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ORIGINAL ARTICLE

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

Francis Gichuho Irungu[1,2] | **Chrysantus Mbi Tanga**[3] | **Francis Gichuki Ndiritu**[4] | **Lucy Mwaura**[5] | **Mukani Moyo**[5] | **Symon Maina Mahungu**[2]

firungu@chuka.ac.ke

[1]Department of Food Technology, Chuka University, Chuka, Kenya

[2]Department of Dairy and Food Science and Technology, Egerton University, Egerton, Kenya

[3]International Centre for Insect Physiology and Ecology, ICIPE, Nairobi, Kenya

[4]Department of Physics, Egerton University, Egerton, Kenya

[5]Food and Nutritional Evaluation Laboratory, International Potato Center (CIP), Nairobi, Kenya

Correspondence
Francis Gichuho Irungu, Department of Food Technology, Chuka University, Chuka, Kenya.
Email: firungu@chuka.ac.ke, gichuhofrancis@gmail.com

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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.

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, 2019). 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 & Mouillé, 2019). Potato tubers, on the other hand, are one of the most perishable types of fresh produce, with as more than 15% 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 (Romancucci 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

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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 3–6 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; Wszelaczyńska 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 (Nie et al., 2019; Okamoto et al., 2020; Rymuza et al., 2020). Zhang and co-researchers (Zhang et al., 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 our 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, color, flavor, texture, and esthetics 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 2-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 1 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.

2 | MATERIALS AND METHODS

The research site, collection of potatoes, application of magnetic fields, and storage of treated tubers were as outlined by Irungu et al. (2022). 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. 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 center of the coils for 80 s. 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 1.

2.1 | Experimental design

A 2 × 3 × 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 (three levels; 1, 2, and 3 mT), and type of store (two levels; control and commercial store). The experiment was replicated thrice.

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.

2.2.1 | Sample preparation

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

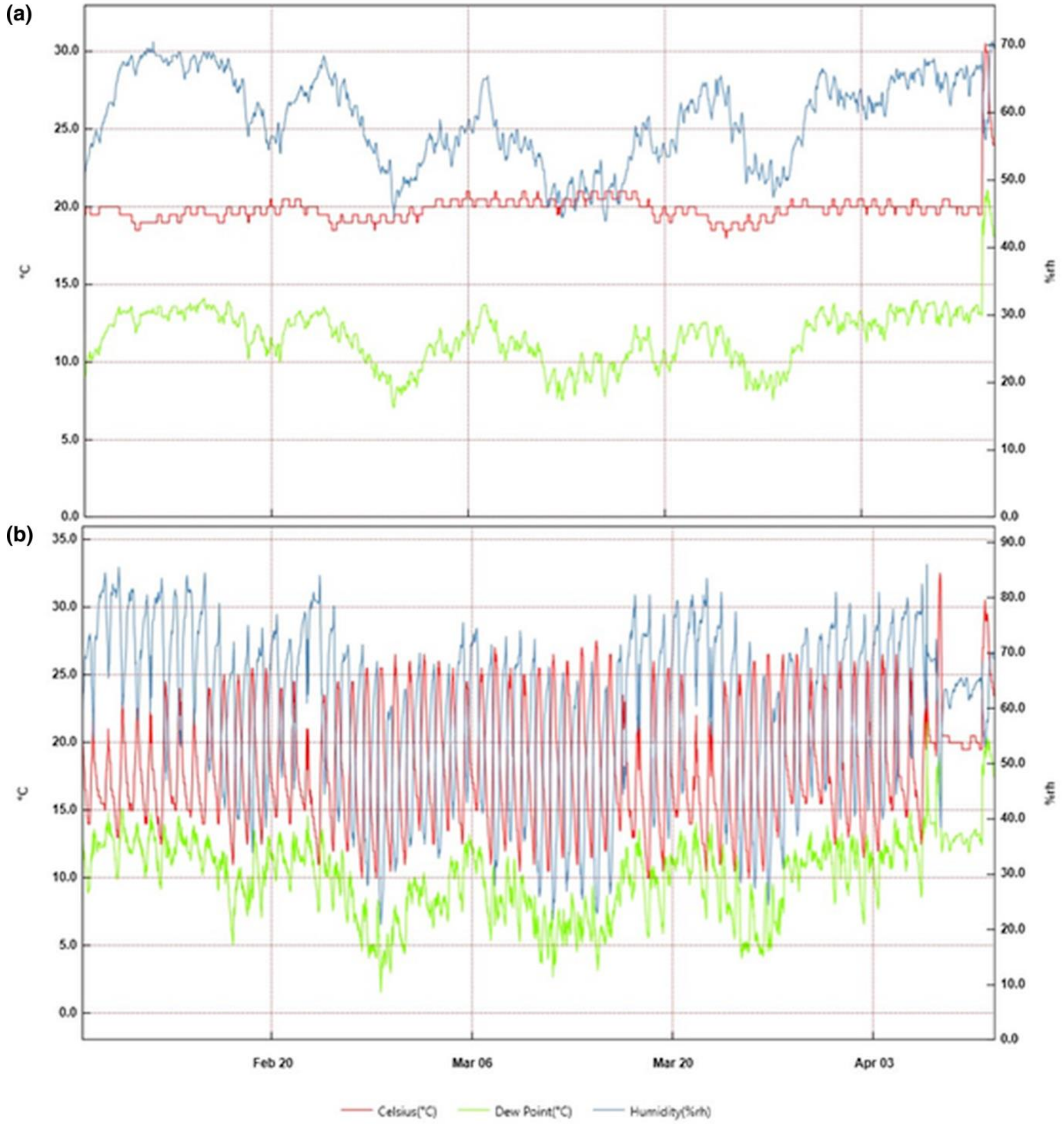


FIGURE 1 Graphical print-out of storage conditions [temperature (°C), dew point (°C), and relative humidity (%)] of the two stores; control store (a) and commercial store (b) during the 8 weeks of storage.

2.2.2 | 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 3000 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 a 4 ml SPE wash solution (15% acetonitrile). For the elution, 4 ml LC mobile phase (60% acetonitrile in 0.01 M 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.

2.2.3 | 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.

2.3 | Statistical analysis

The data obtained were 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.

3 | RESULTS AND DISCUSSION

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 2. There was a significant ($p < .05$) increase in α-chaconine, α-solanine, and TG 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 favors 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 could explain 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 could be 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).

For the commercial store, exposing potatoes to AC MF resulted in significant low amounts of α-chaconine (Figure 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,

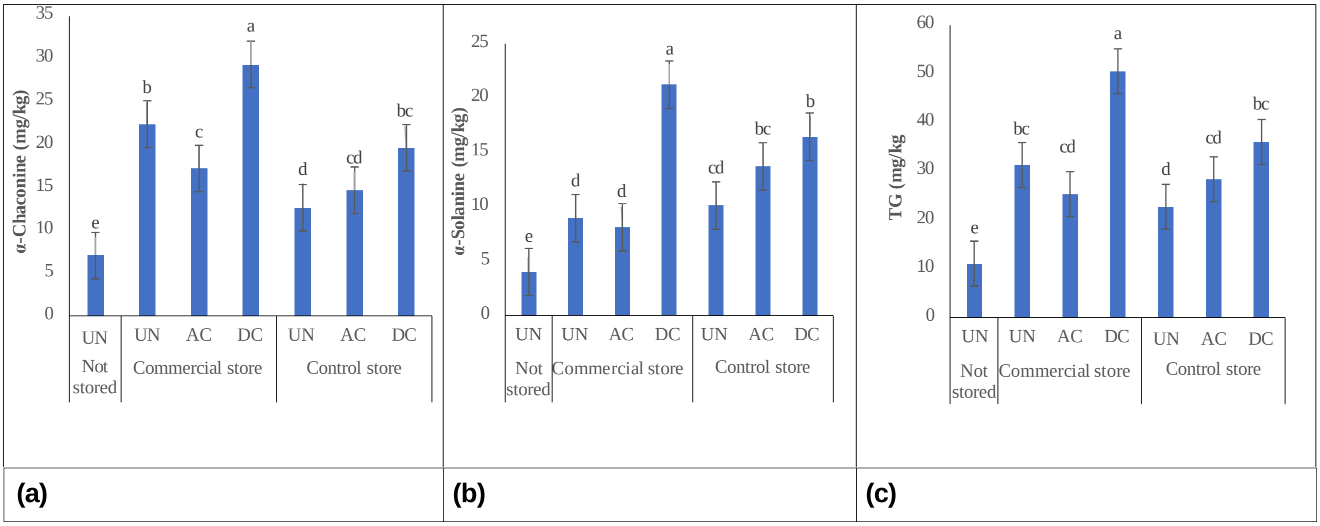


FIGURE 2 Glycoalkaloids (α-chaconine (a), α-solanine (b), and total glycoalkaloids (c)) as affected by the source of magnetic fields under different stores; AC, alternating current as a source of magnetic fields; DC, direct current as a source of magnetic fields; TG, total glycoalkaloids; UN, unexposed to magnetic fields. Values are presented as means ± standard error of the mean. The same letters above the means show that the levels are not significantly different at $p < .05$.

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 2b) and TG (Figure 3c), which were significant ($p < .05$), in comparison with 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 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 significantly ($p < .05$) lower amounts of α-chaconine than their corresponding treatments that were stored in the commercial store (Figure 2a). Subjecting tubers to different AC MF and storing them in the commercial store resulted in significantly ($p < .05$) lower amounts of α-solanine than potatoes that were exposed to AC MF and stored in the control store (Figure 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 ($p < .05$). Similarly, significantly ($p < .05$) higher values of TG were observed for the potatoes that were exposed to DC MF and stored in the commercial store than those that were exposed to DC MF and stored in the control store (Figure 2c).

The high levels of GAs that were reported in potatoes that were stored in the commercial store could be 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 may have 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 favored more expression of these genes, leading to higher levels of GAs.

3.2 | Effects of magnetic field intensity under store types

Figure 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 ($p < .05$) when potatoes were subjected to 2 and 3 mT of MF (Figure 3a).

Interestingly, α-chaconine increased ($p < .05$) when tubers were subjected to increasing strengths of MF (1–3 mT) and stored in the commercial store while it reduced ($p < .05$) during storage in the control store. On the contrary, α-solanine decreased ($p < .05$) when tubers were exposed to increased levels of MF and stored in the commercial store while they increased ($p < .05$) when tubers were stored in the control store (Figure 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 3c).

Synthesis of α-chaconine and α-solanine stems 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

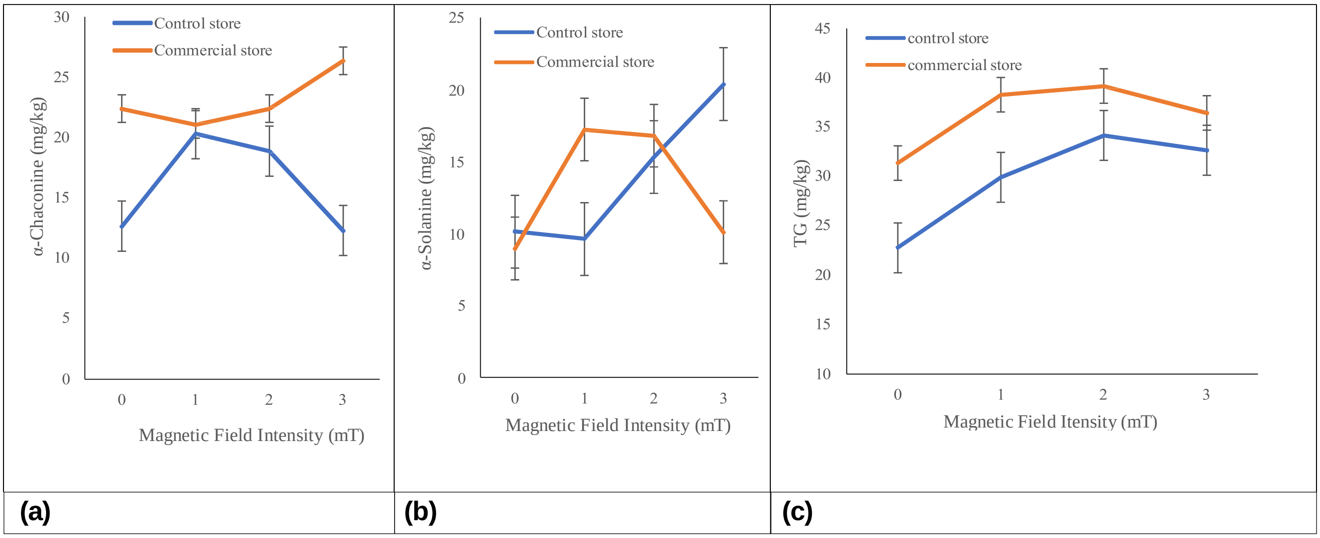


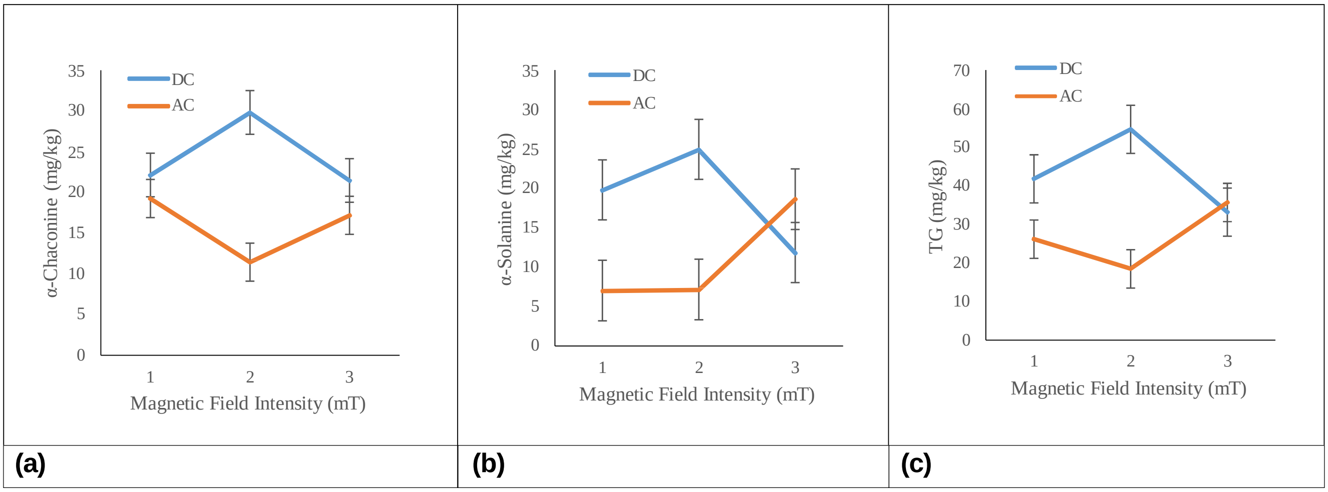
FIGURE 3 Glycoalkaloids (α-chaconine (a), α-solanine (b), and total glycoalkaloids (c)) as influenced by magnetic field intensities under different stores. TG, total glycoalkaloids. Values are presented as means ± standard error of the mean. Where standard error bars overlap, then the levels are not significantly different at $p < .05$.

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; Xu et al., 2021). 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 could have favored 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. (2005, 2006) 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 favored 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. It is therefore plausible that 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). It could therefore be argued that 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, a further increase of magnetic intensity to 3 mT may have inhibited their expression and, as result, the quantities of TG were reduced.

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 4. Subjecting potatoes to DC MF resulted in significant ($p < .05$) 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 ($p < .05$) 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 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



FI G U R E 4 Glycoalkaloids (α-chaconine (a), α-solanine (b), and total glycoalkaloids (c)) as influenced by magnetic field intensities produced either through direct current (DC) or alternating current (AC). TG, total glycoalkaloids. Values are presented as means ± standard error of the mean. Where standard error bars overlap, then the levels are not significantly different at $p < .05$.

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 favor glycosylation. Quantities of GAs can also reduce when enzymes that catalyze the hydrolysis of glycosides are stimulated (Friedman, 2006; Friedman et al., 1997; 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 favored glycosyltransferase enzyme to catalyze 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 may have 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 could have 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 could have 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 them 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.

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 given in Table 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 s 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 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}

Note: Values are presented as means ± standard error of the mean. Means with the same letter along the column are not significantly different at $p < .05$.

Abbreviations: AC, alternating current; DC, direct current; MFI, magnetic force intensity; SMF, source of magnetic field; TG, total glycoalkaloids; UN, unmagnetized.

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.

AUTHOR CONTRIBUTIONS

Francis Gichuho Irungu: Conceptualization; Methodology; Software; Data curation; Formal analysis; Writing - original draft; Writing - review & editing; Visualization; Resources. **Chrysantus Mbi Tanga:** Investigation; Validation; Supervision; Resources; Writing - review & editing. **Francis Gichuki Ndiritu:** Supervision; Validation; Investigation; Writing - review & editing; Conceptualization; Visualization. **Lucy Mwaura:** Methodology; Writing - review & editing; Software; Formal analysis. **Mukani Moyo:** Methodology; Software; Writing - review & editing; Formal analysis. **Symon Maina Mahungu:** Conceptualization; Investigation; Validation; Supervision; Writing - review & editing.

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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Francis Gichuho Irungu https://orcid.org/0000-0002-1980-2519

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