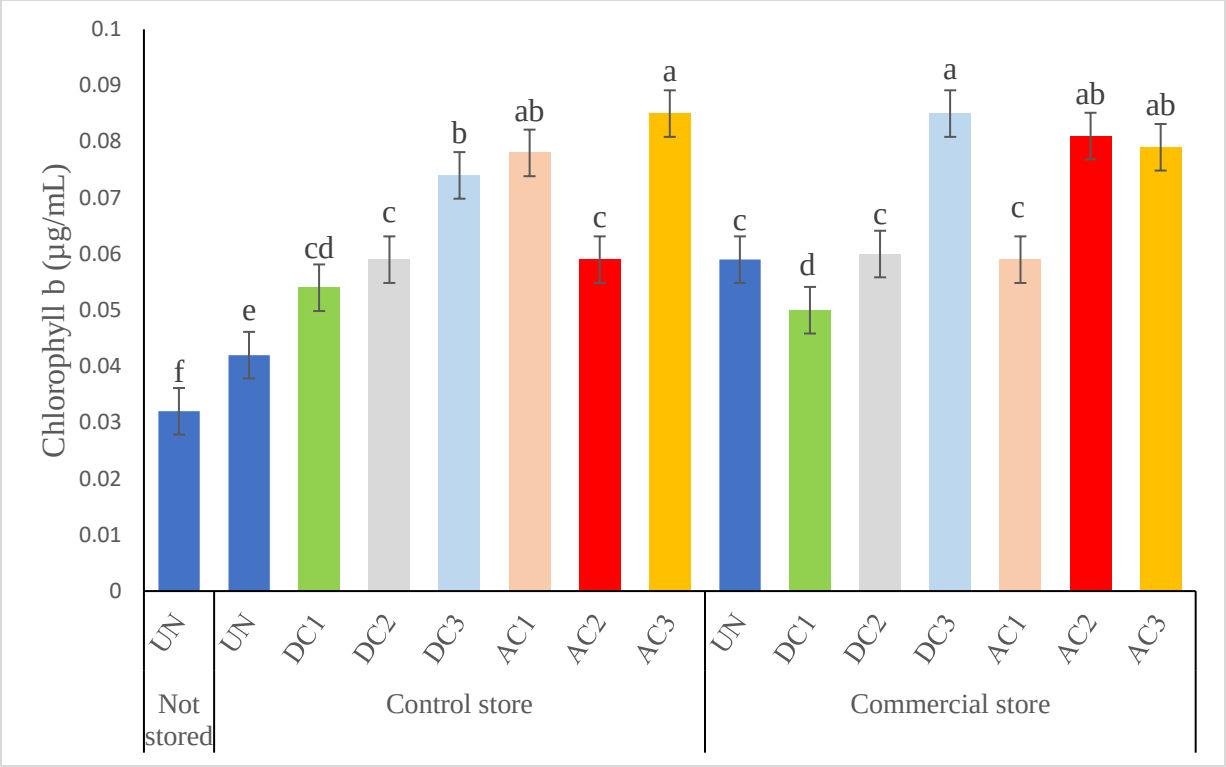

Figure 6. 3: Effects of magnetic fields' sources and intensity on chlorophyll b of potatoes after storage in either the control or the commercial store.

UN; Un-exposed to magnetic fields,

DC1; Potatoes were exposed to 1 mT of magnetic fields supplied through direct current,

DC2; Potatoes were exposed to 2 mT of magnetic fields supplied through direct current,

DC3; Potatoes were exposed to 3 mT of magnetic fields supplied through direct current,

AC1; Potatoes were exposed to 1 mT of magnetic fields supplied through alternating current,

AC2; Potatoes were exposed to 2 mT of magnetic fields supplied through alternating current,

AC3; Potatoes were exposed to 3 mT of magnetic fields supplied through alternating current.

The synthesis of chlorophyll is regulated by phytochrome and cryptochrome, which are the MF receptors in plants (Ahmad *et al*., 2007; Heyer *et al*., 1995; Morris *et al*., 1979; Solov'yov & Schulten, 2012). Thus, treating tubers to DC MF may have activated phytochrome and cryptochrome that ensured more conversion of amyloplasts to chloroplasts thus more amounts of chlorophyll a. The same can be said to be the action of MF (both DC and AC) on chlorophyll b. The first rate-limiting step in the biosynthesis of chlorophyll is the conversion of glutamate to 5-aminolevulinic acid catalyzed by glutamyl-tRNA reductase (GluTR). The GluTR enzyme is

encoded by *HEMA1* (light dependent) and *HEMA2* (not light dependent) genes (Okamoto *et al*., 2020). It is therefore plausible that exposing tubers to DC MF overexpressed *HEMA2* and *HEMA1* genes that led to increased quantities of chlorophyll a in potatoes that were stored in the control and commercial stores respectively. However, treating tubers to AC MF may have down-regulated these genes and as a result, low amounts of chlorophyll a. Another rate-limiting step in the biosynthesis of chlorophyll is the insertion of magnesium ions. This step is catalyzed by magnesium chelatase, an enzyme that is regulated by the GUN4 (genomes uncoupled 4) gene (Larkin *et al*., 2003). It is therefore possible that exposing potatoes to DC MF favoured more interaction of GUN4 with magnesium chelatase, thus high production of chlorophyll a. Chlorophyll b is obtained after reversible conversion of chlorophyllide a, a step that is catalyzed by CAO (chlorophyllide a oxygenase) (Mochizuki *et al*., 2010). This could explain why the treatments that resulted in significantly low quantities of chlorophyll a (1 mT of AC MF with subsequent storage in the control store and 3 mT of AC MF with storage in the commercial store) gave significantly high amounts of chlorophyll b due to the enhanced action of CAO.

Chlorophyll a and b differ in their structure, where chlorophyll a has a methyl group at the 7-carbon position, while chlorophyll b has an aldehyde group at the same position. As a result of these differences, both chlorophylls have different colours; chlorophyll a has a blue-green colour, while chlorophyll b has a blue-yellow colour (Carrillo *et al*., 2021). Therefore, chlorophyll a contributes to the green colouring matter in plants. During the storage of potatoes, greening is undesirable because consumers reject greened tubers and their association with the presence of toxic glycoalkaloids. It is therefore a major postharvest loss. Managing losses from greening is a key concern for the potato industry since tuber greening is a significant factor in quality loss (Tanios *et al*., 2020). It would thus be desirable for potatoes to produce more chlorophyll b than chlorophyll a during storage. Generally, exposure of tubers to DC MF resulted in significantly higher chlorophyll a and lower chlorophyll b, while the converse was the case on exposure to AC MF. Thus, the use of AC MF would be suitable for the preservation of potatoes concerning chlorophyll concentration which is linked to tuber greening and accumulation of glycoalkaloids. In particular, exposing tubers to 2 and 3 mT of AC MF resulted in significantly low amounts of chlorophyll a after storage in either of the stores. This could explain why in chapter five significantly low amounts of glycoalkaloids were reported after exposure of tubers to 2 mT of AC MF. Nevertheless, as nutraceutical agents with antioxidative, antimutagenic, anticarcinogenic, and

anti-inflammatory properties, chlorophylls have demonstrated significant health-promoting effects (Gebregziabher *et al*., 2021). Therefore, their preservation and increased production during potato storage, in particular chlorophyll b, will contribute to the better health of consumers.

6.2.4. Carotenoids

The effects of MF and store type on carotenoids are given in Figure 6.4. Significant higher amounts of carotenoids were observed in tubers that were exposed to 3 mT of DC MF and stored in the control store or AC MF and stored in the commercial store. The levels were higher than all other treatment levels including the untreated tubers than were not stored. Enhanced accumulation of carotenoids in storage organs can occur as a result of manipulation of their biosynthesis pathway. Specifically, *PSY2* (phytoene synthase 2) is the rate-limiting gene during carotenogenesis (Hellmann *et al*., 2021; Morris *et al*., 2004). Thus, it is argued that *PSY2* was overexpressed when potatoes were subjected to DC MF for 3 mT and stored in the control store and AC MF for 3 mT and stored in the commercial store leading to more synthesis of carotenoids. This is solidified by the fact that the signaling of phytochrome is influenced by MF (Agliassa *et al*., 2018) and *PSY* has been identified to be under phytochrome regulation through phytochrome-interacting factors (Toledo-Ortiz *et al*., 2010). Another gene whose increased activity has been proved to promote the production of carotenoids is *CrtRB2* (β – Carotene Hydryxylase) (Pasare, 2012). Therefore, it is possible that exposing tubers to 3 mT of DC MF or AC MF overexpressed the *CrtRB2* gene resulting in increased amounts of carotenoids when potatoes were stored in the control and commercial store respectively. According to Li *et al*. (2012), chromoplasts create a novel way of accumulating large amounts of carotenoids by creating carotenoid-lipoprotein sequestering substructures. It is therefore plausible that exposing potatoes to 3 mT of DC MF and AC MF with storage in the control and commercial stores respectively favoured the production of these storage structures within the potato chromoplasts. This in turn encouraged more production of carotenoids.

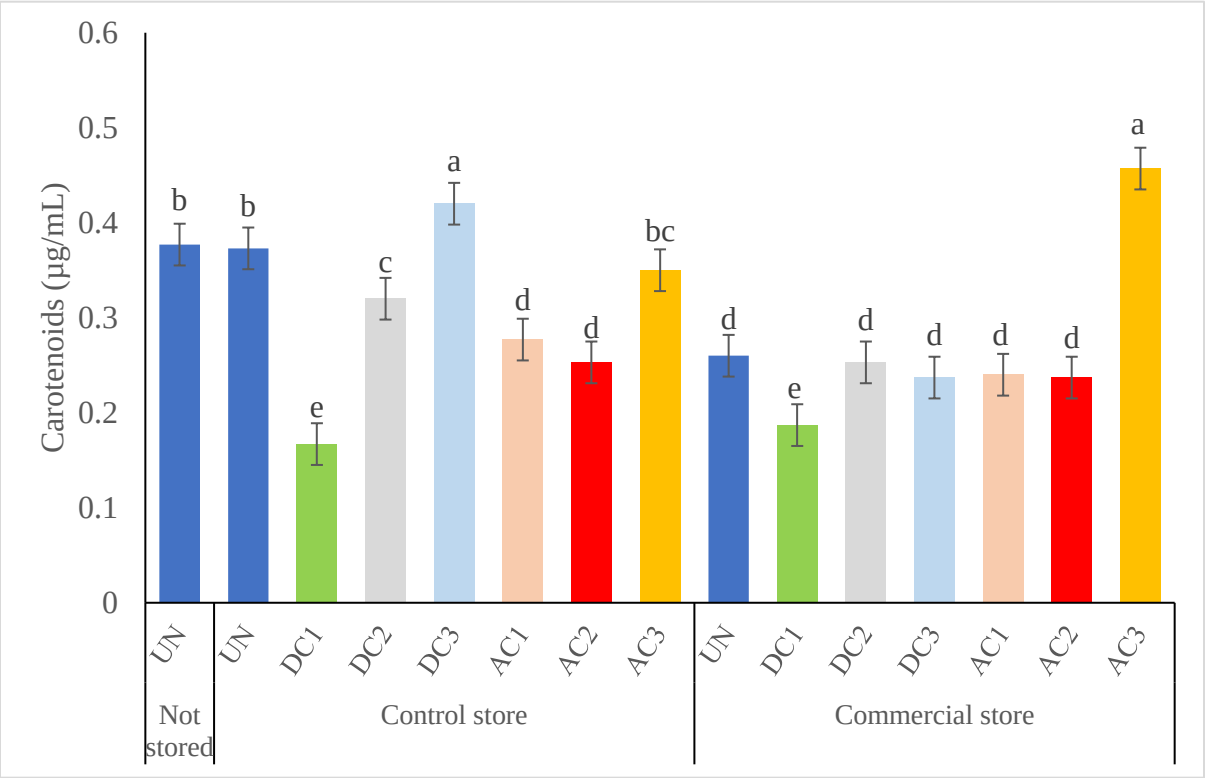

Figure 6. 4: Effects of magnetic fields' sources and intensity on carotenoids of potatoes after storage in either the control or the commercial store.

UN; un-exposed to magnetic fields,

DC1; Potatoes were exposed to 1 mT of magnetic fields supplied through direct current,

DC2; Potatoes were exposed to 2 mT of magnetic fields supplied through direct current,

DC3; Potatoes were exposed to 3 mT of magnetic fields supplied through direct current,

AC1; Potatoes were exposed to 1 mT of magnetic fields supplied through alternating current,

AC2; Potatoes were exposed to 2 mT of magnetic fields supplied through alternating current,

AC3; Potatoes were exposed to 3 mT of magnetic fields supplied through alternating current.

Exposing potatoes to 1 mT of DC MF resulted in lower amounts of carotenoids that were significant at a 95% level of confidence. These levels were fewer for this treatment irrespective of the type of store. According to Pasare. (2012) and Campbell *et al*. (2010) degradation of carotenoids in potato tubers can occur due to the up-regulation of the *CCD4* (carotenoid cleavage dioxygenase 4) gene. Consequently, it is argued that treating potato tubers to 1 mT of DC MF increased the rate of carotenoids catabolism by up-regulating *CCD4* leading to low amounts of carotenoids. It is worth noting that tubers exposed to low intensities (1 and 2 mT) of either DC or

AC MF recorded significantly lower levels of carotenoids than tubers that were not exposed to MF and not stored. Thus, low MF intensities could be said to have favoured the degradation of carotenoids probably by exciting CCD4. However, higher intensity (3 mT) prevented the degradation by hindering the action of CCD4 while promoting the action of PSY2.

Carotenoids are potent antioxidants with significant health-promoting properties, including provitamin A activity, immune system augmentation, a decrease in cardiovascular diseases, some types of cancer, diabetes, osteoporosis, and assistance in the prevention of atherosclerosis. Because increasing consumption of carotenoids can protect consumers, there is currently a lot of interest in creating food crops with higher concentrations of both total and individual carotenoids (Lachman *et al*., 2016). Potato is a good source of carotenoids, especially lutein and zeaxanthin. Lutein is the most heat-stable carotenoid and is among the most abundant carotenoids in the blood plasma of humans (Gebregziabher *et al*., 2021; Kotíková *et al*., 2016). This makes potatoes to be an excellent source of nutraceuticals. However, carotenoids generally are lost during the storage of potatoes (Blessington *et al*., 2019; Li *et al*., 2012). Fortunately, this study has provided an alternative to the preservation and increased production of carotenoids through the exposure of potatoes to 3 mT of DC MF if the potatoes are to be stored in a dark store or 3 mT of AC MF if potatoes are to be stored in a store with varying light intensities.

6.2.5. Total polyphenols

Figure 6.5 shows the total polyphenols as they were influenced by the study variables. The highest amount of total polyphenols was recorded for the potatoes that were not exposed to MF and not stored. However, this did not differ with tubers that were exposed to 1 mT of AC MF and stored in the control store and those that were exposed to 1 mT of DC MF and stored in the commercial store. Exposure of tubers to MF had a major impact upon storage in the control store, where all the exposed potatoes recorded significantly higher amounts of this pigment than the unexposed tubers that were stored in the same store. A peculiar trend was observed for tubers that were exposed to AC MF and stored in the control store, where each increase in the magnetic intensity resulted in a corresponding significant decrease in the content of total polyphenols. Similarly, for the commercial store, an increase in the intensity of DC MF resulted in a subsequent decrease in the pigment.

The polyphenols in potatoes are composed of phenolic acids, flavonoids, and anthocyanins (Rasheed *et al*., 2022). The metabolic pathways of these phenols are different, and therefore it would be difficult to relate the action of MF to a particular pathway. Even though, their preservation during storage is important given that polyphenols have health-promoting benefits since they have demonstrated in vitro antioxidant activity and have been proven to have advantageous anticancer, antibacterial, hypoglycaemic, anti-inflammatory, and vasodilatory properties (Kulasari *et al*., 2019). In addition, potatoes are good sources of polyphenols given that after oranges and apples, they have the highest dietary polyphenol concentration when consumed often (Rasheed *et al*., 2022). Therefore, exposure of potatoes to 1 mT of AC MF and DC MF and storage of the tubers in the control and commercial stores respectively have the potential for the preservation and increased production of polyphenols. This is great news given that a review by Ezekiel *et al*. (2013) documented that studies that stored potatoes at room temperature recorded decreased amounts of phenols than fresh tubers.

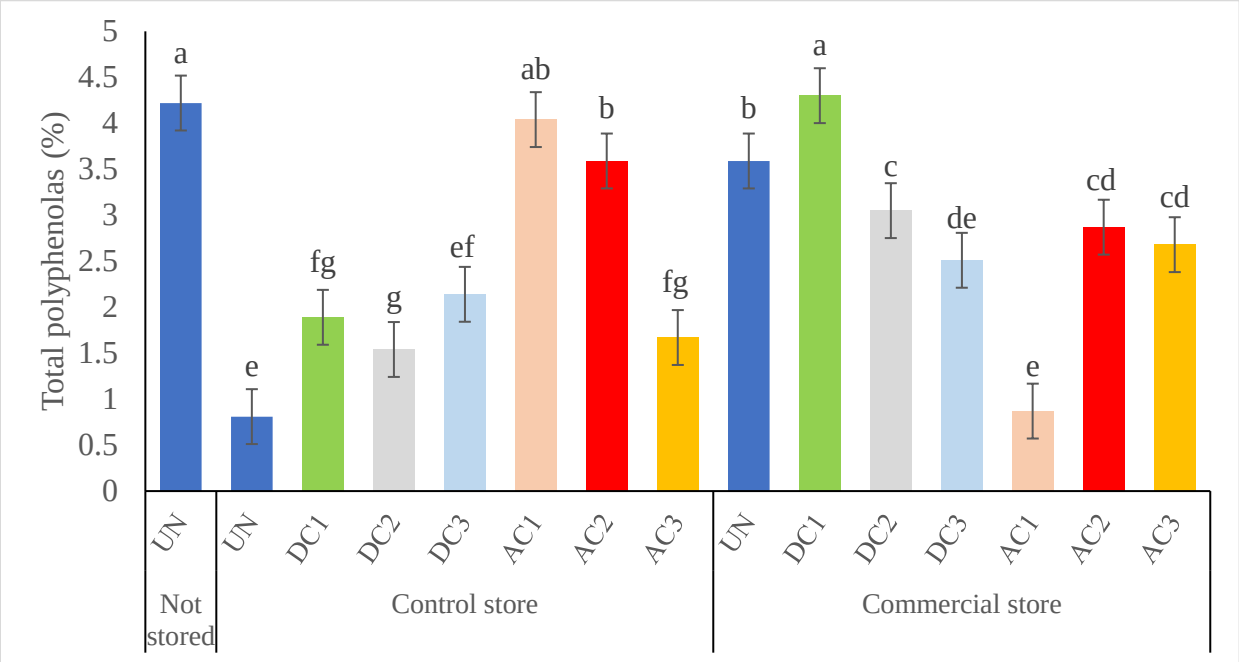

Figure 6. 5: Effects of magnetic fields' sources and intensity on total polyphenols of potatoes after storage in either the control or the commercial store.

UN; Un-exposed to magnetic fields,

DC1; Potatoes were exposed to 1 mT of magnetic fields supplied through direct current,

DC2; Potatoes were exposed to 2 mT of magnetic fields supplied through direct current,

DC3; Potatoes were exposed to 3 mT of magnetic fields supplied through direct current,
AC1; Potatoes were exposed to 1 mT of magnetic fields supplied through alternating current,
AC2; Potatoes were exposed to 2 mT of magnetic fields supplied through alternating current,
AC3; Potatoes were exposed to 3 mT of magnetic fields supplied through alternating current.

6.2.6. Antioxidant activity

The effects of magnetic fields and storage types on the activity of antioxidants are shown in Figure 6.6. The highest activity was recorded for the unexposed potatoes that were stored both in the control and the commercial store. Exposing potatoes to all intensities of AC MF and storing them in the control store resulted in significantly higher activity than potatoes that were not exposed to MF and not stored. On the other hand, exposing tubers to 1 and 2 mT of AC MF and storing them in the commercial store led to significantly low amounts of antioxidant activity than potatoes that were not exposed to MF and not stored. However, exposure of potatoes to DC MF and storage in either of the stores resulted in antioxidant activity that was comparable to the unexposed tubers that were not stored. Generally, potatoes that were stored in the commercial store recorded slightly

lower antioxidant activity than those that were stored in the control store.

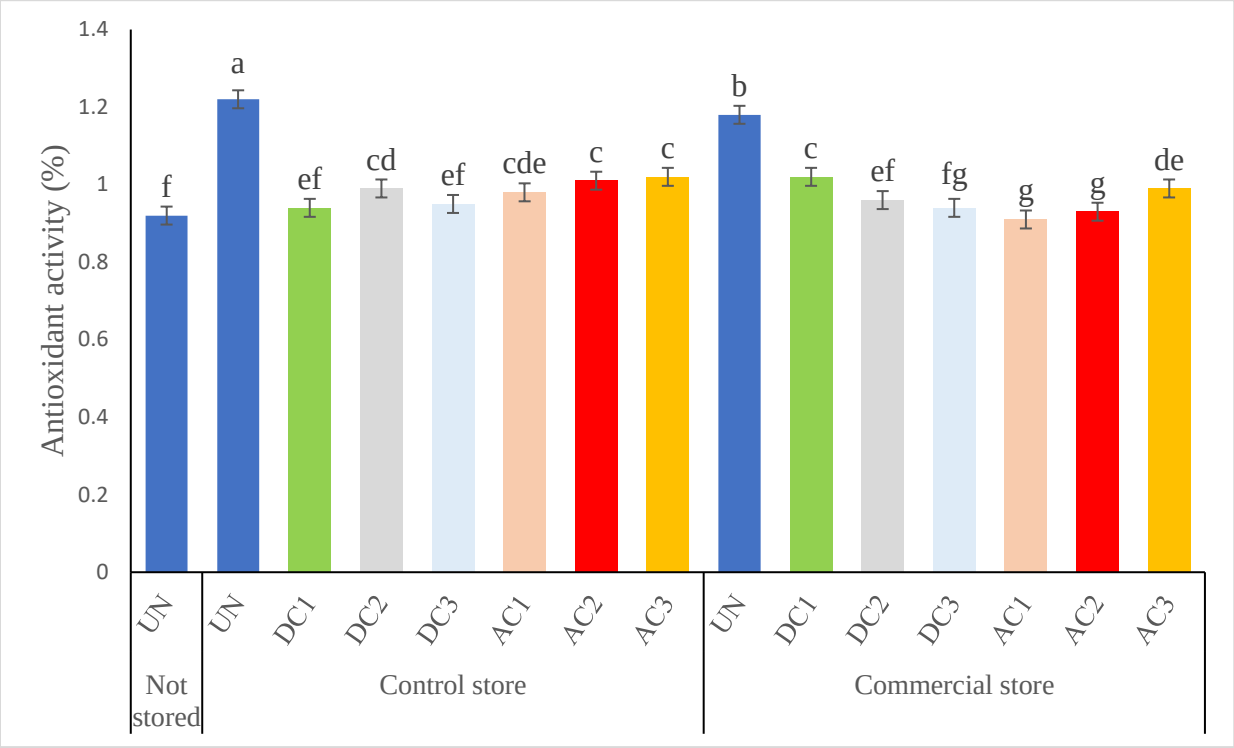

Figure 6. 6: Effects of magnetic fields' sources and intensity on antioxidant activity of potatoes after storage in either the control or the commercial store.

UN; un-exposed to magnetic fields,

DC1; Potatoes were exposed to 1 mT of magnetic fields supplied through direct current,

DC2; Potatoes were exposed to 2 mT of magnetic fields supplied through direct current,

DC3; Potatoes were exposed to 3 mT of magnetic fields supplied through direct current,

AC1; Potatoes were exposed to 1 mT of magnetic fields supplied through alternating current,

AC2; Potatoes were exposed to 2 mT of magnetic fields supplied through alternating current,

AC3; Potatoes were exposed to 3 mT of magnetic fields supplied through alternating current.

The activity of antioxidants in a food matrix can be determined by several mechanisms including trolox equivalent antioxidant capacity (TEAC), oxygen radical absorbance capacity (ORAC), DPPH radical scavenging capacity, and ferric reducing ability of plasma (FRAP). Because antioxidative processes involve a variety of pathways, it is best to use at least two alternative approaches in a study in order to obtain the most accurate conclusions (Albishi *et al*., 2013). In

this study, only the DPPH scavenging method was used and therefore best conclusions on the action of MF on antioxidant activity would not be achieved.

The activity of antioxidants in potatoes can occur as free or bound elements (Ru *et al*., 2019). Thus, exposing potatoes to MF could have increased the bound fractions that were not detected by the DPPH method. On the other hand, potatoes that were not exposed to MF and stored in either of the stores had more free fractions that were easily quantified by the assay method. This could explain why these tubers had more antioxidant activity than those that were exposed to MF and stored in respective stores. An increase in antioxidant activity after storage of potatoes in cold storage has been reported (Külen *et al*., 2013; Madiwale *et al*., 2011; Rosenthal & Jansky, 2008). However, a decrease in activity when potatoes were stored under artificial light has been reported as well (Zariņš *et al*., 2022). This could explain why there was a slight reduction in antioxidant activity for the potatoes that were stored in the commercial store than those that were stored in the control store. A study by Galani *et al*. (2017) reported that at the end of storage at room temperature, the antioxidant activity of stored potatoes was comparable to that of fresh tubers. This supports the current findings that exposure of potatoes to DC MF resulted in the comparable activity of antioxidants to fresh potatoes. Notably, exposure of potatoes to AC MF has shown potential in the retention of antioxidant activity during storage. However, storage has to be done in a dark store.

6.4. Conclusion

The use of magnetic fields has the potential to reduce the loss of antioxidants in potatoes during their postharvest storage. In particular, potatoes that were exposed to 3 mT of magnetic fields produced through direct current and stored in the dark store had significantly higher ascorbic acid and carotenoids than the fresh tubers. Again, the use of direct currents produced magnetic fields whose exposure to potatoes resulted in antioxidant activity that was comparable to that of fresh tubers, irrespective of the type of storage. A significantly higher amount of chlorophyll b can be obtained by exposing tubers to 3 mT of magnetic fields produced by alternating current in the event that storage will be in a dark store. However, if storage is done in a store with varying light intensities, then direct currents should be used for the same results. Comparable amounts of total polyphenols, with respect to fresh tubers, can be obtained by storing tubers in a dark store or commercial store after exposing them to 1 mT of magnetic fields produced through the alternating

current and direct current respectively. Further studies should investigate the effects of exposing potatoes to magnetic fields on other antioxidants such as anthocyanins and individual phenols.

CHAPTER SEVEN

GENERAL CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

A significant impact of potato tuber exposure to magnetic fields on the postharvest quality of the shangi potato variety was observed. According to the experimental study's findings, magnetic fields can be used to decrease potato losses while preserving their quality. The research's findings will be helpful in developing policies that aim to raise the quality of stored potatoes. Consequently, the following conclusions were made from each of the four objectives;

i. In comparison to the control, tubers exposed to MF showed less weight loss, greening, and sprouting. In contrast to tubers exposed to DC MF, those treated to AC MF showed an increase in specific gravity, dry matter, and starch.
ii. The proximate and mineral composition of potatoes that were stored was affected by their exposure to MF. Potatoes exposed to MF and then stored in the control store had considerably more ash content than potatoes not exposed. Potatoes' overall energy increased after they were exposed to AC MF and stored in the control store. Major and minor minerals were both affected favorably by DC MF and unfavorably by AC MF.
iii. A substantial decrease in the amounts of α-chaconine, α-solanine, and total glycoalkaloids was observed after exposing potatoes to AC MF at the intensity of 2 mT.
iv. In comparison to fresh tubers, potatoes exposed to 3 mT of DC MF and kept in the control store showed considerably higher levels of ascorbic acid and carotenoids. Furthermore, regardless of the method of storage, exposure of potatoes to DC MF produced antioxidant activity that was comparable to that of fresh tubers.

7.2. Recommendations

The following recommnendations were made from this study;

i. Potato farmers, aggregators, distributors and processors should consider exposing their harvested tubers to 2 or 3 mT of magnetic fields before storage in order to reduce postharvest losses and assure sustainability of the potato value chain.
ii. A dark store is recommended for the storage of potatoes after their exposure to magnetic fields, as opposed to a store with varying light intensities, given that fewer losses are experienced in a dark store as opposed to many losses observed in a commercial store.

iii. The Kenyan national and county governments should develop policies that will allow the use of magnetic fields during the storage of potatoes, especially in the major potato producing regions.

iv. The action of magnetic fields on the biosynthetic pathway of various compiunds is hypothesized in this study. Future studies should examine how magnetic fields interfere with genes that encode various enzymes that mediate specific steps in the synthesis of potato bio compunds.

7.3. Areas for further research

i. This study focused on only one potato variety -shangi. It is therefore advised that more work should be done to assess the effects of magnetic fields on other potato varieties and in other regions.

ii. Further studies could consider investigating how the acceptability of processed potatoes are to cosnumers after their treatment with magnetic fields.

iii. A linear regression analysis would be suitable to identify the best combinations of treatment factors for each desired quality parameter.

iv. The internal structure of the potato tuber was not studied before and after the exposure to magnetic fields, which is a shortcoming of this work. Therefore, it is recommended that future research carefully consider how the magnetic fields affect the structure of the potato tuber.

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APPENDICES

Appendix A: National Commission for Science, Technology, and Innovation (NACOSTI) research permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **672230**

Date of Issue: **06/April/2021**

RESEARCH LICENSE

This is to Certify that Mr.. Francis Gichuho Irungu of Egerton University, has been licensed to conduct research in Nakuru on the topic: POTENTIAL OF MAGNETIC INDUCTION ON REDUCTION OF POSTHARVEST LOSSES IN POTATOES AND ITS EFFECTS ON PHYSICO-CHEMICAL, NUTRITIONAL AND QUALITY OF POTATO PRODUCTS for the period ending : 06/April/2022.

License No: **NACOSTI/P/21/9675**

672230

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

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Appendix B: Snapshot of published paper 1

Applied Food Research 2 (2022) 100191

Contents lists available at ScienceDirect

Applied Food Research

journal homepage: www.elsevier.com/locate/afres

Enhancement of potato (*Solanum tuberosum* L) postharvest quality by use of magnetic fields – A case of shangi potato variety

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ARTICLE INFO

Keywords:
Magnetic fields
Helmholtz coils
Potatoes
Shangi
Post-harvest losses
Storage

ABSTRACT

Production of potatoes in the developing countries has been on the rise. This reinforces the growing importance of potatoes throughout Africa, Asia, and Latin America as a source of food and livelihood. However, this crop continues to experience major postharvest losses that are associated with a lack of effective storage facilities in these regions. This study used magnetic fields (MF) as an innovative technology to reduce potato losses while under storage. The effects of test variables; sources of magnetic fields intensity and exposure time on physicochemical properties of stored shangi potatoes were investigated. Double Helmholtz coils were used to generate MF. The coils were supplied with either direct current (DC) or alternating current (AC). Potatoes were then exposed to MF and stored in either the control or the commercial store. At the end of storage, physicochemical analyses were done following standard methods. AC MF resulted in significant ($\rho < 0.05$) higher specific gravity, dry matter, starch, and the number of sprouts per tuber but lower weight reduction, total sugars, reducing sugars, and non-reducing sugars than DC MF. Exposing potatoes to 3.00 mT of both DC and AC MF resulted in significant ($\rho < 0.05$) lower weight reduction, internal and external greening, sprouting, and the number of sprouts per tuber than in potatoes that were not exposed to MF. The current work has shown that it is possible to extend the shelf-life of the shangi potato variety by about 1 month, by use of MF, without compromising on quality parameters.

Appendix C: Snapshot of published paper 2

Received: 12 May 2022 | Revised: 11 July 2022 | Accepted: 17 July 2022

DOI: 10.1111/jfpp.16941

Journal of Food Processing and Preservation

WILEY

ORIGINAL ARTICLE

Use of magnetic fields reduces α-chaconine, α-solanine, and total glycoalkaloids in stored potatoes (*Solanum tuberosum* L.)

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Funding information
Centre of Excellence in Sustainable Agriculture and Agribusiness Management (CESAAM)

Abstract

This work aimed to assess the suitability of magnetic fields (MF) to reduce glycoalkaloids (GAs) in stored potatoes. The effects of the source of magnetic fields (direct current [DC] and alternating current [AC]), magnetic field intensity (1, 2, and 3 mT), and storage type (dark store—herein referred to as the control store and a commercial store with varying light intensity) on quantities of GAs were investigated. Subjecting tubers to increasing levels of MF intensities and placing them in the control store led to a significant ($p < .05$) decrease in α-chaconine and an increase in α-solanine. However, storage of potatoes in the commercial store after exposure to increasing MF intensities led to a significant ($p < .05$) decrease in α-solanine and an increase in α-chaconine. The use of AC MF with an intensity of 2 mT resulted in a significant ($p < .05$) reduction in α-chaconine, α-solanine, and TG.

Novelty impact statement: Magnetic fields are an emerging non-thermal technology that has wide potential in food processing applications. The findings in the current work revealed that magnetic fields can be used to reduce quantities of toxic glycoalkaloids in potatoes during storage, and thus improve their postharvest quality. The results offer practical insights on postharvest management of potatoes to ensure reduction of losses and thus positively impact food and nutritional security.

Appendix D: Snapshot of published paper 3

Irungu et al., *Cogent Food & Agriculture* (2022), 8: 2079207
https://doi.org/10.1080/23311932.2022.2079207

cogent food & agriculture

FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

Static and varied magnetic fields effects on shrinkage and sprouting characteristics of stored potatoes

Francis Gichuho Irungu[1,2,3]*, Francis G. Ndiritu[4], Christopher M. Mutungi[3], Simon G. Mathenge[4] and Symon M. Mahungu[2]

Received: 12 February 2021
Accepted: 14 May 2022

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Abstract: The effects of static and varying magnetic fields (MF) on shrinkage and sprouting characteristics of stored potatoes were studied. Static MF was produced by the use of direct current (DC), while alternating current (AC) produced varying MF. Intensities of DC MF were set at 0.5, 1.0, 1.5, and 2.0 mT and those of AC MF set at

Appendix E: Certificate of conference participation at Chuka University

CU/04/12/2020/34

CHUKA UNIVERSITY

Knowledge is Wealth *(Sapientia divitia est)*

CERTIFICATE OF PARTICIPATION

IN THE 7TH INTERNATIONAL RESEARCH CONFERENCE

Awarded to:

Irungu Francis G., Faraj, A.K., Mutungi, C.M., Ndiritu, F.G. and Mathenge, S.G.

Paper Title: DC and AC Activated Magnetic Fields Effects on Shrinkage and Sprouting Characteristics of Stored Potatoes

Conference Theme:
Sharing Current Innovations to Revitalize Economic Development (SCIRED)

Conference Subthemes:

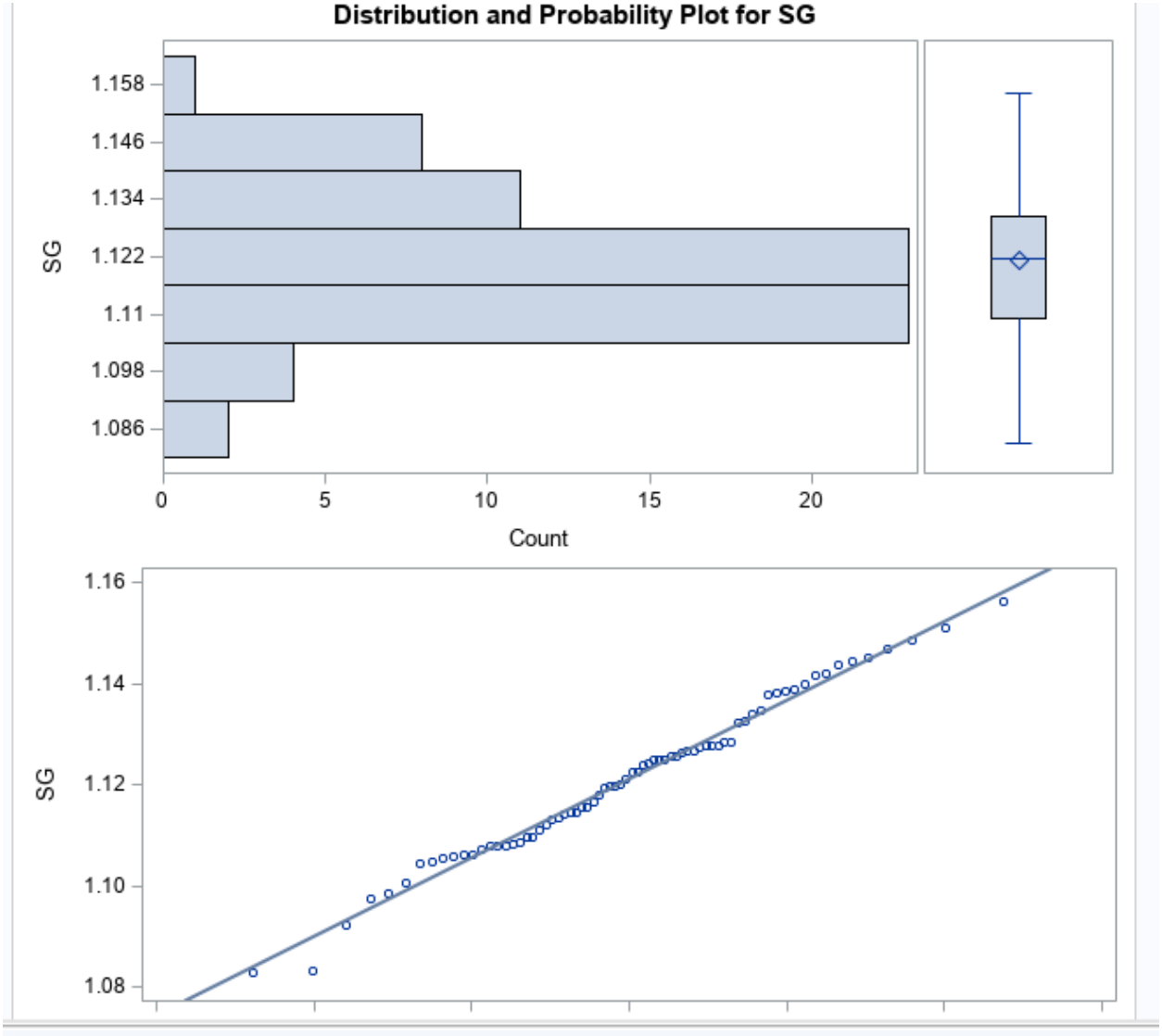
- Agriculture and Environmental Revitalization Innovations
- Hospitality and Business Revitalization Innovations
- Education and Training Revitalization Innovations
- Humanities and Social Sciences Revitalization Innovations
- Engineering and Technology Revitalization Innovations
- Health and Affirmative Action Revitalization Innovations

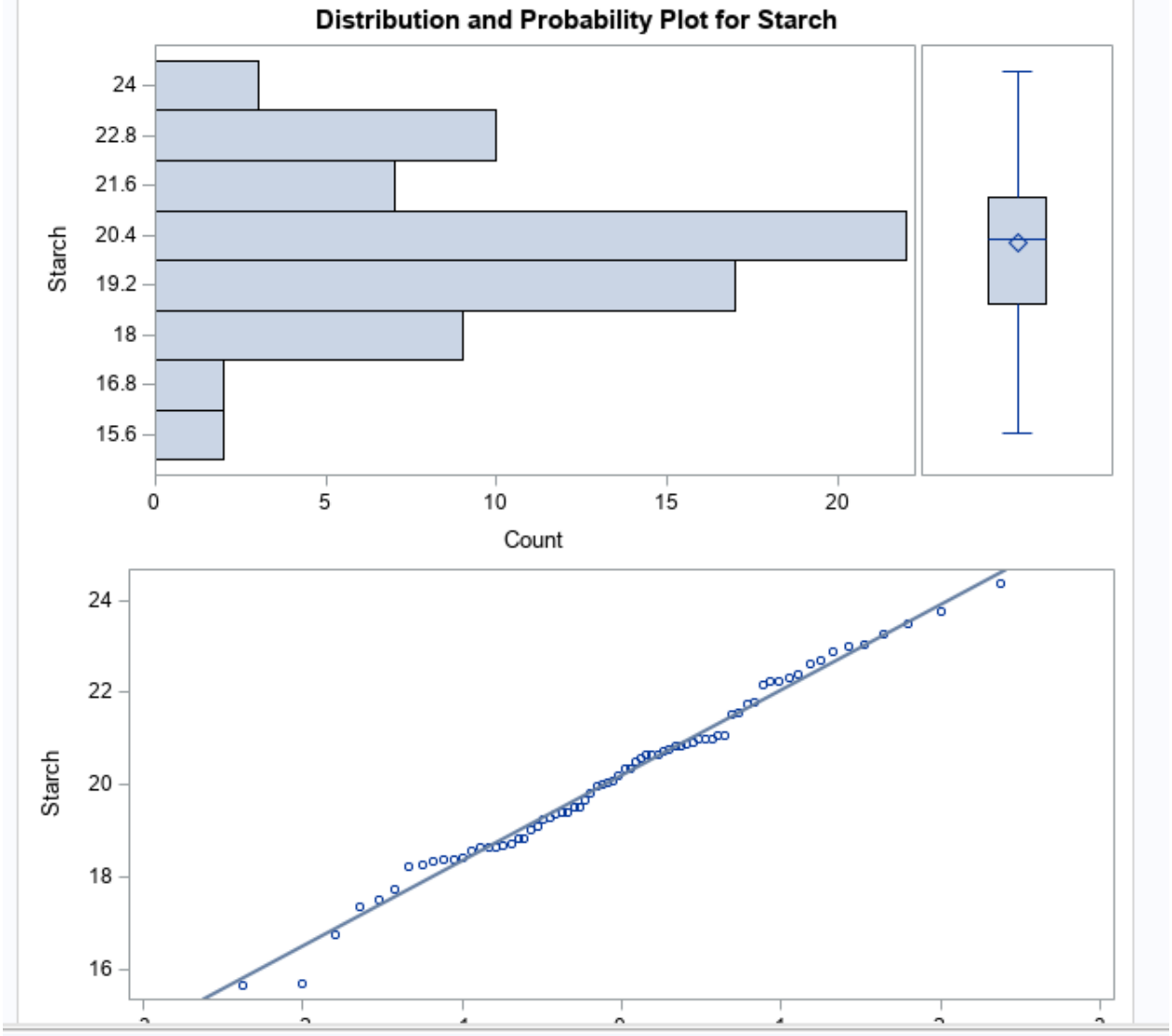
Issued on 4th December, 2020

Dr. Charles M. Kariuki, Ph.D.
(Director Research, Extension & Publications)

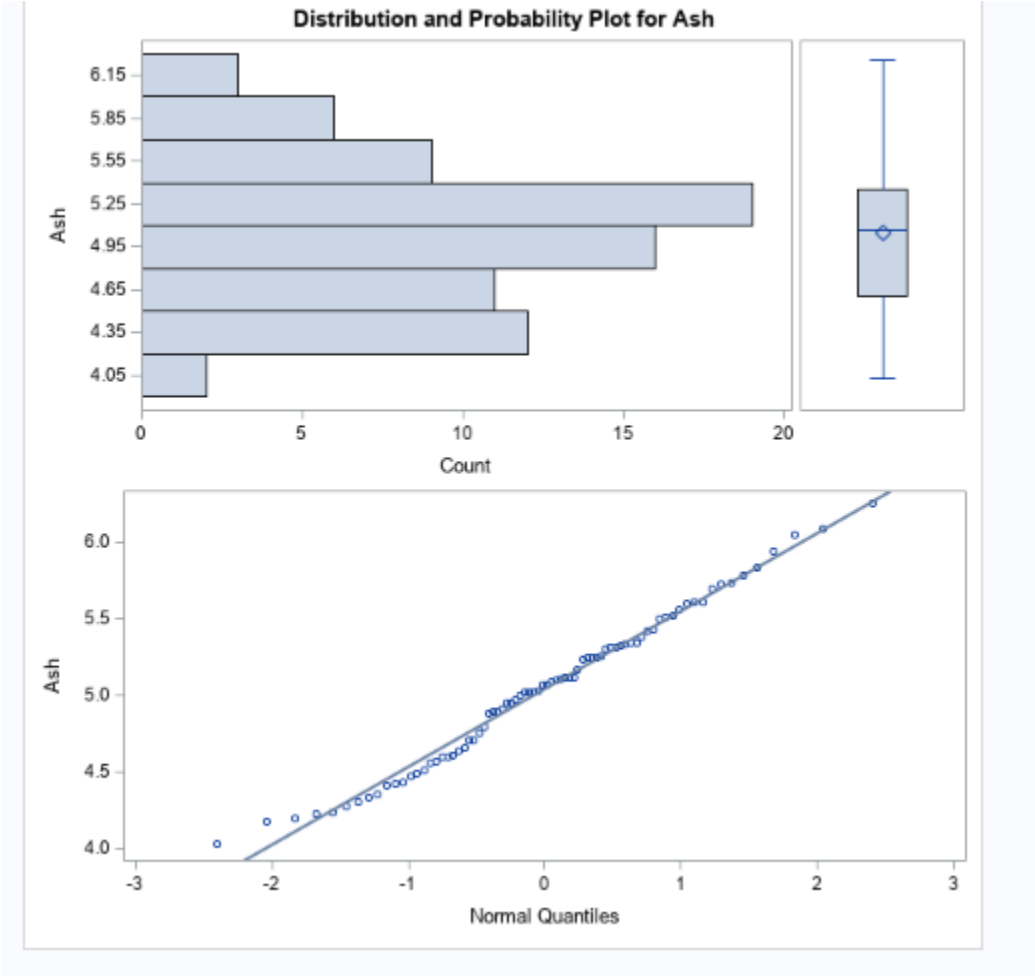
Prof. Dorcas K. Isutsa, Ph.D.
Deputy Vice-Chancellor (Academic, Research & Student Affairs)

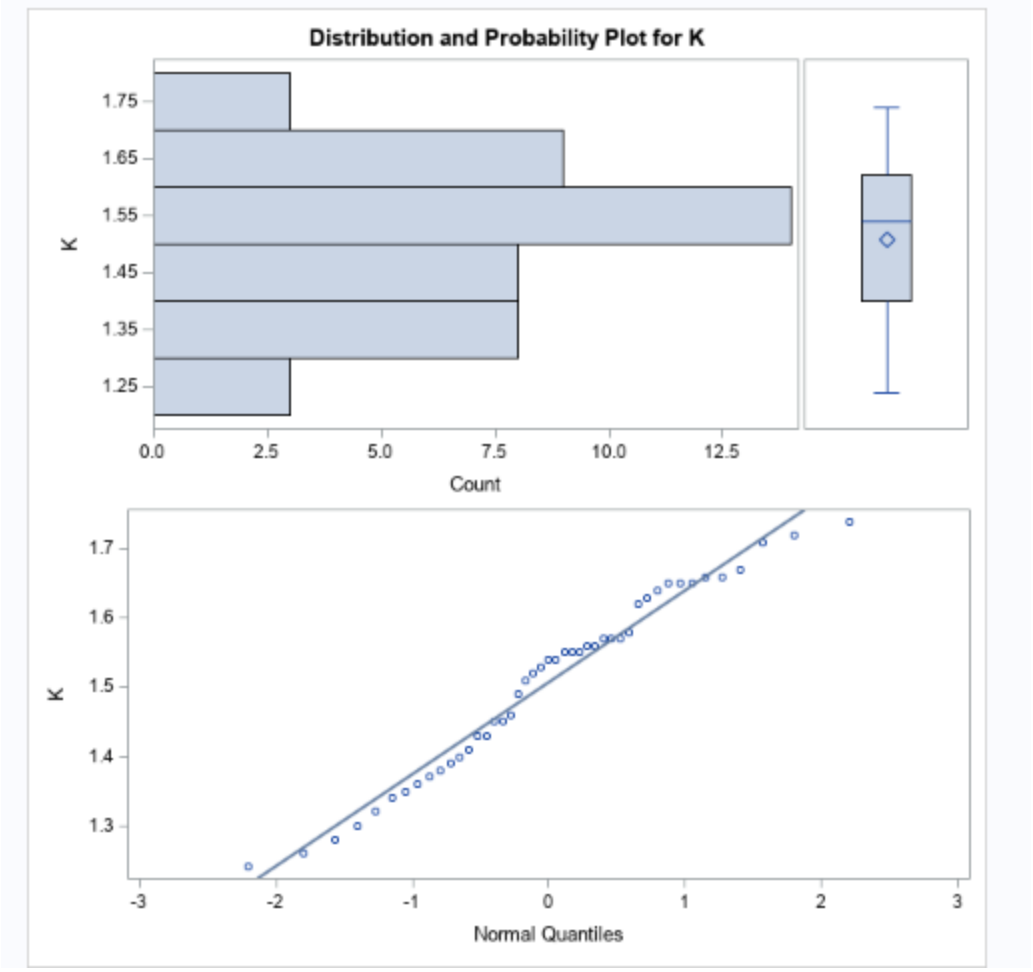
Appendix F: Seleced normality test output for objective one



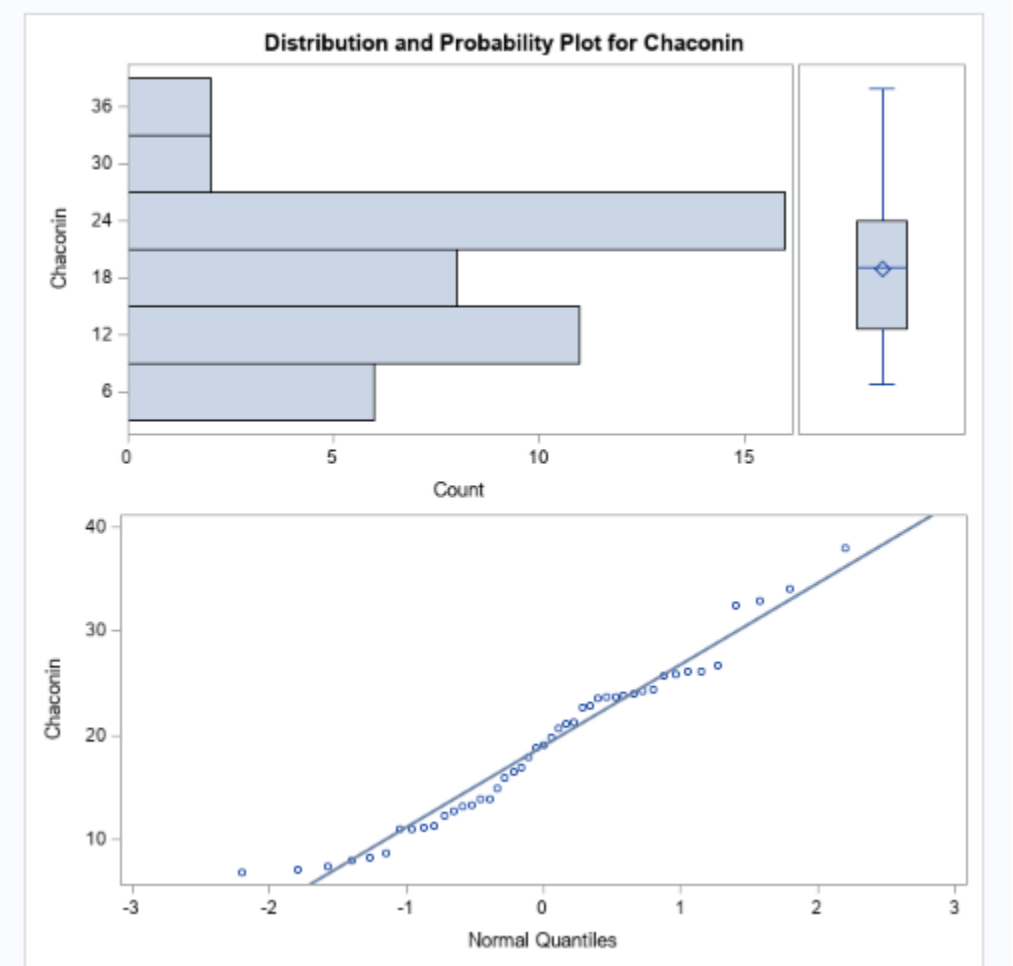

Distribution and Probability Plot for Starch
Starch
24
22.8
21.6
20.4
19.2
18
16.8
15.6
0
5
10
15
20
Count
Starch
24
22
20
18
16

Appendix G: Selectied normality test output for objective two

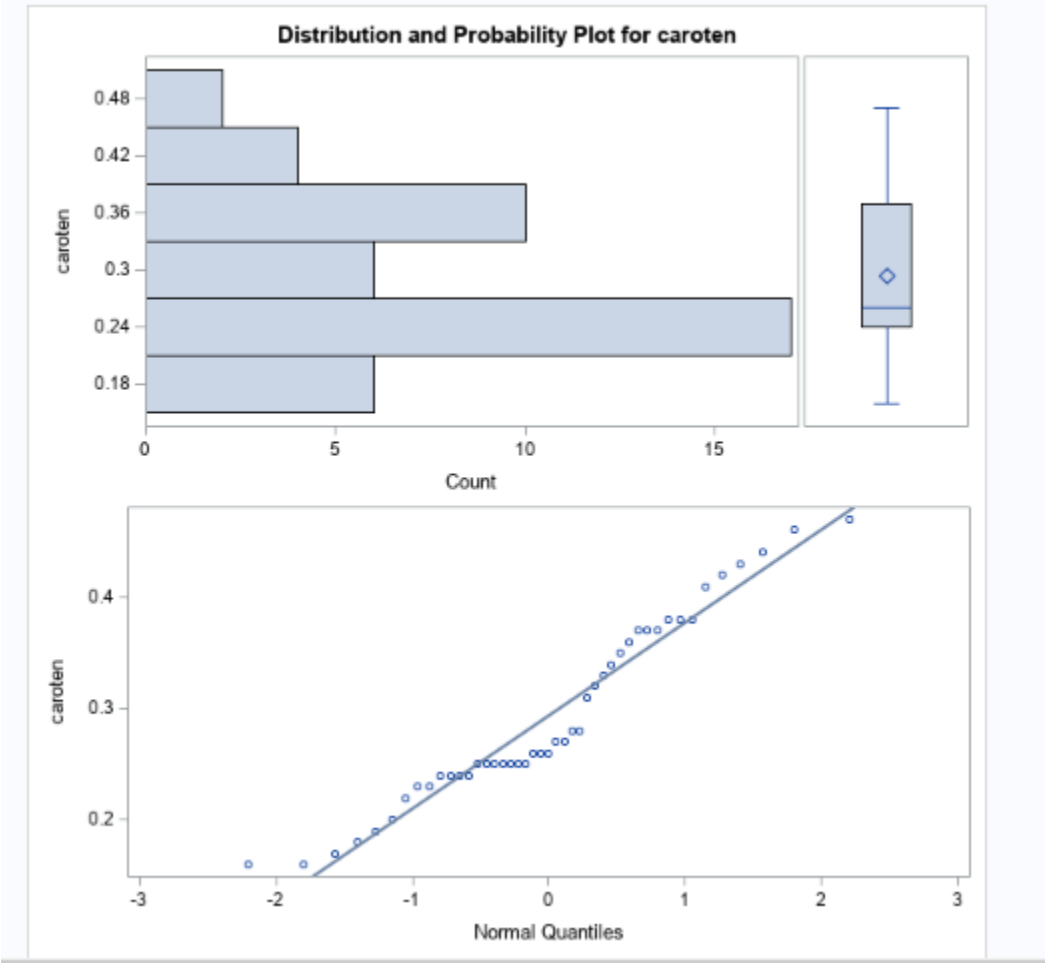



Distribution and Probability Plot for K
K
1.75
1.65
1.55
1.45
1.35
1.25
0.0
2.5
5.0
7.5
10.0
12.5
Count
K
1.7
1.6
1.5
1.4
1.3
-3
-2
-1
0
1
2
3
Normal Quantiles

Appendix H: Selected normality test output for objective three



Appendix I: Selected normality test output for objective four



Appendix J: Selected ANOVA otputs

Mean Squares of ANOVA for the effect of study variables nn sugars

Source of Variation	**DF**	**Total Sugars (%)**	**Reducing Sugars (%)**	**Non-Reducing Sugars (%)**
Store	1	0.008083ns	0.073359**	0.032740*
Source of MF	1	0.746999**	0.005759*	0.621582**
MFI	2	0.098548*	0.012016*	0.041814*
Store*Source	1	0.003284ns	0.001969ns	0.000167ns
Store*MFI	2	0.133928*	0.002832ns	0.162980**
Source*MFI	2	0.208787*	0.010838*	0.286084**
Error	2	0.002241	0.000151	0.001231
Root MSE		0.0473441	0.012913	0.0350823
R^2 (%)		99.73	99.77	99.85
R^2_Adj (%)		98.50	98.75	99.17
CV		2.553172	3.182359	2.389656
MF; Magnetic fields; MFI: magnetic field intensity;				

Mean Squares of ANOVA for the effect of study variables nn antioxidants

Source of Variation	DF	Ascorbic acid (mg/100 mL)	Carotenoids (%)	Total Polyphenols (%)	Chlorophyll-a (ug/mL)	Chlorophyll-b (ug/mL)	Antioxidant Activity (%)
Store	1	2.15053**	0.04320*	2.25333**	0.00006ns	0.00001ns	0.00188ns
SMF	1	0.06163ns	0.04563*	0.48803*	0.00063**	0.00301*	0.00041ns
MFI	2	0.65141**	0.08416*	0.65333*	0.00035*	0.00391*	0.00413*
Store*SMF	1	0.23520*	0.00003ns	0.16333*	0.00037*	0.00141*	0.00521*
Store*MFI	2	0.01886ns	0.01133ns	0.00023ns	0.00004ns	0.00006ns	0.00030ns
SMF*MFI	2	0.05176ns	0.02056ns	0.00813ns	0.00004ns	0.00041ns	0.00003ns
Error	2	0.00678	0.00206	0.00803	0.00000	0.00006	0.00013
Root MSE		0.08231	0.04537	0.08963	0.00202	0.00764	0.01155
R^2 (%)		99.65	98.73	99.62	99.58	99.12	98.40
R^2_Adj (%)		98.09	93.03	97.92	97.69	95.17	91.21
CV		99.65	14.96	3.44	10.41	9.45	1.19

MF; Magnetic fields; MFI: magnetic field intensity;