# GLYCOALKALOIDS IN COMMERCIAL KENYAN POTATO VARIETIES: EFFECT OF POST-HARVEST HANDLING AND STORAGE CONDITIONS

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**A dissertation submitted in partial fulfillment for the Degree of Master of Science in Food Safety and Quality of the University of Nairobi**

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## DECLARATION

This dissertation is my original work and has not been presented for a degree award in any other university or institution of higher learning.

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# DEDICATION

I dedicate this work to my loving parents, Mr. Fanuel Musita and Mrs. Mary Goretti Wamukoya, for all the sacrifices they made to ensure that I got the best education and for the solid foundation they laid in my life.

To my siblings David, Patrick, Inviolata and Albert for being my inspiration and providing me with encouragement and support in my academic journey.

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## ACRONYMS/ABBREVIATIONS

| | | |
|---|---|---|
| ANOVA | - | Analysis of Variance |
| BW | - | Body Weight |
| CBD | - | Central business district |
| CIP | - | International Potato Center |
| FAO | - | Food and Agriculture Organization |
| FW | - | Fresh weight |
| GAs | - | Glycoalkaloids |
| HPLC | - | High performance liquid chromatography |
| KNBS | - | Kenya National Bureau of Statistics |
| LSD | - | Least Significant Difference |
| MoA | - | Ministry of Agriculture |
| TGA | - | Total glycoalkaloids |
| SAS | - | Statistical analysis software |

## GENERAL ABSTRACT

The potato (*Solanum tuberosum)* is an important staple food crop contributing to food and nutrition security of many households globally. However, of concern to food safety is the fact that potatoes can accumulate glycoalkaloids which are a family of steroidal toxic secondary metabolites. Although they contribute to flavor, at high levels, glycoalkaloids which are naturally occurring in potatoes, pose food safety concerns as they can lead to bitterness and intoxication to consumers. Their concentrations in potatoes are dependent on postharvest handling, variety and stress factors that tubers are exposed to. Variation of glycoalkaloids in commercial potatoes is yet to be established hence the current research.

This study was carried out in three phases to fulfil three objectives. The first phase fulfilling objective one and it involved a survey that was cross-sectional in design where the post-harvest handling practices and perception of potato safety among potato traders in open-air markets in Nairobi County were assessed. A total of 100 potato traders were interviewed using a semi-structured questionnaire that determined post-harvest handling practices such as potato transportation, exposure to sunlight and storage. The second objective focused on determining the levels of glycoalkaloids in commercial potato varieties in the Kenyan Market. Three potato varieties, Shangi, Dutch Robjin and Royal sold in open air markets and supermarkets in Nairobi County were randomly sampled and their glycoalkaloid levels determined by HPLC method. The third objective sought to establish the influence of storage conditions on the glycoalkaloid levels of potatoes. Three potato varieties, Shangi, Dutch Robjin and Royal, were stored for 12 weeks at different conditions of temperature (5, 10 and 25 $^oC$) and light intensity, with glycoalkaloids in both flesh potato (peeled) and whole potato (unpeeled) being determined at 4-week intervals.

Results showed that 42% of the potatoes on the market were stored for a period ranging from 2 to 3 days. Forty seven percent (47%) of the vehicles and hand-pulled carts used to transport potatoes to the market had open backs while 53% had closed backs. Over half (69%) the potatoes

in the markets were directly exposed to sunlight, with 75% of the traders leaving their potatoes in the open covered with a polythene bag after the day's activities. This exposed the tubers to potential risk of glycoalkaloid accumulation. Greening, sprouting or bruised potatoes were sold to consumers at a lower price (20%), which may pose a serious health risk to consumers if these potatoes are consumed. Additionally, more than half of the traders did not think that consumption of greened potatoes is harmful to health, meaning that they had poor knowledge on the effects of glycoalkaloids on health.

For the market samples collected, Shangi variety had the highest levels of glycoalkaloids with a mean of 410.35 $mgkg^{-1}$ dry weight; with samples from supermarkets having the highest levels (550.8 $mgkg^{-1}$). The same variety (Shangi) from open air markets averaged glycoalkaloid levels of 382.26 $mgkg^{-1}$ dry weight. Dutch Robjin (129.2 $mgkg^{-1}$ dry weight) and Royal variety (98.2 $mgkg^{-1}$ dry weight) had the least levels of glycoalkaloids. However, the levels in sampled tubers did not exceed the recommended levels of 1000mg/kg on dry weight basis and, therefore, consumption of these potatoes would not raise safety concerns.

For storage trials, results indicated that storage conditions and potato variety were factors that significantly ($p<0.05$) influenced glycoalkaloids levels; with glycoalkaloid levels in both whole potatoes and potato flesh significantly ($p<0.05$) increasing with increasing period of storage. Storage of all the varieties of whole potatoes beyond eight weeks at elevated temperatures (>10$^{o}$C) and in light resulted in accumulated levels of 1000 mg/kg dry weight (converted to 200 mg/kg fresh weight), which are levels deemed unsafe for consumption. However, Storage of the potatoes in the dark and at 5 $^{o}$C resulted in the lowest accumulation of total glycoalkaloids (<1000 mg/kg). Therefore, storage of the potatoes at lower temperatures (<10$^{o}$C); in dark and for shorter period of storage (less than 8 weeks) is recommended to assure their safety

# CHAPTER ONE: GENERAL INTRODUCTION

## 1.1 Background Information

The potato (*Solanum tuberosum)* is an important staple food crop globally and in in Kenya it is being second to maize in terms of consumption. It is cultivated by over 800,000 growers who are mostly smallholders and its production in Kenya is currently worth about KSH 50 billion (MoA, 2009). In 2010, Kenya's annual production averaged 7.7 tonnes/ha (Wiersema *et al*., 2013). Globally the potato is among the top 5 crops produced with an estimated annual production of over 300 million metric tonnes (FAO, 2015). The potato is ranked third after rice and wheat in terms of global human consumption with more than 1 billion people eating it on a regular basis (CIP, 2015).

It is a crop with stable yields where other crops fail making it one of the highly valued crops by many poor households in terms of food security. In addition, it is of high nutritional importance because it is low in fat, is a good source of carbohydrates, protein, fibre and vitamins B1, B3, B6 and C (Gastelo *et al.*, 2014*)*. In addition to being a staple food crop, the potato is a common cash crop in many parts of the world thus playing an important income earner for all the players its value chain.

Glycoalkaloids (GAs) are a family of steroidal toxic secondary metabolites present in plants of the Solanaceae family which include potato, eggplant, tomato and pepper. Glycoalkaloids are part of the biologically active metabolites found in the potato and which include calystegine, protease inhibitors, lectines, phenolic compounds and chlorophyll (Nema *et al.*, 2008). The chemical composition of potato thus significantly affects its quality (Burlingame *et al*., 2009). Glycoalkaloids occur in all parts of the potato as natural toxins which are synthesized as a form of defense against parasites and diseases due to their antimicrobial, insecticidal and fungicidal properties (Nema et al., 2008).

Because of the increased consumption of potato and potato products exposure to glycoalkaloids is increasingly becoming an issue of public health concern.

In low concentrations (less than 150mg/kg fresh weight) glycoalkaloids actually contribute to flavor. However, at higher concentrations above the widely accepted limit a bitter taste may develop (Nema et al., 2008). These compounds are accumulated mainly in the peels, sprouts and flowers with high concentrations of glycoalkaloids occurring in the flowers and sprouts (Burlingame *et al*., 2009). Glycoalkaloids, however, have toxicological effects with the lethal dose in humans being about 3-6 mg/kg body weight (BW) (Jadhav, 1997; van Gelder, 1991).

The major alkaloids found in the potato and which share a common steroidal alkaloid part, the aglyconesolanidine, are α- chaconine and α-solanine (Bacigalupo *et al*., 2004). Chaconine and α-solanine comprise about 95% of the glycoalkaloids present in potatoes; α-chaconine generally being present in a somewhat higher proportion and being the most toxic of the two (Friedman, 2006). However, when these compounds occur in the same tissue there is bound to be some form of synergy (Nema et al., 2008).

The level of glycoalkaloids usually increases with exposure of the tuber to stress conditions such as injury/damage, or exposure to non-ideal conditions of light and temperature especially during storage. In Kenya, potatoes are exposed to sunlight in the open market making them prone to accumulation of total glycoalkaloids (Abong' *et al*., 2009). Current exposure to this toxin especially due to increased consumption of poorly handled potato tubers and their products in major urban areas is not well documented and hence the consequences or its contribution on health and safety of meals prepared from potatoes is unknown to many. The current study thus seeks to address the food safety aspect in regard to the glycoalkaloid content in Kenyan potato tubers and how it is affected by post-harvest handling and storage.

**1.2 Problem statement**

Potatoes are known to accumulate glycoalkaloids during growth and postharvest storage. Glycoalkaloids arebe toxic with toxicity beginning with gastrointestinal disturbances followed by neurological disorders at higher doses (Mensinga *et al*., 2005). Its stability to heat when subjected to different cooking conditions is a major concern that calls for concerted efforts in its reduction prior to processing (Bushway & Ponnampalam, 1981; Friedman, 2006). Furthermore, it has been established that both α-chaconine and α-solanine have long half-lives of 44hours and 21 hours, respectively, indicating that continuous consumption of potato products containing these compounds can lead to accumulation thus result in adverse health effects (Mensinga *et al*., 2005).

The contribution of potato tubers and products in terms of glycoalkaloids is, however, not supported by adequate data especially in the Kenyan context. Poor post-harvest handling including exposure of raw tubers to sunlight in open air markets and poor storage in Kenya grossly puts the potato to high risk of glycoalkaloids accumulation. Despite this obvious risk, little has been done to quantify the level of glycoalkaloids in tubers traded in urban markets in Kenya. Furthermore, the little information that is available on this subject is scattered and not readily available or well understood by the public especially the consumers and traders. The current study, therefore, is designed to fill these knowledge gaps.

**1.3 Justification**

Most potato tubers sold in open air markets around Nairobi are openly exposed to sunlight thus putting the tubers at risk of glycoalkaloids development. These glycoalkaloids are toxic compounds with consumption of high quantities above set limits being potentially harmful.

Yet most traders are unaware of presence of glycoalkaloids in potatoes and the factors promoting development of these toxins and the deleterious effects on health. This research will, therefore, be critical in generating important information regarding the effect of post-harvest handling and storage on the development of these toxins. This is especially important in protecting the health of consumers through awareness creation. Additionally, information generated will be useful in educating potato traders and other handlers on appropriate post-harvest handling and storage strategies so as to reduce the economic losses that are associated with "greening" in potatoes. Furthermore, since glycoalkaloids have not received much attention in terms of policy, this research will be crucial in informing policy for the formulation of appropriate strategies for the prevention and control of glycoalkaloids accumulation along the potato value chain in Kenya.

### 1.4 Aim

This study aims to contribute knowledge towards appropriate safety measures in relation to content of glycoalkaloids in potato tubers in order to ensure that the consumer is protected against their toxicity.

### 1.5 Purpose

To quantify the levels of glycoalkaloids in commercial potato varieties in Kenya and give insight on how these levels are influenced by post-harvest handling and storage.

### 1.6 Objectives

#### 1.6.1 Main Objective

To determine the levels of glycoalkaloids in potatoes traded in Nairobi and assess the impact of postharvest handling and storage.

#### 1.6.2 Specific Objectives

1. To identify the current post-harvest handling and storage practices among potato traders in Nairobi, Kenya.

2. To determine the levels of glycoalkaloids in potatoes traded in open markets in Nairobi, Kenya.
3. To determine the effect of post-harvest handling and storage conditions of light and temperature on the levels of glycoalkaloids in potatoes.

**1.7 Hypotheses**

1. The current post-harvest handling practices among potato traders significantly affect the levels of glycoalkaloids
2. The levels of glycoalkaloids do not exceed the recommended 200mg/kg fresh weight of tuber.
3. The levels of glycoalkaloids in potatoes are not significantly affected by temperature and light during storage.

# CHAPTER TWO: LITERATURE REVIEW

## 2.0 Potato production and utilization

The potato is an important staple food crop globally and is among the top 5 crops produced with an estimated annual global production of over 300 million metric tonnes (FAO, 2015). The crop is ranked third after rice and wheat in terms of global human consumption with more than 1 billion people eating it on a regular basis (CIP, 2015). In Kenya the potato is second to maize in terms of consumption. It is cultivated by over 800,000 growers who are mostly smallholders and its production in Kenya is currently worth about KSH 50 billion (MoA, 2009). In addition to being a staple food crop, the potato is a common cash crop in many parts of the world thus playing an important income earner for all the players its value chain. This makes the crop an important part of the diets of many households around the world.

Globally potatoes and potato products are highly consumed hence the need to ensure its safety for the benefit of the consumers. In Kenya, potatoes are an important part of the diets of many Kenyans, with the tubers being eaten boiled, baked, fried or incorporated into traditional dishes (Walingo *et al*., 2004). For instance, potato products such as French fries (locally known as *chips*) and crisps have gained prominence in major urban centers such as Nairobi (Walingo *et al*., 2004; (Abong, *et al*., 2010). Other potato products that are highly utilized in Kenya include potato based snack foods and frozen chips with their demand rapidly increasing (Walingo *et al*., 2004). Some of the reasons that have been reported to contribute to the rising demand of these potato products is their generally pleasant flavor and texture, affordability, and convenience especially for the younger individuals who have difficulty preparing their own meals (Abong & Kabira, 2015; Rytel *et al*., 2005).

## 2.1 Occurrence and distribution of glycoalkaloids in potatoes

Glycoalkaloids are synthesized in all tissues of the potato plant. However, these levels vary significantly between different parts of the plant. Variations in levels also occur between similar parts of different plants and varieties (Nema et al., 2008). Generally the glycoalkaloid content of potato tubers is expressed as total glycoalkaloids (TGA) per kg fresh weight (FW)which is the sum of α-chaconine and α-solanine content (Knuthsen *et al*., 2009). Generally, the acceptable safe upper limit of GAs in potatoes is 200mg TGA/kg FW (FAO/WHO, 1999). Under normal conditions, the levels of glycoalkaloids in potato tubers are usually low. However, these significantly change when the tubers are exposed to unfavorable conditions e.g. temperature, light, injury (Barceloux, 2009).

Glycoalkaloids are highly concentrated in the superficial layer of the tuber, next to sprouting points normally called "eyes", and injured or wounded parts with decreasing concentration observed towards the centre of the tuber (Friedman *et al.*, 2003).Within the tuber itself, glycoalkaloids have been shown to be mainly concentrated in the skin, implying that consumption of unpeeled potatoes exposes the consumer to more toxicity than consumption of peeled potatoes.

Generally, the ratio of α-chaconine to α-solanine in the tuber is about 60: 40 meaning that the presence of α-chaconine is slightly higher than that of α-solanine (Knuthsen *et al*., 2009).

## 2.2 Health effects of glycoalkaloids

Plants of the Solanaceae family, which include potato (*Solanum tuberosum* L.), tomato (*Lycopersicon esculentum*), egg-plant (*Solanum melongena*) and peppers (*Capsicum annum*), produce secondary metabolites called glycoalkaloids which are toxic and act as a defense against fungi, pests and herbivores. These compounds have the potential of being harmful to humans if consumed in large quantities (Korpan *et al*., 2004). Toxicity is thought to be due to two actions: (i) cell membrane disruption, thereby causing gastrointestinal disturbances and (ii) inhibition of the enzyme acetylcholinesterase resulting in impaired regulation of acetylcholine; this disrupts normal conduction of nerve impulses which eventually affecting the functioning of the nervous system (Mensinga *et al*., 2005; Milner *et al*., 2011). Higher doses can damage the nervous system, result in coma and even cause death (Friedman, 2006)

The high levels of potato consumption makes the possible health risks associated with glycoalkaloids toxicity a health concern. It has been shown that a dose of 1-5 mg/kg BW will result in toxicity (Friedman et *al.*, 1997). Symptoms generally occur a few hours after ingestion (8–12 h after ingestion) and usually present as gastrointestinal and neurological disorders (Mensinga *et al*., 2005). In mild cases glycoalkaloids poisoning presents with such symptoms as headaches, dizziness, abdominal pain, nausea, vomiting and diarrhea (Milner *et al*., 2011). Symptoms that are associated with impaired neurological function include apathy, restlessness, drowsiness, mental confusion, rambling, incoherence, hallucinations, trembling and visual disturbances (Jadhav *et al*., 1981). However, many of these symptoms are closely related to symptoms of many other diseases making misdiagnosis a common occurrence (Smith *et al*., 1996).

The levels of glycoalkaloids in many potato varieties have been shown to be lower than the widely accepted upper value of 200 mg glycoalkaloid/kg fresh weight (FW) (Smith et al., 1996a); although certain conditions can result in these levels exceeding the these set limits levels . Furthermore, some researchers have suggested that these limits may be too high (Friedman *et al.*, 1997; Friedman, 2006) suggesting that risk to exposure can occur even at lower levels. This was proved in a study where gastrointestinal disturbances were shown to develop after consumption of glycoalkaloids at the recommended 200mg/kg limit (Mensinga *et al*., 2005).

### 2.3 Factors affecting glycoalkaloid content in potatoes

#### 2.3.1 Potato Variety

There is considerable variation in glycoalkaloid content among potato cultivars. The average content in a given variety is probably as a result of genetic inheritance from its ancestors. Additionally, some varieties may be affected greatly or slightly by storage conditions than others. For instance, varieties with high content of GAs are likely to synthesize more GAs when subjected to stress or improper handling than those with lower content (Sinden *et al*., 1984). Furthermore, a study comparing the levels of GAs between potato varieties tolerant to drought and those not tolerant to drought  found the lowest amounts of GAs in drought-tolerant varieties than in non-drought tolerant varieties (Bejarano *et al*., 2000).Smaller potatoes, because of the high surface area/volume ratio have more concentration of these toxins than large potatoes.

#### 2.3.2 Maturity

Maturity of tubers affects the glycoalkaloid levels in potatoes. Immature parts of the tuber i.e. those undergoing high metabolic activity are associated with high concentrations of GAs. Small immature tubers normally have high concentrations because of the high metabolic activity in the tissues (Grunenfelder *et al*., 2006). As the potato matures, the level of glycoalkaloids decreases with a considerable decrease being noted as early as 52 days after vegetation (Papathanasiou *et al*., 1998). Greater amounts of glycoalkaloids were found in the very early harvesting varieties while middle-to-late harvesting varieties displayed lower amounts (Peksa *et al*., 2002).

### 2.3.3 Exposure to light

Light has been reported as one of the most important factors that influences post-harvest synthesis and accumulation of GAs in potato tubers (Plhak & Sporns, 1992; Machado *et al*., 2007). The concentration of total and individual glycoalkaloids has been shown to increase significantly after exposure to light (Şengül *et al*., 2004). Even short exposure of tubers to intense sunlight can result in significant increases in GAs levels (Sinden *et al*., 1984). Light also plays a significant role in chlorophyll formation, resulting in a phenomenon called "greening" where the potato turns green on the surface. This phenomenon is associated with a rise in the concentration of glycoalkaloids, especially the α-solanine (Pavlista, 2001). Although GAs can be synthesized when potatoes are stored in the dark the rate of synthesis is very low (about 20%) compared to the rate of synthesis under light exposure (Cantwell, 1996). This can be observed in retail outlets especially in tubers that are displayed under light e.g. fluorescent lighting. It has, therefore, been suggested that this can be reduced by using mercury lighting instead of fluorescent lights during display (G. C. Percival, 1999). Therefore, exposure of tubers to various forms of lighting (e.g. sunlight, fluorescent, ultraviolet) for different durations during harvesting, transportation, packaging and marketing poses a major food safety concern with regard to accumulation of glycoalkaloids.

### 2.3.4 Storage temperature

Storage temperature has been found to be one of the factors that greatly influences the levels of glycoalkaloids in potatoes (Petersson *et al.* 2013). Studies have generally shown that low temperature storage results in more potatoes with a characteristic bitter taste than those stored at higher temperatures. For instance, (Machado *et al*., 2007) reported greater synthesis of glycoalkaloids in tubers stored under refrigeration (7–8$^0$C) in darkness than for tubers stored under room temperature (19–26$^0$C) in darkness. In contrast, other researchers report higher synthesis of glycoalkaloids at high temperatures than at low temperatures. For instance, it was reported that storing tubers at higher temperatures ($5^0$C and $23^0$C) causes the solanine content to increase significantly (Rosenfeld *et al*., 1995). Furthermore, Cantwell (1996) reported that the synthesis of glycoalkaloids at $24^0$C is about double the rate of synthesis at $7^0$C.

**2.3.5 Injury/damage**

Glycoalkaloids have been shown to accumulate due to any injury or damage. Mechanical damage to the tuber during post-harvest handling such as bruising and abrasion, even when not visible, leads to accumulation of GAs in the wounded tissues with the level of accumulation being significantly affected by the extent of injury. Any damage to potatoes that causes bruising and/or black spots, splitting or cracking can significantly result in increased glycoalkaloids level (Dale *et al*., 1998). Elevated levels of glycoalkaloids have been shown to occur in damaged or injured potatoes which is part of a 'wound response' thought to be associated with the tuber defense mechanisms (Jadhav *et al*., 1981).

**2.3.6 Effect of processing on Glycoalkaloids**

Glycoalkaloids in the potato tubers can be reduced when various unit operations are carried out during processing including peeling, chipping, cutting and dicing when producing products such as crisps and French fries are made. Cooking the potato only slightly affects the levels of glycoalkaloids (Bushway & Ponnampalam, 1981); (Friedman, 2006). Glycoalkaloids show relatively high heat stability with their concentrations only being reduced by about 40% when potatoes are heated to 210 oC for 10 minutes (Barceloux, 2009). Boiling or microwaving whole tubers has little or no effect in terms of reducing the glycoalkaloid content (Mulinacci et al., 2008), but peeling of potatoes before boiling results in about 39% reduction in the content of glycoalkaloids (Tajner-Czopek et al., 2008).

Although frying has been reported to be the most effective method of lowering the levels of glycoalkaloids, reported differences exist between raw, peeled and fried potatoes (Pęksa, Gołubowska, Aniołowski, Lisińska, & Rytel, 2006; Tajner-Czopek, Rytel, Kita, Pęksa, & Hamouz, 2012). However, it has been indicated that deep-frying temperatures of about 150°C do not result in significant changes in glycoalkaloid content since their degradation usually only begins at temperatures above 170 °C (Barceloux, 2009). Glycoalkaloids formation, fortunately, is localized near the skin hence peeling the potato before cooking can reduce the level (Rytel et al,., 2005). Blanching results to a significant loss of glycoalkaloids by up to 28 % compared to peeled potatoes. Cieślik (1995) observed that blanching decreases the total glycoalkaloids by about 40–50 %. This is because they dissolve in water although α-solanine is poorly dissolved as compared to α-chocanine (Barceloux, 2009). Other reports indicate that cutting, slicing, and rinsing with water do not significantly affect the glycoalkaloid concentration in potatoes tubers, with dehydration reducing the levels (Zarins & Kruma, 2017).

### 2.4 Post-harvest handling as a measure of glycoalkaloids control

Poor post-harvest handling especially exposure of tubers to light and non-ideal temperature is mainly responsible for the increase in glycoalkaloids levels in potatoes. Cooking, however, does not destroy the glycoalkaloids since they are stable to heat. Therefore, to prevent this accumulation proper postharvest handling and management is important.

Most of the factors that result in elevated GA content can actually be controlled during handling, processing or marketing (Sinden *et al*., 1984).

### 2.4.1 Avoidance of mechanical damage

The stress conditions that the potato is subjected to during harvesting, transportation, storage or processing can lead to mechanical damage thus result in elevated glycoalkaloids levels. For instance, any type of stress and tissue damage will induce synthesis of glycoalkaloids at the wounded points (Sinden *et al*., 1984). Mechanical damage is reported to be one of the most important environmental stress agents influencing the synthesis of GAs in potato tubers after harvesting. In fact injuries due to careless harvesting and handling, even when not visible to the naked eye, cause GAs to accumulate in the tissues surrounding the wound with the extent of injury determining the degree of their accumulation; which starts within 24 hours of damage occurring (Burlingame *et al*, 2009).

Avoiding any type of handling practice that results in mechanical damage such as bruising and abrasion in addition to removal of visibly damaged tubers prior to sale will thus help in controlling the GAs (Dale *et al*., 1998).

### 2.4.2 Minimizing exposure to light

Studies have shown that rates of glycoalkaloid accumulation within potato tubers can be significantly influenced by light. Light also induces chlorophyll formation in the tuber, which is associated with accumulation of glycoalkaloids (Zarins & Kruma, 2017). Limiting exposure of potatoes to light can significantly result in lowered formation of glycoalkloids. It has been shown that storing potatoes in the dark is one way of reducing accumulation of these toxins since in the dark, the rate of synthesis is very low (about 20%) compared to the rate of synthesis under light exposure (Cantwell, 1996). Accumulation of these toxins due to light exposure has also been shown to be dependent on the spectral composition of the light source. For instance, the rates of glycoalkaloid accumulation were four to six times higher in tubers exposed to fluorescent or sodium light sources compared with tubers exposed to mercury light sources. This was attributed to the fact that mercury illumination contains few spectral lines (ultraviolet and infrared) which are unlikely to enhance synthesis of glycolalkaloids and chlorophyll. This is unlike fluorescent light which contains ultraviolet spectra (Nema *et al*, 2008).

Harvesting in the absence of the sun, use of covered trucks for transportation, marketing in opaque plastics films and bags, storage in the dark, minimizing exposure to sunlight during grading and rotating frequently on retail displays and counters will reduce chances of GAs synthesis (Cantwell, 1996;  Şengül *et al*., 2004 ;Machado *et al*., 2007).

Also, use of mercury lighting instead of fluorescent lights during display of tubers significantly improves the safety of the tubers by reducing the glycoalkaloid levels ( Percival, 1999).

**2.4.3 Harvesting and storage at appropriate temperatures**

The temperature at which the tubers are harvested and/or stored is also a major contributor to GAs levels. However, conflicting reports exist of level of temperature where accumulation of GAs is enhanced. For instance, some reports indicate that avoiding low temperatures (0-5$^{O}$C) during storage will help control synthesis of GA (Şengül *et al*., 2004; Machado *et al*., 2007). On the other hand, other reports indicate that harvesting or storage of potatoes above room temperature will result in synthesis of glycoalkaloids (Cantwell, 1996; Rosenfeld *et al*., 1995). However, a review of glycoalkloids formation and mitigation strategies has shown that many researchers stdying the formation of GAs in tubers stored between 5-25$^{o}$C report occurrence of glycoalkloids with higher storage temperatures (Nema *et al*., 2008).

# CHAPTER THREE: POST-HARVEST HANDLING PRACTICES AND PERCEPTION OF POTATO SAFETY AMONG POTATO TRADERS IN NAIROBI, KENYA

## 3.0 Abstract

Post-harvest handling of the potato is an important factor not only in preventing post-harvest losses but also in maintaining its safety and nutritional quality. Exposure of the potato to unfavourable conditions such as light, extreme temperatures and bruising can result in accumulation of glycoalkaloids, which are toxic substances. This study was a cross-sectional survey aimed to investigate the post-harvest handling practices of potatoes and perception of potato safety among open air market traders in Nairobi County, Kenya. Information was collected from 100 potato traders using a semi-structured questionnaire that assessed post-harvest handling practices such as potato transportation, exposure to sunlight and storage. Results indicated that most of the potatoes (88%) took one day to be transported to the market, with the storage period at the market ranging from 2 to 3 days for most traders (42%). Forty seven percent (47%) of the vehicles and hand-pulled carts used to transport potatoes had open backs while 53% had closed backs. Over half (69%) the potatoes in the markets were directly exposed to sunlight, with 75% of the traders leaving their potatoes in the open covered with a polythene bag after the day's activities. Greening, sprouting or bruised potatoes were mostly sold as seed, sold to restaurants and French fries vendors, or sold to consumers at a lower price. More than half of the traders did not think that consumption of greened potatoes is harmful to health. The results clearly show that there is poor handling of the potatoes by the traders which increases the risk of consumer exposure to glycoalkaloids. There is, therefore, need to create awareness among traders on appropriate post-harvest handling of potatoes to protect consumer health and reduce economic losses as well.

## 3.1 Introduction

The potato (*Solanum tuberosum)* is an important staple food crop globally. The crop is ranked third after rice and wheat in terms of global human consumption with more than 1 billion people eating it on a regular basis (FAOSTAT, 2015). It is a crop with stable yields and high nutritional content and is, therefore, important in terms of achieving food and nutritional security. In addition to being a nutritious staple food crop, it an important income earner for all the players along its value chain from production, marketing and processing.

In Kenya potato production and consumption are on the increase with the crop being second to maize in terms of consumption. In 2010, Kenya's annual potato production averaged 7.7 tonnes/ha (Janseens *et al*., 2013) with the main potato growing regions being Nyandarua, Bomet, Meru, Nakuru, Uasin Gishu, Narok, Nyeri, Kiambu, West Pokot and Keiyo Marakwett (MoA, 2013). There are 19 adapted potato varieties in Kenya (NPCK, 2017) with Shangi variety being the most common and highly consumed variety due to its early maturity and high productivity (Abong' *et al*., 2015) although the number of varieties has increased beyond 50 with introduction of new ones from other countries such as Netherlands and Germany. Most of the potatoes produced in Kenya are sold locally on the market as fresh produce and are subsequently processed into different foodstuffs either at household or industrial level. Furthermore, processed potato products such as crisps and French fries (locally known as chips) are on high demand among urban consumers hence are a great part of menus in restaurants and hotels in major urban centers (Abong *et al*, 2009). This, therefore, makes the potato a major part of the diet of many Kenyan consumers.

Post-harvest management of the potato is an important factor not only in preventing post-harvest losses of but also in maintaining its nutritional quality. Furthermore, the safety of the potato for consumption is greatly influenced by post-harvest management and storage. This is because the potato contains glycoalkaloids (GAs), a family of steroidal toxic secondary metabolites that occur in all parts of the potato as natural toxins, synthesized as a form of defense against parasites and diseases due to their antimicrobial, insecticidal and fungicidal properties (Nema *et al*, 2008). Of interest to food safety is the fact that these toxins can be harmful to humans if consumed in large quantities (Korpan *et al*., 2004). Toxicity can cause gastrointestinal disturbances and impaired nerve function (Mensinga *et al*., 2005; Milner *et al*., 2011). Higher doses can result in coma and even cause death (Mendel Friedman, 2006). The levels of these toxins are significantly affected by post-harvest handling stress factors with exposure to light, storage temperatures and injuries/bruising being important stress factors.

In Kenya, one of the major constraints facing the potato value chain is poor post-harvest handling especially during marketing and distribution, and significant losses have been reported to occur at this stage. In fact, it has been reported that of the potatoes placed on markets in Kenya, nearly a quarter are damaged or green (GIZ, 2014). In Nairobi, it is not uncommon for traders to expose potatoes to unfavorable temperature, light and other stress factors which favors the accumulation of GAs in the tubers. This does not only cause concern with respect to food losses but also to the health of potato consumers in Nairobi since these damaged or greened potatoes are sold to consumers thus resulting in continued exposure to these lethal toxins. Addressing the aspects of post-harvest handling among potato traders will help prevent food losses while at the same time promoting food safety hence protecting consumer health. This study, therefore, sought to identify the post-harvest handling practices among potato traders in open-air markets in Nairobi County and their perception of the safety of greening and bruised potatoes. Results from the study will be helpful in sensitizing potato traders on appropriate postharvest handling of potatoes in order to protect consumer health as well as reduce post-harvest losses at the marketing stage.

### 3.2 Materials and methods

#### 3.2.1 Study area

The study was carried out in Nairobi County, Kenya. The county hosts the capital city of Kenya and has nine sub-counties: Makadara, Embakasi, Starehe, Langata, Kasarani, Westlands, Kamukunji, Dagorreti and Njiru (**Figure 3.1**). The county's population is estimated to be over 3 million according to the latest census (KNBS, 2009). Most of the people are low income earners hence live in slums. The county has many markets dealing in food stuffs with most of these food markets being open air markets. Five sub-counties were purposively selected for this study: Dagoretti, Westlands, Embakasi, Kamukunji and Starehe. These were purposively selected because most of Nairobi's population is concentrated in these areas. From these 5 sub-counties, 5 major markets were purposively selected from which traders were interviewed. The 5 markets were Kawangware (Dagoretti), Kangemi (Westlands), Wakulima (Starehe), Kona (Embakasi) and Gikomba (Kamukunji).

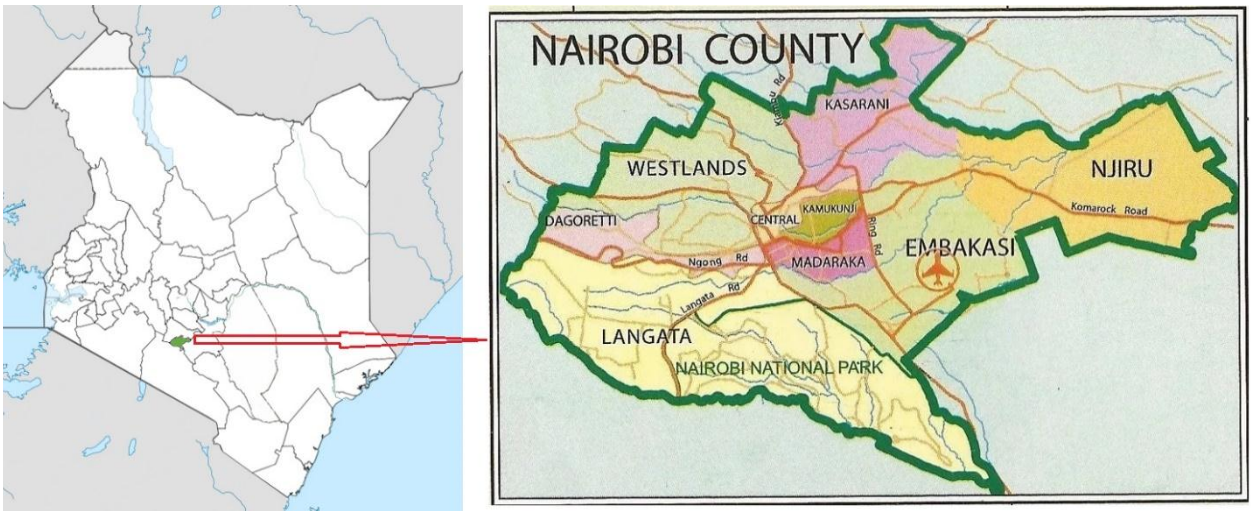


**Figure 3.1: Study area, Nairobi County.** Source: https://softkenya.com.

#### 3.2.2 Study type and design

The study was a cross-sectional study design employing qualitative data collection methods through interviews and observation.

### 3.2.3 Study population and sampling technique

The study population consisted of open air market traders who sell potato tubers. Simple random sampling technique was used to get the traders who participated in the study. To determine the sample size Fischers formula (Fischer *et al*., 1991) was used as follows:

$$n = \frac{Z^2 pq}{d^2}$$

Where

n = desired sample size

p=proportion expected to have the features under study; in this case those who sell potatoes (50%) =0.5

Z=standard deviation set at 1.96 (95% confident interval)

q=1-p i.e. proportion not expected to have the features under study (50%) =0.5

d=degree of accuracy/sampling error-±10% = 0.1

Using the formula$n = \frac{Z^2 pq}{d^2}$

$$n = \frac{1.96^2 \times 0.5 \times 0.5}{0.1^2}$$

$$n = 3.8416 \times \frac{0.25}{0.01} = 96.4$$

Four traders were added to this number *n* to cater for attrition.

Therefore, the number of traders that were interviewed was **100**.

The 100 traders to be interviewed were distributed among the five markets as follows: 19 traders each for Kawangware, Kangemi, Gikomba and Kona markets and 24 traders for Wakulima market. Wakulima market had more respondents since it is in Starehe sub-county which comprises of the CBD and hence has more traders than the other 4 markets. Simple random sampling was again employed to pick the traders who participated in the study from each market.

#### 3.2.3 The survey instrument

A semi-structured questionnaire was used for this study. The tool was written in English and captured information on demographic characteristics and post-harvest handling practices of potatoes such as transportation, exposure to sunlight, storage, what is done for greened and injured/bruised potatoes and any other relevant information.

The tool was pretested on a randomly picked sample of 20 traders from Kawangware and Kangemi markets (10 traders from each). Pre-testing is important in ensuring that the questions will be understood by the respondents and to estimate the time that will be taken to complete the questionnaire.

### 3.3 Data collection

The questionnaire was administered to the randomly selected traders who were present in the respective markets during the interview period. Those who could read and write were given to fill the questionnaire on their own while those who could not were interviewed by well-trained enumerators who translated the questions from English to Kiswahili and filled the responses given by the respondents.

### 3.4 Study ethics

Before answering any question, consent was sought from the respondents. The respondents were taken through the purpose of the study, asked to voluntarily participate in the study and assured of the confidentiality of their responses. They were then asked to sign a consent form to show that they agreed to participate in the study.

## 3.5 Data analysis

Data obtained were coded and entered into SPSS for Windows software (IBM version 21) and analyzed. Descriptive statistics namely, percentages and frequencies were used to express the results of socio-demographic characteristics of the study population and the different post-harvest handling practices. Chi-square test of significance was used to test for any existing significant associations between the various variables under study with a p-value = 0.05 being set as the level of significance.

## 3.6 Results and discussion

### 3.6.1 Socio-demographic characteristics of the respondents

The socio-demographic characteristics of the potato traders are represented in **Table 3.1**. More than half of the traders were male (53%). The fact that there were more male traders than female traders concurs with Laititi (2014) who reported more male than female involvement in the potato value chain in Kenya. Additionally, other research found more male traders (57%) than female traders (43%) in a study on potato traders and farmers in some of the major potato producing regions in Kenya (GIZ, 2014). The dominance of men over women in potato retail and trade could be explained by the fact that most of the potato farming in Kenya is small scale and women are more involved in production activities especially at the farm level while men engage in other off-farm activities like marketing.

The age of the respondents ranged from 20 years to 80 years with the majority falling in the 30-39 years bracket (35%). With regard to education level, most of the traders had attained primary (44%) and secondary (44%) levels with only 2% of them having studied up to tertiary level.

**Table 3.1: Socio-demographic characteristics of potato traders in open air markets in Nairobi County**

| Characteristic | Frequency (n=100) | Percentage (%) |
|---|---|---|
| **Gender** | | |
| Male | 53 | 53 |
| Female | 47 | 47 |
| **Age** | | |
| 20-29 years | 20 | 20 |
| 30-39 years | 36 | 36 |
| 40-49 years | 20 | 20 |
| 50-59 years | 18 | 18 |
| >59 years | 6 | 6 |
| **Education Level** | | |
| No education | 10 | 10 |
| Primary | 44 | 44 |
| Secondary | 44 | 44 |
| Tertiary | 2 | 2 |

### 3.6.2 Potato varieties traded

Shangi variety was the most common variety sold in Nairobi (94%) as shown in **Figure 3.2**. The other varieties identified by the study were Golf (5%) and Nyayo (1%). Previous studies have reported Shangi to be the most commonly marketed and consumed variety in Kenya *(*Abong' *et al*., 2015). The variety is common because it is early maturing and has high productivity compared to other varieties thus preferred by most farmers. It is also preferred by many low income consumers due to its short cooking time thus saving on energy costs (Janseens *et al*., 2013). In addition, Shangi has good cooking qualities hence preferred for processing of French fries, commonly known as chips (Abong' *et al*., 2015).

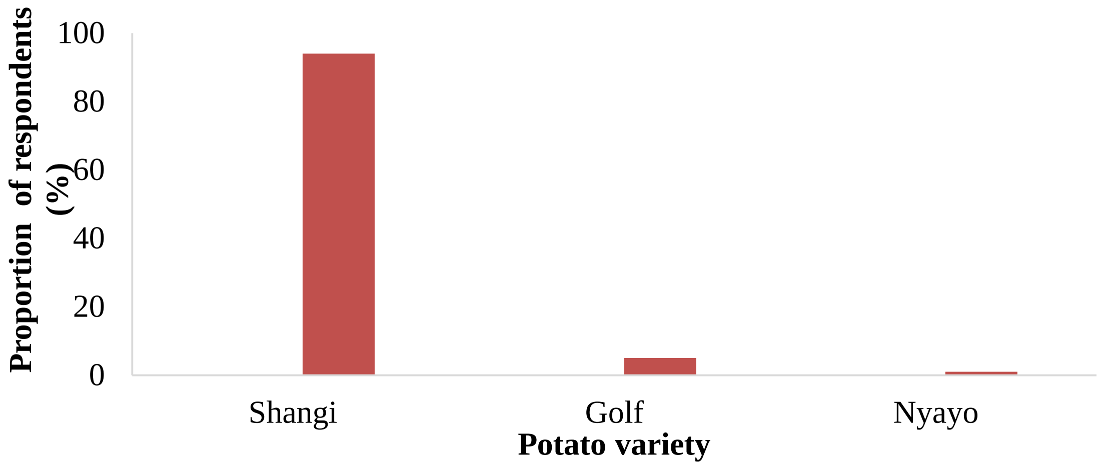


**Figure 3.2: Varieties of potatoes sold in open air markets in Nairobi.**

As shown in **Figure 3.3** most of the potatoes traded in Nairobi's open air markets come from Bomet County (45%) followed by Nyandarua County (38%) with the least supply among the surveyed respondents being from Elgeyo Marakwett County (2%). Nyandarua and Bomet are some of the major potato producing regions in Kenya (NPCK, 2017) and this could explain why most of the traders in Nairobi source their supply from these regions.

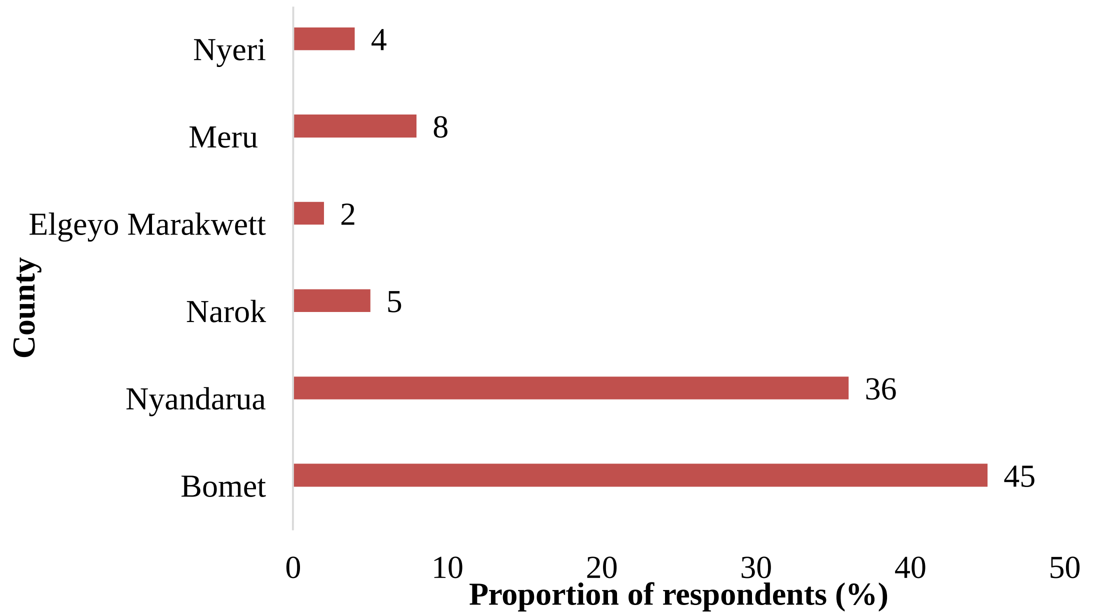


**Figure 3.3: Source of ware potatoes sold in open air markets in Nairobi.**

### 3.6.3 Postharvest handling practices

Most of the traders (88%) took one day to be transport potatoes from the point of supply to the market). This short duration taken could be explained by the fact that potatoes are highly perishable products hence need to be transported to the market as quickly as possible. This short duration could also be attributed to the high demand for potatoes and potato products in Nairobi, necessitating a constant supply of fresh ware potatoes to the market.

Ninety three (93) traders said they used a vehicle (lorry or pick-up truck) or hand-pulled cart to transport their potatoes from point of supply to the point of sale while 7 traders used motorcycles. Further assessment of the design of the back of the vehicles and hand-pulled carts used for transporting potatoes revealed that 47% had open backs while 53% had closed backs. This shows that over half of the potatoes are not exposed to sunlight during transportation since the closed backs protect the potatoes from direct sunrays. However, a sizeable proportion of potatoes (43%) are exposed to direct sunlight during transportation which is a risk factor for development of glycoalkaloids in the tubers during transportation and subsequent storage.

Three quarters (75%) of the traders interviewed left their potatoes outside covered with a polythene bag after the day’s activities until the next day when they opened their businesses. The covering of potatoes with a polythene bag means that there is no sufficient aeration and the temperatures inside might rise thus exposing the potatoes to higher temperatures. This is a risk factor for the development of glycoalkaloids due to exposure to high temperatures. Furthermore, since the potatoes are stored outside and sold in the open, they are exposed to sunlight further increasing the chance of accumulation of glycoalkaloids in the tubers.

**Figure 3.4** shows the duration of time potatoes stay on the market before the traders get a fresh supply of potatoes. Generally, most of the potatoes take 1 to 3 days on the market meaning that they are high moving commodities due to the high demand for potato products among Nairobi residents. However, a few of the traders who stocked large quantities of potatoes stored them for longer periods of 1 to 4 weeks. This may be a food safety risk given that potatoes are highly perishable products and longer storage periods increases the chances of greening, sprouting and development of glycoalkaloids in the tubers especially if stored for long under poor storage conditions (Nema et al., 2008).

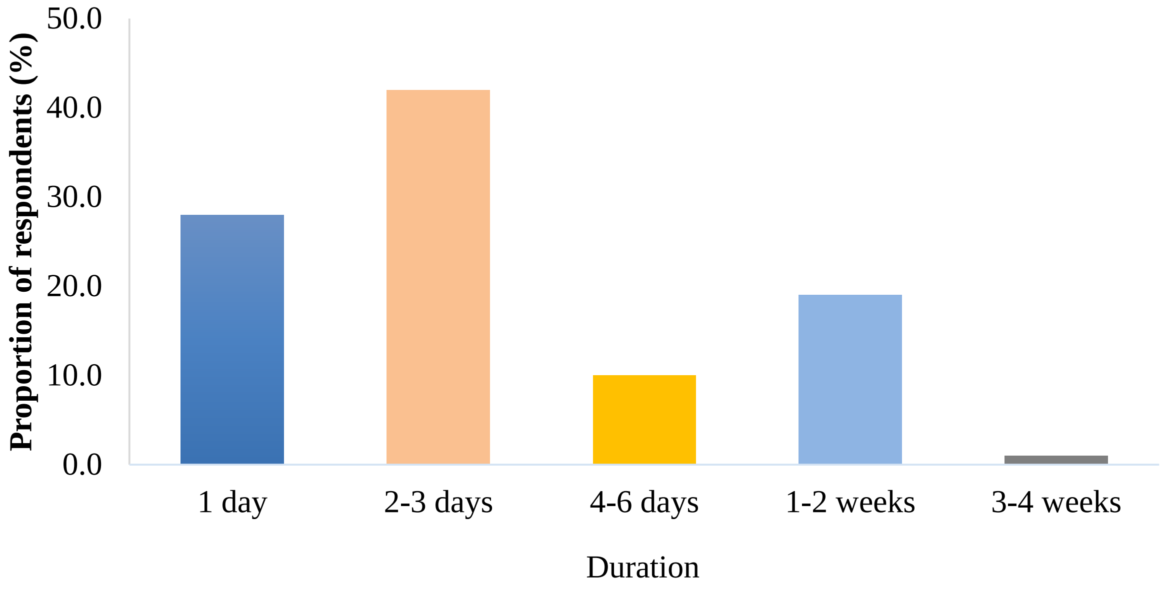


**Figure 3.4: Time taken by potatoes on the market.**

The location, gender and variety of potato were found to influence the postharvest handling practices of potato (**Table 3.2).** Duration taken for potatoes to reach the market was significantly ($p<0.05$) associated with gender, while means of transport was significantly ($p<0.05$) dependent on the sub-county, specific market, gender and potato variety being traded. The means of transport preferred by traders in Starehe and Dagoretti Sub-counties was vehicles which significantly ($p<0.05$) differed from that preferred by traders from Embakasi Sub-County where handcarts were used (**Table 3).** Potato traders in Kona and Gikomba markets mainly preferred vehicle as means of transport at 65.9% and 60.9%, respectively whereas majority (56.2%) of those in Kangemi market preferred handcarts ($p<0.05$). More (68.1%) males tend to use vehicles as means of transport as compared to females who only had 63% using vehicle as a mode of transportation ($p<0.05$). Those transporting the golf variety of potatoes used vehicles as their means of transport.

The findings reveal different preferences on the mode of transport for different markets, locations, gender and different potato variety. Vehicle transportation was most preferred by significant proportions of the various segments of the population. Potato production in Kenya is mainly done in the highlands and due to their high perishability, a faster means of transport is most preferred; however, this attracts additional costs in terms of transportation (Muthoni & Nyamongo, 2009). A study by Laititi (2014) found similar results where vehicle transportation was used to deliver potatoes from various producing areas in the country to markets in Nairobi; the handcart served just as a complementary mode of transportation. Therefore, the use of handcart isn't the primary mode for most of potato traders in Nairobi. However, studies done in the rural areas by Kaguongo *et al*. (2014) showed contrary findings with cart transportation being the most preferred means of transport due to the short distances involved.

**Table 3.2: Association between postharvest handling practices and socio-economic and demographic characteristics**

| Post-harvest handling practices | Sub-County | Market | Gender | Level of education | Potato variety | Age |
|---|---|---|---|---|---|---|
| Duration taken to market | 5.18 | 4.23 | 8.80* | 3.21 | 2.20 | 7.51 |
| Means of transport | 38.55* | 38.89* | 9.62* | 5.34 | 7.25* | 9.90 |
| Vehicle/handcart design | 32.89* | 32.89* | 9.36* | 6.78 | 9.36* | 5.49 |
| Storage of potato | 8.33 | 8.33 | 2.27 | 2.25 | 1.14 | 3.31 |
| Duration of storage of potato | 10.98 | 10.98 | 8.84 | 8.14 | 8.58 | 8.54 |

*significant at $p<0.05$

Closed-back vehicles were used for transportation mostly in Kamukunji and Starehe Sub-Counties at 51.3% and 65.3%, respectively, this being significantly ($p<0.05$) higher than other sub-counties (**Table 3.3**). Different vehicle designs were preferred in different markets as Kawangware and Kangemi at 55.7% and 59%, respectively preferred closed back modes of transport ($p<0.05$). The golf variety of potatoes was majorly (100%) transported using closed-back vehicle designs ($p<0.05$).

The study findings reveal that a higher proportion of the respondents from majority of the Sub-Counties and markets would prefer using closed back design of vehicles to transport their potatoes. Regardless of the gender or potato variety, most of the traders would still prefer using closed back modes of transport to ferry their products. This is in effort to reduce spoilage of the potato during transportation. Further, use of vehicles with closed backs reduces the exposure of the tubers to direct sunlight which has food safety implications as this reduces the risk of accumulation of glycoalkaloids in the potatoes.

**Table 3.3: Preferences (%) for different modes of transport**

| Factors | | Means of transport | | Design of the vehicle | |
|---|---|---|---|---|---|
| | | **Vehicle** | **Handcart** | **Open-back** | **Closed back** |
| Sub-County | Dagoretti | 84.4 | 15.6 | 49.6 | 50.4 |
| | Westlands | 66.7 | 33.3 | 57.1 | 42.9 |
| | Kamukunji | 52.6 | 47.4 | 48.7 | 51.3 |
| | Starehe | 79.2 | 20.8 | 34.7 | 65.3 |
| | Embakasi | 42.2 | 57.8 | 59.2 | 40.8 |
| Market | Kawangware | 49.2 | 50.8 | 44.3 | 55.7 |
| | Kangemi | 43.8 | 56.2 | 41 | 59 |
| | Gikomba | 60.9 | 39.1 | 56.2 | 43.8 |
| | Wakulima | 56.7 | 43.3 | 67.1 | 32.9 |
| | Kona | 65.9 | 34.1 | 49.9 | 50.1 |
| Gender | Male | 68.1 | 31.9 | 50 | 50 |
| | Female | 63 | 37 | 49.4 | 50.6 |
| Potato variety | Shangi | 62.8 | 37.2 | 46.5 | 53.5 |
| | Golf | 100 | 0 | 0 | 100 |

### 3.6.4 Exposure of potatoes to sunlight

From observations, it was noted that more than half (69%) of the potatoes in the surveyed markets were exposed to sunlight. Potato variety and gender were found to be factors that predicted likelihood of exposure of potato to sunlight as shown in **Table 3.4.** Male traders were five times more likely to expose the potatoes to sunlight than the female traders. The logit regression model for the equation is:

$y = Ax + Bz$, where y is exposure of potato to sunlight, *x* and *z* are the independent variables gender and potato variety, A and B are constants. $A$ and $B$ accounted for 30% change in *y*.

**Table 3.4: Logit model for exposure of potatoes to sunlight**

| Variable | | Odds Ratio |
|---|---|---|
| Sub-County | Dagoretti | 0.638 |
| | Westlands | 0.542 |
| | Kamukunji | 1.486 |
| | Starehe | 1.791 |
| | Embakasi[R] | |
| Gender | Male | 5.256* |
| | Female[R] | |
| Education level | Primary | 0.431 |
| | Secondary | 1.008 |
| | Tertiary | 0.694 |
| | No education[R] | |
| Variety of potato | Shangi | 0.060* |
| | Golf[R] | |
| Supply of potatoes | Own production | 0.298 |
| | Buy from other retailers[R] | |
| Age | | 2.547 |

*significant at $p<0.05$, R-reference category, $R^2$=0.30, constant=0.00

The findings reveal that exposure of potatoes to sunlight is a common practice among the traders regardless of education level, age and all location with no difference in handling to curtail the same. Individuals who were males were five time more likely to have their potatoes exposed to light than the females. Purchase of potatoes from the male traders poses greater risk of exposure to consumption of glycoalkaloids. Interestingly, the education level of the traders did not influence how they handled the potatoes with respect to exposure to sunlight.

### 3.6.5 Trader perception of safety of greened, bruised or sprouting potatoes

More than half (56%) of potato traders in open air markets in Nairobi sell greened potatoes or potatoes that show signs of greening to farmers as seed (**Figure 3.5**). This shows that almost half of the greened potatoes on the market are sold back to the farmers for replanting. This observation supports earlier findings where poor access to certified/good quality seed was found to be one of the major constraints by potato farmers in Kenya (Janseens *et al*., 2013) . However, some of these greening potatoes are sold to consumers at a lower price (20%) or some dubious traders stash them among fresh potatoes and sell to unsuspecting customers (4%). This may pose a serious health risk to consumers if these potatoes that show signs of greening are consumed since greening in potatoes is a phenomenon associated with formation of glycoalkaloids. A sizeable number of traders (27%) threw away potatoes that showed signs of greening. This means that potato losses are one of the major challenges experienced by traders which translates to major food losses in a country that is already grappling with food insecurity. A study by Kaguongo *et al*. [12] found that postharvest loss is a major problem facing many potato farmers in Kenya with 19% of produce being lost per season, translating to 815,000 tonnes lost which represents an estimated monetary loss of Ksh. 12.9 billion every year. This problem can be mitigated through efforts such as sensitizing the potato value chain players on proper storage, development of modern and affordable storage technologies and development of potato varieties with longer storage duration.

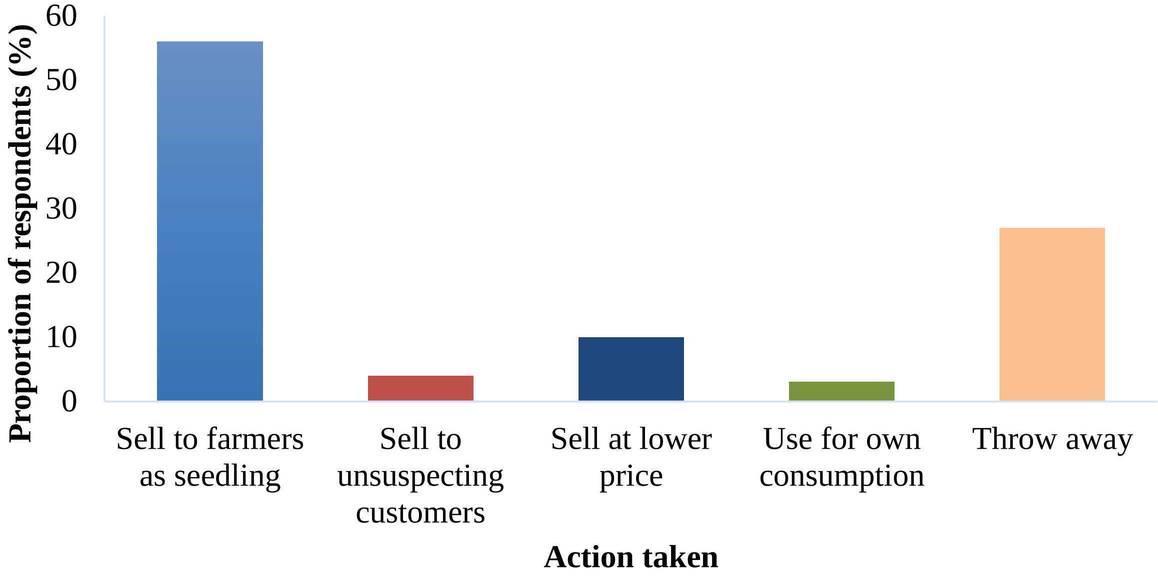


**Figure 3.5: Action taken by traders for potatoes that show signs of greening**

**Figure 3.6** shows various actions taken by potato traders for potatoes that are bruised or sprout while still on the market. Bruising and sprouting have been shown to be some of the factors that contribute to increased levels of glycoalkaloids in potatoes (Nema et al., 2008), hence potatoes that are sprouting or have been bruised should not be consumed. Only a small number of traders (2%) threw away such potatoes. The remaining traders either sold bruised or sprouting potatoes directly to consumers at a lower price; or sold to restaurants or other vendors who traded in potato products especially French fries.

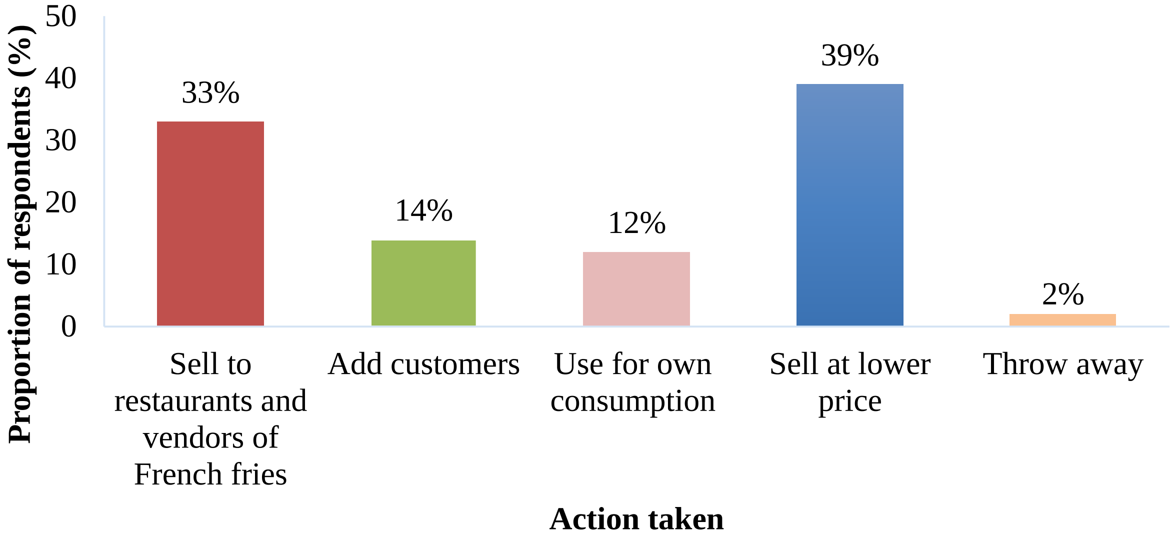


**Figure 3.6: Action taken by traders on bruised or sprouting potatoes**

The present study sought to assess the knowledge of traders regarding the harmful effects of consuming greening or sprouting potatoes. More than half the traders (53%) said that consuming greening or sprouting potatoes does not have any harmful effects on health; 28% said that greening or sprouting potatoes are harmful to health while 19% did not know whether greened or sprouting potatoes were harmful to health or not. This means that a large number of them do not know the harmful effects of consuming such potatoes which may explain why some of them sold such potatoes to unsuspecting customers, sold them at a lower price, used them for own consumption or added them to their customers as an incentive.

Socio-demographic characteristics of the traders significantly ($p<0.05$) influenced their perception on the safety of potatoes (**Table 3.5**). Majority of the traders from Dagoretti and Westlands sub-counties sold greening potatoes as seed at 68.5% and 72.2%, respectively, a higher proportion than other sub-counties ($p<0.05$). Majority of traders who were older or were from Kawangware and Kangemi markets would also prefer to sell greening potatoes as seed. Damaged or bruised potatoes are majorly sold at discounted prices by majority of the traders who are males, from Dagoretti Sub-county or from Kawangware markets; this shows that potato buyers in these regions may be more exposed to potato glycoalkaloids than the other regions/markets.

The findings show gender, location and age as the possible factors that may influence trader perception on the safety of potatoes. Best practice of avoiding consumption of greening potatoes was mainly among traders in Kawangware and Kangemi markets, Dagoretti and Westlands Sub-counties or those of older ages. However, poor food safety practices of selling damaged or bruised potatoes were common among male traders and in Dagoretti Sub-county and Kawangware market. Stress factors such as bruising and damage results in increased glycoalkaloid levels in potatoes (Zarins & Kruma, 2017). In as much as these potatoes are unsafe, the profit incentive is used by traders to avoid losses on their end.

The variety of ware potato was significantly ($p<0.05$) associated with the traders' understanding of greening in potatoes. Majority of potato traders that traded in Shangi variety perceived greening as a sign of seed whereas those trading in Golf saw it as a sign of spoilage. Shangi variety is the most utilized variety in Kenya thus most traders would not prefer to suffer losses by discarding greening potatoes but would rather sell them off as seed.

**Table 3.5: Factors associated with trader perception of safety of potatoes**

| | | Traders' understanding of greening in potatoes (%) | | | | | |
|---|---|---|---|---|---|---|---|
| **Socio-economic and demographic factors** | | **Seed** | **Effects of light or high temperature** | **Effect of plant disease** | **Immature potato** | **Spoilage** | **P-value** |
| **Potato variety** | Shangi | 51.6 | 25.8 | 0 | 4.3 | 18.3 | 0.04 |
| | Golf | 14.3 | 28.6 | 14.3 | 0 | 42.9 | |

| | | Action taken by traders for potatoes that show greening | | | | | |
|---|---|---|---|---|---|---|---|
| | | **Sell as seed** | **Sell to consumers** | **Sell at lower price** | **Consume it** | **Dispose** | **P-value** |
| **Sub-County** | Dagoretti | 68.5 | 5.1 | 15.7 | 0 | 10.7 | 0.02 |
| | Westlands | 72.2 | 0 | 11.2 | 0 | 16.6 | |
| | Kamukunji | 58.1 | 10.6 | 5.1 | 5.1 | 21.2 | |
| | Starehe | 34.7 | 0 | 0 | 4.2 | 61.1 | |
| | Embakasi | 53.1 | 5.6 | 17.5 | 0 | 23.7 | |

**Table 3.5: Continued**

| Socio-economic and demographic factors | | Sell as seed | Sell to consumers | Sell at lower price | Consume it | Dispose | P-value |
|---|---|---|---|---|---|---|---|
| | | **Action taken by traders for potatoes that show greening** | | | | | |
| **Market** | Kawangware | 68.5 | 5.1 | 15.7 | 0 | 10.7 | 0.02 |
| | Kangemi | 72.2 | 0 | 11.2 | 0 | 16.6 | |
| | Gikomba | 58.1 | 10.6 | 5.1 | 5.1 | 21.2 | |
| | Wakulima | 34.7 | 0 | 0 | 4.2 | 61.1 | |
| | Kona | 53.1 | 5.6 | 17.5 | 0 | 23.7 | |
| **Age** | <20 | 0 | 100 | 0 | 0 | 0 | 0.02 |
| | 20-25 | 36 | 11.9 | 16.1 | 0 | 36 | |
| | 26-30 | 71.4 | 0 | 5.8 | 2.7 | 20.1 | |
| | >30 | 57.1 | 0 | 8.5 | 2.7 | 31.6 | |

**Table 3.5: Continued**

| | | Action taken by traders for potatoes that show signs of damage/bruising | | | | | |
|---|---|---|---|---|---|---|---|
| **Socio-economic and demographic factors** | | **Sell to vendors or restaurants** | **Given as additional to customers** | **Consume** | **Sell at discounted price** | **Dispose** | **P-value** |
| **Sub-County** | Dagoretti | 20.9 | 20.9 | 5.3 | 52.9 | 0 | 0.00 |
| | Westlands | 15.9 | 15.9 | 20.8 | 47.3 | 0 | |
| | Kamukunji | 31.6 | 10.7 | 20.9 | 31.6 | 5.3 | |
| | Starehe | 56 | 12.6 | 12.6 | 12.6 | 6.3 | |
| | Embakasi | 42 | 10.6 | 0 | 47.3 | 0 | |
| **Market** | Kawangware | 20.9 | 20.9 | 5.3 | 52.9 | 0 | 0.00 |
| | Kangemi | 15.9 | 15.9 | 20.8 | 47.3 | 0 | |
| | Gikomba | 31.6 | 10.7 | 20.9 | 31.6 | 5.3 | |
| | Wakulima | 56 | 12.6 | 12.6 | 12.6 | 6.3 | |
| | Kona | 42 | 10.6 | 0 | 47.3 | 0 | |
| **Gender** | Male | 34.8 | 17.4 | 2.2 | 43.4 | 2.2 | 0.00 |
| | Female | 30.4 | 10.8 | 21.8 | 34.8 | 2.2 | |

### 3.7 Conclusion and recommendations

Post-harvest handling practices among the potato traders in open air markets in Nairobi may impact negatively on the quality of the potatoes especially in terms of safety. There is low level of knowledge on the health effects of consuming greened, bruised or sprouting potatoes leading to poor perception of potato safety among the traders. More than half of the potatoes on the market are exposed to unfavourable temperature and light conditions as seen through the direct exposure of the tubers to sunlight. This means potato consumers in Nairobi may be experiencing long term exposure to these toxins due to buying of greening, bruised or sprouting potatoes for home consumption or consuming of potato products especially French fries from restaurants or roadside vendors who use greening, bruised or sprouting potatoes sold to them by the traders to make these potato products.

Therefore, it is important that all potato traders be continuously sensitized and educated on the health effects of glycoalkaloids and proper post-harvest handling of potatoes to prevent continued consumer exposure to these toxins. Farmers and transporters of the tubers to the market should also be included in the sensitization activities. In addition, the Nairobi County Government should channel resources towards building permanent stalls that have proper storage places with proper protection against the sun to prevent against direct exposure of potatoes to the sun. The traders should also be facilitated to acquire sacks and bags made from other material such as sisal or net bags which allow for good aeration and less build-up of heat to store their potatoes.

# CHAPTER FOUR: LEVELS OF GLYCOALKALOIDS IN COMMERCIAL POTATO VARIETIES TRADED IN NAIROBI, KENYA

## 4.0 Abstract

Although they contribute to flavor, at high levels, glycoalkaloids which are naturally occurring in potatoes, pose food safety concerns as they can lead to bitterness and intoxication to consumers. Their concentrations in potatoes are dependent on postharvest handling, variety and stress factors tubers are exposed to. Limited information, however, exists on levels of glycoalkaloids in commercially traded potato tubers in Kenya. The current study sought to determine the glycoalkaloids levels in potatoes traded in Nairobi County. Three potato varieties, Shangi, Dutch Robjin and Royal sold in open air markets and supermarkets were randomly sampled and their GAs levels determined by HPLC method. The levels of glycoalkaloids varied significantly ($p<0.05$). The Shangi variety had the highest glycoalkaloids with a mean of 410.35 $mgkg^{-1}$ dry weight with samples from supermarkets having the highest levels (550.8 $mgkg^{-1}$). the same variety from open air markets averaged 382.26 $mgkg^{-1}$ dry weight compared to the Dutch Robjin (129.2 $mgkg^{-1}$ dry weight) and Royal variety (98.2 $mgkg^{-1}$ dry weight) which had the least levels of glycoalkaloids. The levels in sampled tubers did not exceed the recommended levels of 1000mg/kg on dry weight basis and, therefore, consumption of these potatoes would not raise safety concerns. There is, however, need to ensure that marketing of tubers is carried out under conditions that minimize occurrence of glycoalkaloids especially for the Shangi variety which is the most common in the markets but had relatively high levels of these toxins. There is also need to educate marketers on the need for proper storage and handling of potatoes during marketing to avoid risk of accumulation of glycoalkaloids.

## 4.1 Introduction

Potatoes are important food crop in sub-Saharan Africa (SSA). The estimate annual production of potatoes in SSA in 2016 was 11.6 million tonnes (FAOSTAT, 2018). Potatoes are ranked among the four most important and largely consumed food crops globally (King & Slavin, 2013). Potatoes provide the consumers with nutrients such as carbohydrates, vitamins and minerals (Furrer *et al*., 2016) and improve the nutrient density of diets when incorporated into other foods (Gibson & Kurilich, 2013). Glycoalkaloids (GAs) in potato tubers compromise their safety and can render them or the derivative products unsuitable for consumption with levels beyond 200 mg $kg^{-1}$ fresh weight being considered unsafe for human consumption (Smith *et al*., 1996). The most common GAs in potatoes are the α-solanine and α-chaconine with the most potent of the two being α-chaconine, which is twice more toxic than the α-solanine (Mendel Friedman, 2006).

Glycoalkaloid levels in potatoes traded in the market may be influenced by transportation and storage conditions (Chuda et al., 2004). Potatoes that are sprouting or subjected to light exposure, inappropriate storage, extreme temperature, wounding, and mechanical injury accumulate GAs at a faster rate (Cantwell, 1996). In addition, the level of accumulation of glycoalkaloids potatoes subjected to these stress factors varies among varieties (Furrer *et al*., 2016).

Ware potatoes are made available to consumers through different marketing systems and handling of these potatoes may influence the formation of GAs. In Kenya, the potato forms a major part of the diet of many consumers. It is incorporated into the local Kenyan dishes or may be eaten boiled, baked or fried. Furthermore, processed potato products such as crisps and French fries (locally known as chips) are on high demand among urban consumers hence are a great part of menus in restaurants and hotels in major urban centers (George O Abong' et al., 2009). Of interest to food safety, however, is that in Kenyan markets, it is not uncommon to find potatoes exposed to these stress factors thus exposing consumers to the dangers of GAs. However, the exposure of Kenyan consumers to these toxins as a result of consuming potatoes and potato products is not supported by adequate data. Furthermore, not much has been done to quantify the levels of GAs in tubers traded in Kenyan markets meaning that the level of risk to consumers has not been adequately documented. The current study, therefore, sought to establish the glycoalkaloid levels of potatoes traded in various markets and supermarkets in Nairobi County.

## 4.2 Materials and methods

### 4.2.1 Study Area

The study was carried out in Nairobi County, Kenya. The county hosts the capital city of Kenya and has nine sub-counties: Makadara, Embakasi, Starehe, Langata, Kasarani, Westlands, Kamukunji, Dagorreti and Njiru (Figure 1). The county's population is estimated to be over 3 million according to the latest statistics (KNBS, 2009). Most of the people are low income earners hence live in slums. The county has many markets dealing in food stuffs with most of these food markets being open air markets. Five sub-counties were purposively selected for this study: Dagoretti, Westlands, Embakasi, Kamukunji and Starehe. These were purposively selected because most of Nairobi's population is concentrated in these areas. From these 5 sub-counties, 5 major markets were purposively selected from which samples (from both open air markets and supermarkets) were obtained. The 5 markets were Kawangware (Dagoretti), Kangemi (Westlands), Wakulima (Starehe), Kona (Embakasi) and Gikomba (Kamukunji).

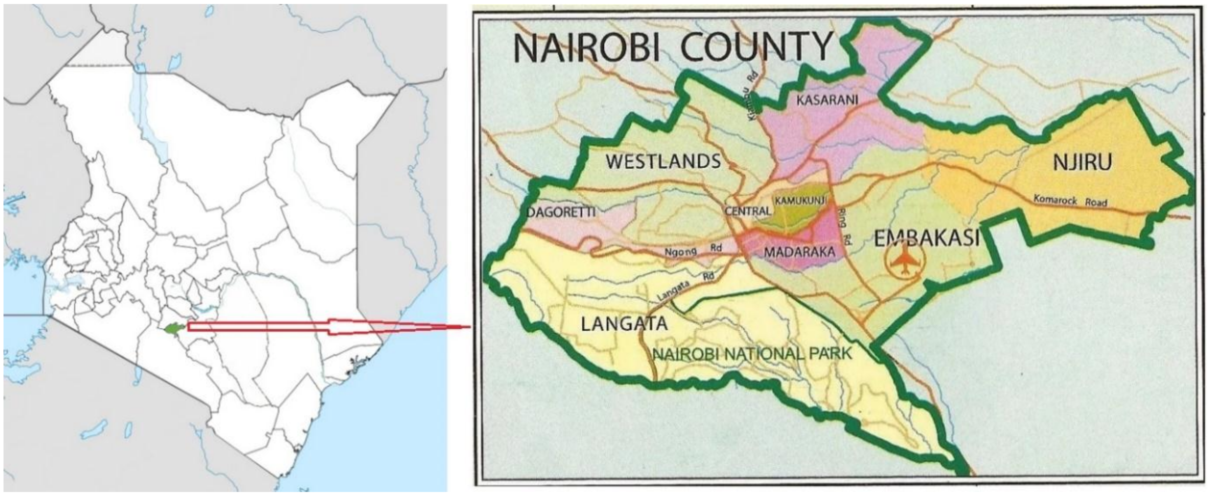


**Figure 4.1: Study area, Nairobi County.** Source: https://softkenya.com.

### 4.2.2 Sampling

#### 4.2.2.1 Sample size determination

The sample size for the study was determined according to Fisher *et al.* (1991) shown:

$$n = \frac{Z^2 pq}{d^2}$$

Where:

n = the quantity of sample size desired

p = the ratio in the selected population expected to have the features under study (50%)

q = (1-p) i.e. the ratio in the selected population expected not to have the features under study, (50%).

d = the margin of error set. For this study a level of 0.141 was used.

Z = normal standard variation at the required confidence level. A 95% confidence was used.

$$n = \frac{1.96^2 \times 0.5 \times 0.5}{0.141^2} = 48$$

Therefore, the sample size was 48 where 31 samples were collected from supermarkets and 17 samples were obtained from open air markets.

#### 4.2.2.2 Sample collection

Three potato varieties were used in the study i.e. from open air markets (Shangi variety) and supermarkets (Dutch Robjin, Royal and Shangi varieties). The supermarket samples were randomly obtained from major supermarkets in the same sub-counties from which the open air market samples were obtained. Only Shangi variety was obtained from the open air markets since it was the most common variety in the markets during the sampling period hence easily available. For the market samples, more Shangi samples were obtained from Wakulima market given that this market is located in the central business district with a high population of traders compared to the other markets. The sampling procedure is shown in **Figures 2** and **3**.

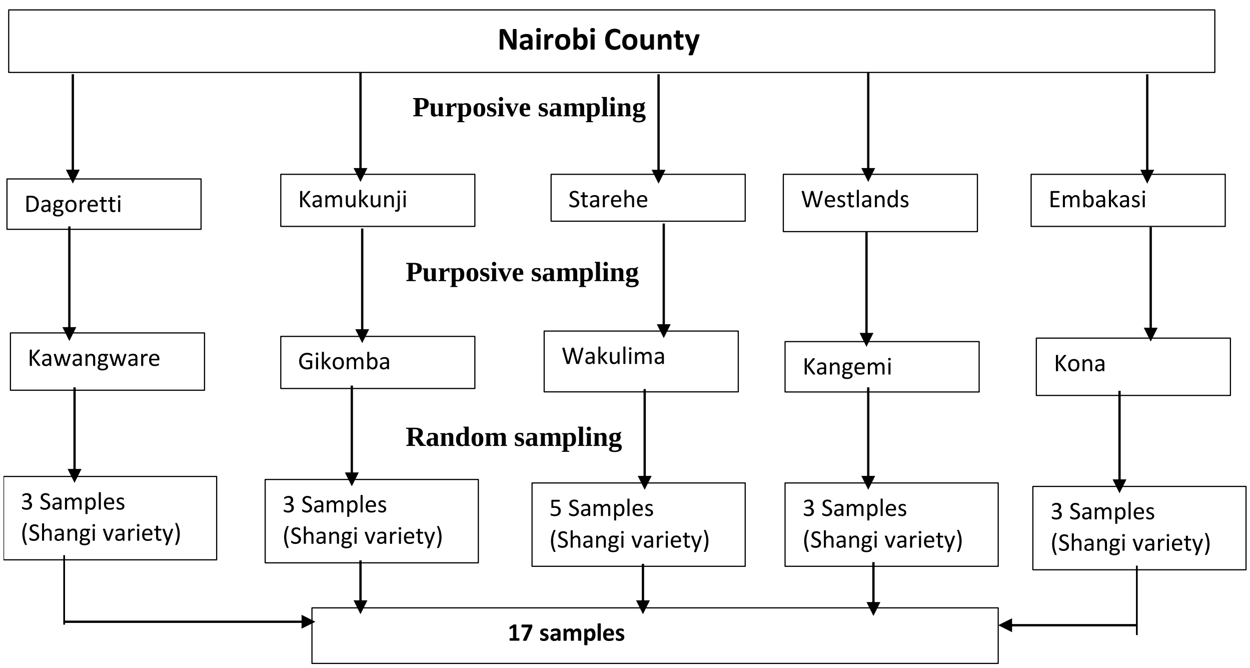


**Figure 4.2: Sampling for open air market samples.**

For supermarket samples, 2 supermarkets were purposively selected from each of the 4 sub-counties (Dagoretti, Kamukunji, Westlands and Embakasi) given that the number of supermarkets selling fresh produce in these locations were few. However, for Starehe sub-county

3 supermarkets were selected because of the high number of supermarkets in this location. Additionally, Dutch Robjin and Royal varieties were obtained from supermarkets in Starehe sub-county since they were only found to be sold these supermarkets unlike the other supermarkets which only sold Shangi variety.

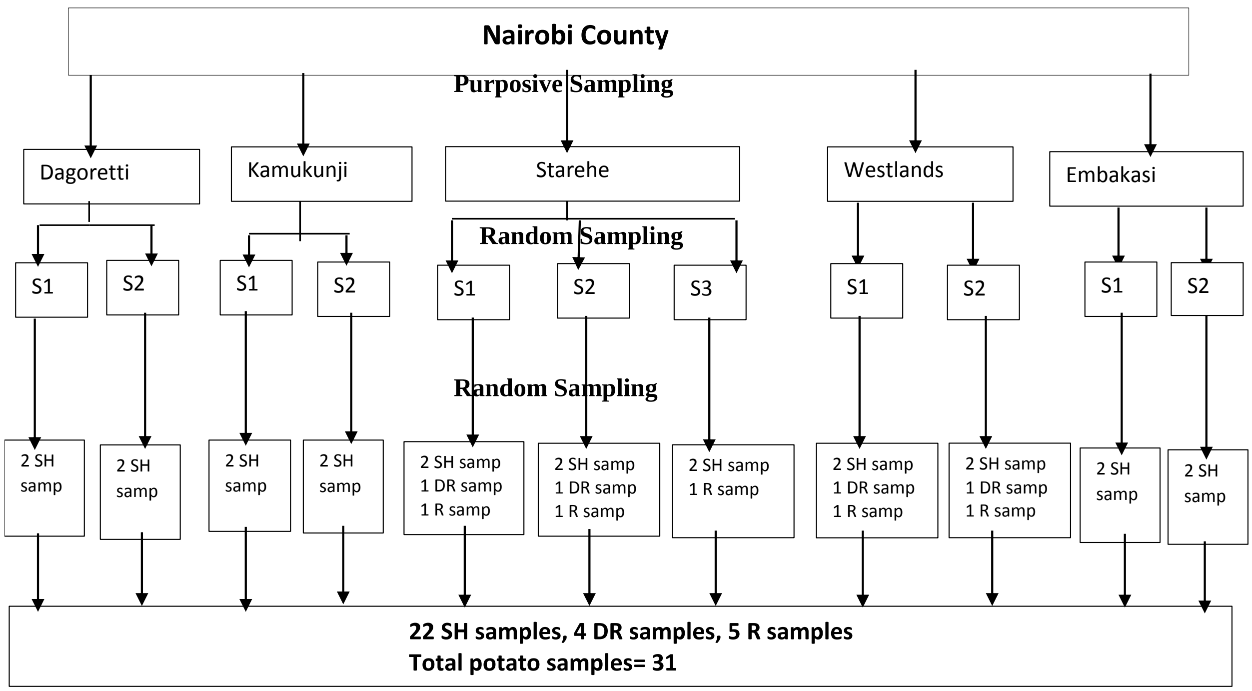


**Figure 4.3: Sampling for supermarket samples.** SH-Shangi, DR-Dutch Robjin, R-Royal, samp-samples.

## Analytical methods

### 4.2.2.3 Determination of moisture content

Moisture content of different potato varieties was determined in triplicate as per AOAC (2005) method number 930.15. The oven used was memmert 40500-IP20 (Schutzart, Germany).

#### 4.2.2.4 Determination of glycoalkaloids

The levels of glycoalkaloids were determined by high pressure liquid chromatographic methods using Waters HPLC (Waters 2695- Waters corporation, USA) and detection set at a wavelength of 202 nm using photodiode array detector (Waters 2996, USA).

##### 4.2.2.4.1 Sample preparation

Potato samples obtained from each market were mixed thoroughly into one batch, from which a single sample was picked randomly for analysis. This was done for all the samples from all the five markets thus resulting into 5 open air market Shangi samples for analysis (representing the 5 study sub-counties). The same procedure was followed for the supermarket samples, resulting into 5 Shangi variety supermarket samples, 2 Dutch Robjin samples and 2 Royal samples for analysis.

Tubers were washed under running water, dried using cloth towel, peeled and chopped into 5mm pieces. Twenty grams (20 g) of each set were oven dried to a constant weight at 105$^{o}$C. The dry samples were ground and packaged in sealed plastic bottles and stored for chemical analysis.

##### 4.2.2.4.2 Extraction of glycoalkaloids

A 2 g sample was mixed with 20 ml extraction solution comprising of water, acetic acid and sodium hydrogen bisulfite (100 + 5 + 0.5, v/v/w) and shaken for 15 minutes by Burrell vertical shaker (Burrel Corp, Pittsburg, UK). Clarification of the mixture was then done by centrifugation for 30 min at 800*g* using Labofuge A (Heraeus, Germany).

##### 4.2.2.4.3 Cleaning of extract

Five ml (5 ml) acetonitrile followed by 5 ml extraction solution were used in conditioning Solid Phase Extraction (SPE) columns (Strata, Phenomenex). Into these columns, 10 ml of the supernatants were passed through the SPE columns at a controlled pressure after which SPE 4 ml wash solution (15% acetonitrile) was used to wash glycoalkaloids. This was followed by elution with 4 ml LC mobile phase (60% acetonitrile in 0.01M phosphate buffer) at a rate of 1–2 drops/s. The final volume collected was adjusted to 5 ml with LC mobile phase filtered through a 0.45 µm filter into vials and frozen ready for injection.

#### 4.2.2.4.4 Chromatographic analysis

The HPLC instrument (Waters-2595, USA) was fitted with stainless steel LC column—250 ×4.6 mm, packed with Hypersil ODS (Shandon Southern Products Ltd., Astmoor, UK), 5 µm particle size, C18 phase. The operating conditions included a flow rate of 1.5 ml/min, injection volume of 50 µl, run time of 15 minutes, column temperature of 40 °C and wavelength detection set at 202 nm. Glycoalkaloids were calculated based on external calibration curves generated from standards stock solutions and expressed as mg GAS/kg on dry weight basis.

## 4.3 Statistical analysis

The data were analyzed using Genstat version 15 software. Descriptive statistics in terms of mean, standard deviation were generated for moisture content and glycoalkaloids levels. Test for significant differences in the means was performed using one way ANOVA at $p<0.05$. Means that were statistically different were separated using Fischers LSD test ($p\leq0.05$).

## 4.4 Results and discussion

### 4.4.1 Moisture content of potato varieties

The moisture content between the samples varied significantly ($p\leq0.05$) (**Table 4.1**). However, there were no significant differences ($p>0.05$) in the moisture content for the sampled potato varieties obtained from supermarkets and open air markets. The Royal variety had the highest moisture content (77.08%) while Shangi had 76.56% and the least was Dutch Robjin with

76.42%). These findings are lower than those reported by other researchers (Elbatawi *et al.*, 2008; Zhang *et al.*, 2018). However these values are in agreement with other studies where similar findings have been reported (Sablani and Mujumdar, 2006; Xiao *et al.*, 2011; Hafezi *et al.*, 2015). These variations may be attributed to transpiration due to exposure of potatoes to sunlight and higher temperatures during marketing as well as the high relative humidity and period on shelves before marketing (Chourasia, Maji, Baskey, & Goswami, 2005).

**Table 4.1: Moisture content of marketed potato varieties**

| Sample | Moisture content (%) | Sample | Moisture content (%) |
|---|---|---|---|
| D1 | $77.45 \pm 0.91^{cde}$ | WK4 | $78.15 \pm 1.48^{cd}$ |
| D2 | $76.45 \pm 0.77^{bcde}$ | WK5 | $76.95 \pm 0.63^{cd}$ |
| D3 | $75.5 \pm 1.13^{bcde}$ | SD1 | $76.72 \pm 6.46^{bcd}$ |
| D4 | $76.3 \pm 0.70^{bcde}$ | SD2 | $76.2 \pm 3.81^{bcdef}$ |
| R1 | $77 \pm 0.28^{cdef}$ | SD3 | $76.6 \pm 2.40^{bcdef}$ |
| R2 | $78.35 \pm 1.34^{de}$ | SD4 | $75.3 \pm 3.67^{abc}$ |
| R3 | $79.51 \pm 0.83^{ef}$ | SE1 | $77.15 \pm 3.18^{cde}$ |
| R4 | $72.8 \pm 1.27^{ab}$ | SE2 | $76.96 \pm 2.74^{cde}$ |
| R5 | $77.75 \pm 2.15^{cde}$ | SE3 | $78.05 \pm 1.20^{cde}$ |
| CN1 | $77.55 \pm 2.33^{cdef}$ | SE4 | $75.45 \pm 2.61^{bcd}$ |
| CN2 | $75.1 \pm 0.84^{abcd}$ | SK1 | $71.21 \pm 1.13^{a}$ |
| CN3 | $76.6 \pm 0.56^{bcde}$ | SK2 | $76.91 \pm 1.42^{bcde}$ |
| GK1 | $78.2 \pm 2.68^{cdef}$ | SK3 | $77 \pm 1.697^{def}$ |
| GK2 | $76 \pm 0.56^{bcde}$ | SK4 | $74.9 \pm 0.424^{abcd}$ |
| GK3 | $76.8 \pm 1.83^{bcd}$ | SS1 | $74.1 \pm 2.546^{abc}$ |
| KN1 | $75.85 \pm 0.63^{bcde}$ | SS2 | $76 \pm 1.69^{bcdef}$ |

**Table 4.1: Continued**

| Sample | Moisture content (%) | Sample | Moisture content (%) |
|---|---|---|---|
| KN2 | $77.15\pm2.89^{cdef}$ | SS3 | $79.85\pm2.19^{f}$ |
| KN3 | $77.2\pm0.84^{cdef}$ | SS4 | $78.25\pm0.21^{def}$ |
| KW1 | $76.35\pm1.20^{bcd}$ | SS5 | $75.81\pm0.2^{bcde}$ |
| KW2 | $75.45\pm0.91^{bcd}$ | SS6 | $76.45\pm2.33^{bcdef}$ |
| KW3 | $77.2\pm0.84^{cdef}$ | SW1 | $76.16\pm1.51^{bcd}$ |
| WK1 | $76.85\pm1.84^{bcd}$ | SW2 | $75.75\pm2.62^{bcdf}$ |
| WK2 | $75.8\pm0.84^{bcd}$ | SW3 | $77.7\pm2.263^{cdef}$ |
| WK3 | $78.4\pm2.40^{def}$ | SW4 | $77.85\pm2.05^{cdef}$ |

### 4.4.2 Glycoalkaloid levels in traded potato varieties

The total glycolakaloid levels varied significantly ($p<0.05$) among the samples (**Table 4.2**). The Royal potato variety had the least glycoalkaloids levels (104.8mgkg$^{-1}$) compared to Dutch Robjin (136.1mgkg$^{-1}$) and Shangi (483.6mgkg$^{-1}$) variety which had the highest levels of glycoalkaloids on dry weight basis (**Table 4.3**). These values were, however, higher than those reported in a similar study except for the Royal variety where the values ranged from 55.6 to 122.3mg kg$^{-1}$ (Bejarano *et al*., 2000). The values in the current study may be indicative of poor postharvest handling of potatoes during marketing of potatoes as well as the varietal influence on glycoalkaloid levels. Since Shangi variety accumulates more glycoalkaloids than the other varieties, it is possible that many Kenyan consumers are exposed to these toxins since this variety is the most common on the market.

**Table 4.2: Glycoalkaloid levels in potato varieties traded in Nairobi**

| Sample | α Solanine(a) (mgkg-1) | α Chaconine (b) (mgkg-1) | Total (a+b) (mgkg-1) | Ratio (b/a) |
|---|---|---|---|---|
| D1 | 59.5±4.03a | 69.8±2.12abcd | 129.3±6.15ab | 1:1.2 |
| D2 | 76.45±0.94a | 54.5±2.86ab | 103.3±1.92a | 1:0.7 |
| D3 | 61.9±2.31a | 93.1±5.18abcde | 154.9±2.87abc | 1:1.5 |
| D4 | 72.9±4.76ab | 83.7±7.52abcde | 156.6±12.28abc | 1:1.1 |
| R1 | 51.3±1.48a | 50.6±1.63ab | 102±0.14a | 1:1.0 |
| R2 | 44.1±0.6a | 50.3±0.93ab | 94.4±0.33a | 1:1.1 |
| R3 | 55.9±2.84a | 56.2±7.06ab | 112.1±9.9ab | 1:1.0 |
| R4 | 47.7±2.73a | 49.7±0.83a | 97.4±3.56a | 1:1.0 |
| R5 | 57.3±1.36a | 60.6±1.68abc | 117.9±0.32ab | 1:1.1 |
| CN1 | 255.1±13.06ijk | 255.9±78.42ijklm | 480.9±91.48hijk | 1:1.0 |
| CN2 | 299.4±1.3opq | 389.6±15.6rst | 689±16.9mnop | 1:1.3 |
| CN3 | 177.6±4.33efgh | 187.4±3.56fghij | 365±7.89efgh | 1:1.1 |
| GK1 | 134.2±1.63cd | 233±17.54hijkl | 367.1± 15.91efgh | 1:1.7 |
| GK2 | 325.7±20.58pqr | 409.8±2.25t | 735.5±22.83nop | 1:1.3 |
| GK3 | 208.6±29.77jklm | 244.6±10.25ghijklm | 453.2± 19.52hij | 1:1.2 |
| KN1 | 109.8± 9.81cd | 122.6± 1.56abcde | 232.4±11.37bcd | 1:1.1 |
| KN2 | 178.1± 2.67efgh | 405.5± 38.42st | 583.6±41.09klm | 1:2.3 |
| KN3 | 128.2±11.98cd | 166.2 ±10.11efghi | 294.3±1.87defg | 1:1.3 |
| KW1 | 53.8± 3.96cd | 140.8± 8.63abcde | 194.6± 12.59abcd | 1:2.6 |
| KW2 | 215.8±16.77hij | 522.1± 61.15u | 737.9± 77.92op | 1:2.4 |
| KW3 | 257.1± 6.71klmn | 338.2± 19.29opqrst | 595.3±26klm | 1:1.3 |
| WK1 | 383.4±11.38s | 366.7±19.37qrst | 750±30.76p | 1:1.0 |
| WK2 | 108.2±26.35bc | 196.2±147.67ghijk | 304.4±174.02defg | 1:1.8 |
| WK3 | 143.8±7.43cdef | 223.4±121.55hijkl | 367.1±128.98efgh | 1:1.6 |
| WK4 | 192±8.49hij | 180.7±1.91fghij | 372.6±10.39efghi | 1:0.9 |
| WK5 | 206.4±5.77ghi | 194.4±7ghijk | 400.8±12.77ghi | 1:0.9 |

Values are given as mean of duplicate samples ± SD (standard deviation), $n$ = 48. Means with different letters are significantly different (Tukey's test, $p \leq 0.05$). D-Dutch Robjin, R- Royal variety, CN-samples from Kona, GK-Gikomba markets, KN-Kangemi markets, WK-Wakulima markets, SD-SW – Shangi samples from the supermarkets.

**Table 4.2: Continued**

| Sample | α Solanine(a) (mgkg$^{-1}$) | α Chaconine (b) (mgkg$^{-1}$) | Total (a+b) (mgkg$^{-1}$) | Ratio (b/a) |
|---|---|---|---|---|
| SD1 | 291.5±16.78$^{nop}$ | 260.4±38.11$^{ijklmn}$ | 551.9±21.33$^{jkl}$ | 1:0.9 |
| SD2 | 285.2±6.42$^{mnop}$ | 301± 15.04$^{mnopq}$ | 586.3±21.46$^{klm}$ | 1:1.1 |
| SD3 | 281.5±2.64$^{mno}$ | 269.5±33.45$^{jklmno}$ | 551.1±30.82$^{jkl}$ | 1:1.0 |
| SD4 | 279.2±14.98$^{lmno}$ | 301.2±20.58$^{mnop}$ | 580.4±35.55$^{klm}$ | 1:1.1 |
| SE1 | 125.8±14.35$^{cd}$ | 144.8±6.87$^{bcdefg}$ | 270.6±21.23$^{cde}$ | 1:1.2 |
| SE2 | 350.9±25.39$^{rs}$ | 378.7±13.64$^{rst}$ | 729.5±39.03$^{nop}$ | 1:1.1 |
| SE3 | 157.1±20.3$^{bc}$ | 152.8±0.25$^{cdefg}$ | 309.9±20.05$^{defg}$ | 1:.0 |
| SE4 | 339.6±25.1$^{qr}$ | 299.6±8.06$^{lmnop}$ | 639.2± 17.04$^{lmno}$ | 1:0.9 |
| SK1 | 271.8±66.31$^{lmno}$ | 272.7± 84.43$^{jklm}$ | 544.5±150.73$^{jkl}$ | 1:1.0 |
| SK2 | 239.6±41.41$^{jkl}$ | 282.5±116.12$^{klm}$ | 522.1±157.53$^{jkl}$ | 1:1.2 |
| SK3 | 305.4±27.65$^{opq}$ | 329.8±51.12$^{opqrs}$ | 635.1±78.77$^{lmno}$ | 1:1.1 |
| SK4 | 230.8±19.73$^{ijk}$ | 310.1±100.88$^{nop}$ | 540.9±120.61$^{jkl}$ | 1:1.3 |
| SS1 | 239.1±26.52$^{jkl}$ | 379.4±78.51$^{rst}$ | 618.5±105.3$^{lmno}$ | 1:1.6 |
| SS2 | 181.60.18$^{fgh}$ | 311±15.21$^{nopq}$ | 492.1±75.39$^{ijk}$ | 1:1.7 |
| SS3 | 296.8±39.3$^{nop}$ | 294.9±7.71$^{lopqr}$ | 591.8±31.59$^{klm}$ | 1:1.0 |
| SS4 | 256.7±0.02$^{klmn}$ | 358.4±65.63$^{pqrs}$ | 615.1±61.65$^{lmn}$ | 1:1.4 |
| SS5 | 137.8±22.78$^{defg}$ | 296.1±29.92$^{lopq}$ | 433.9±7.13$^{hij}$ | 1:2.1 |
| SS6 | 183.9±2.71$^{fgh}$ | 205.9±9.18$^{ghijk}$ | 389.8±6.47$^{efghi}$ | 1:1.1 |
| SW1 | 194.2±13.22$^{cde}$ | 158.8±62.3$^{defgh}$ | 278.8±57.76$^{def}$ | 1:1.3 |
| SW2 | 194.2±13.22g$^{hi}$ | 197.5±25.88$^{ghij}$ | 391.8±39.1$^{fghi}$ | 1:1.0 |
| SW3 | 119.9±4.54$^{cd}$ | 153.7±54.99$^{cdefg}$ | 273.6±50.45$^{cdef}$ | 1:1.3 |
| SW4 | 194.2±13.22$^{ghi}$ | 197.5±25.88$^{ghijk}$ | 391.8±39.1$^{fghi}$ | 1:1.0 |

Values are given as mean of duplicate samples ± SD (standard deviation), $n$ = 48. Means with different letters are significantly different (Tukey's test, $p \leq 0.05$). D-Dutch Robjin, R- Royal variety, CN-samples from Kona, GK-Gikomba markets, KN-Kangemi markets, WK-Wakulima markets, SD-SW – Shangi samples from the supermarkets.

**Table 4.3 Average glycoalkaloid levels in potato varieties traded in Nairobi**

| Market/ Variety | | α Solanine(a) ($mgkg^{-1}$) | α Chaconine (b) ($mgkg^{-1}$) | Total (a+b) ($mgkg^{-1}$) | Ratio b/a |
|---|---|---|---|---|---|
| Open air markets (Shangi variety) | **Wakulima** | 206.7± 100.65$^{a}$ | 232.2±96.7$^{a}$ | 439.0±182.6$^{a}$ | 1:1.1 |
| | **Kawangware** | 175.6±96.46$^{a}$ | 333.7±173.0$^{a}$ | 509.3±254.7$^{a}$ | 1:1.9 |
| | **Gikomba** | 231.8±87.58$^{a}$ | 283.8±98.6$^{a}$ | 515.6±173.0$^{a}$ | 1:1.2 |
| | **Kona** | 234.0± 55.26$^{a}$ | 277.6±98.7$^{a}$ | 511.6±152.6$^{a}$ | 1:1.1 |
| | **Kangemi** | 138.7 ± 32.41$^{a}$ | 231.4±137.4$^{a}$ | 370.1±168.8$^{a}$ | 1:1.7 |
| Shangi overall | **Open air** | 199.0±80.84$^{b}$ | 267.1±119.88$^{b}$ | 466.1±185.1$^{b}$ | 1:1.3 |
| | **Both markets** | 217.1±60.81$^{b}$ | 266.2± 80.95$^{b}$ | 483.6±99.09$^{b}$ | 1:1.2 |
| Supermarkets | **Shangi** | 231.0 ±84.8$^{B}$ | 266.2± 80.95$^{B}$ | 497.2±102.2$^{B}$ | 1:1.2 |
| | **Dutch Robjin** | 60.8±9.52$^{A}$ | 75.3±16.0$^{A}$ | 136.1 ±23.89$^{A}$ | 1:1.2 |
| | **Royal** | 51.3±5.42$^{A}$ | 53.5±5.2$^{A}$ | 104.8±10.0$^{A}$ | 1:1 |

Values are given as means of samples ± SD (standard deviation), $n = 48$
Means with different letters are significantly different (Tukey's test, $p \leq 0.05$)

The levels of glycoalkaloids in potato tubers from the Shangi varieties procured from supermarkets and open air markets did not have significant differences (p>0.05) with the former having the highest levels of glycoalkaloids at 497.2 $mgkg^{-1}$ compared to GAs levels in Shangi samples obtained from open air markets which averaged 466.1 $mgkg^{-1}$ (**Table 4.3**) The high levels of GAs in the supermarket samples may be an indication of long periods of exposure to fluorescent light and longer periods before sales from the supermarket shelves. During these periods the tubers accumulate chlorophyll and subsequently have increased levels of GAs. There is need for the local supermarkets and other retail shops to make use of greening scales that have been developed for discarding greened potatoes from retail displays so as to ensure that the potatoes sold in wholesale and retail shops are safe for consumption (Grunenfelder *et al.*, 2006; Grunenfelder *et al*, 2006). These retail outlets could also substitute the fluorescent lighting in the display shelves with mercury lighting since studies have shown the rate of glycoalkaloid accumulation can be reduced by using mercury lighting instead of fluorescent lighting during display (Percival, 1999).

The concentrations of *α*-solanine and *α*-chaconine for the samples varied significantly ($p<0.05$) and ranged from 47.7 to 206.6mgkg$^{-1}$ and 50.5 mgkg$^{-1}$ to 283.1 mgkg$^{-1}$, respectively (**Table 4.2).** The ratio of α-solanine to α-chaconine ranged from 1:0.7 to 1:2.6. Glycoalkaloid intoxication is relative to this ratio and should therefore be as low as possible since they occur simultaneously in potato tubers (Mendel Friedman, 2006). These ratios are in agreement with other studies which have reported variations from 1:0.5 to 1:7 (Kozukue *et al*., 2008; Lisiěska *et al*., 2009; Tajner-Czopek *et al*., 2008; Valcarcel *et al*., 2014).

None of the sampled potato tubers exceeded the recommended safety levels of 1000 mgkg$^{-1}$ dry weight assuming a water content of 80% (Valcarcel, Reilly, Gaffney, & O'Brien, 2014) which is equivalent to 200 mgkg$^{-1}$ on fresh weight basis ( Smith *et al*., 1996). Therefore, consumption of these varieties would have insignificant glycoalkaloids intoxication to consumers.

Disparities in the levels of glycoalkaloids could be as result of varietal effect. Studies have shown that some potato varieties tend to accumulate higher levels of GAs compared to others. These findings are therefore in agreement with other studies (Bejarano *et al.*, 2000; Friedman *et al*., 2003; Aziz *et al.*, 2012; Valcarcel *et al.*, 2014). The Shangi variety has also been shown to sprout easily when exposed to stressful conditions an indication of elevated levels of glycoalkaloids (Abong' *et al*., 2015).

The rate of GA accumulation is also dependent on the storage conditions. Light and temperature have been shown to be stress factors that lead to accumulation of GAs (Griffiths *et al*., 1998; Grunenfelder *et al.*, 2006). The rate of glycoalkaloids accumulation is about 20% more when potatoes are exposed to light and direct sunlight as compared to storage in dark conditions. Synthesis and accumulation of glycoalkaloids when potatoes are stored at 24°C has also been shown to be about twice the rate at 7°C (Cantwell, 1996; Griffiths *et al*., 1998; Şengül *et al.*, 2004). Therefore, it is essential that vendors be enlightened on the need for proper storage during marketing to avoid GAs accumulation.

### 4.5 Conclusion and recommendations

The current findings show that the glycoalkaloids levels of the sampled marketed potatoes did not exceed the recommended safety levels. Therefore, minimal intoxication would occur to consumers. However, the supermarkets samples had slightly higher levels of GAs and there is need to conduct further studies on the factors that lead to this so as to formulate necessary policies for sales of potato in supermarkets.

It is essential that consumers and potato handlers select potato cultivars with minimal glycoalkaloids occurrence in order to ensure that there is minimum glycoalkaloids intoxication. Moreover, postharvest practices that will reduce occurrence of GAs is paramount. Concerned authorities should therefore be involved in raising awareness and implementation of policies among potato vendors. These include storage of potatoes at lower temperatures, of about 7°C-10°C, keeping potatoes away from direct sunlight, marketing in opaque plastic films and bags that minimize effect of light on tuber as well as ensuring regular rotations of potatoes in retail shops exhibitions and replacing fluorescent lighting with mercury lighting for potatoes on display in supermarkets and wholesale retail outlets.

# CHAPTER FIVE: EFFECT OF LIGHT AND TEMPERATURE ON THE LEVELS OF GLYCOALKALOIDS IN STORED THREE COMMERCIAL POTATO VARIETIES IN KENYA

## 5.0 Abstract

Glycoalkaloids in potatoes pose serious food safety concerns when consumed at high levels; levels being affected by storage conditions. This study sought to establish the influence of storage conditions on the glycoalkaloid levels of potatoes. Three potato varieties, Shangi, Dutch Robjin and Royal, were stored for 12 weeks at different conditions of temperature (5, 10 and 25 $^{o}$C) and light intensity. Levels of glycoalkaloids in both flesh potato (peeled) and whole potato (unpeeled) were determined at 4-week intervals. Results indicated that storage conditions and potato variety were factors that significantly ($p<0.05$) influenced glycoalkaloids levels. Dutch Robjin accumulated the highest levels of glycoalkaloids, up to 2775 ± 1587 mg/kg in the whole potato and 1772±1405 mg/kg in the flesh potato. Storage of all the varieties of whole potatoes beyond eight weeks at elevated temperatures (>10$^{o}$C) and light resulted in accumulated levels of 1000 mg/kg dry weight (converted to 200 mg/kg fresh weight), levels deemed unsafe for consumption. Accumulation of α-chaconine was higher than that of α-solanine in all the varieties at different storage conditions over different storage periods. Storage of the potatoes in the dark and at 5 $^{o}$C resulted in the lowest accumulation of total glycoalkaloids (<1000 mg/kg). The potato flesh had safer levels of glycoalkaloids, up to four weeks of storage. However, whole potatoes had unsafe levels of glycoalkaloids by the fourth week when stored at elevated temperatures (>10$^{o}$C) and in light. Royal variety averaged the least levels of glycoalkaloids, 1598±1274 mg/kg and 722±678 mg/kg in whole potato and potato flesh respectively, during the entire storage period. Glycoalkaloid levels in both whole potatoes and potato flesh significantly

($p<0.05$) increased with increasing period of storage. Therefore, storage conditions, duration and the variety affect glycoalkaloid levels in potatoes. The utilization of the Royal potato variety and storage of the potatoes at lower temperatures or in dark is recommended to assure their safety.

### 5.1 Introduction

The potatoes (*Solanum tuberosum*) is a nutritionally important crop worldwide with the global production quantity in 2016 estimated at 376.8 million tonnes (FAOSTAT, 2018). It is the most consumed non-cereal crop globally and is ranked among the four most utilized food crops in the world (Fen et al., 2017). The potato produced in sub-Saharan African (SSA) countries is meant both for subsistence and industrial use (G O Abong' et al., 2015; Ugonna, Jolaoso, Onwualu, & others, 2013). Potatoes are known to be rich in vitamins such as vitamin C and minerals such as iron, potassium, magnesium and zinc (Ikanone & Oyekan, 2014; Rahman, Ali, & Hasan, 2016). Potatoes are not only known for their nutrition value, but are also rich in antioxidant properties (Kita, Bakowska-Barczak, Hamouz, Kułakowska, & Lisińska, 2013). Despite all the nutritional benefits derived from potatoes, the safety of potatoes can be compromised by the occurrence of glycoalkaloids (Omayio, Abong, & Okoth, 2016). Elevated levels of glycoalkaloids in potatoes can render these potatoes unsafe for consumption thus limiting their utilization. Contents above 20 mg $100g^{-1}$ fresh weight in potato tuber render them unpalatable and unsafe for use even in food processing (Ginzberg, Tokuhisa, & Veilleux, 2009).

Until 2012, potato stakeholders in Kenya had commercially utilized over 15 potato varieties (Komen, Ngeny, & Osena, 2017). These varieties vary in their utilization in Kenya with Shangi being the most utilized variety in the country (G O Abong' et al., 2015). Other varieties that have been exploited in Kenya include Sherehekea, Nyayo, Tigoni, Kenya Mpya, Dutch Robjin and Asante (G O Abong' et al., 2015; Kaguongo et al., 2008). Storage of these potatoes largely influences the glycoalkaloid levels and this differs among potato varieties. Therefore, it is important to establish appropriate conditions for their storage, not only to reduce postharvest losses but also to ensure the safety of the consumers.

Stress treatments and storage conditions are known to result in elevated levels of glycolakaloids in potatoes (Omayio et al., 2016). Exposure of potatoes to direct sunlight is known to raise the glycoalkaloid levels (Zarins & Kruma, 2017). Petersson *et al.* (2013) in their study on influence of storage conditions on glycoalkaloid levels in different potato cultivars found that temperature and exposure to light are factors influencing glycoalkaloid levels in potatoes. Furthermore, they found that the effect of these two stress conditions on glycoalkaloid levels varied across different potato cultivars. The variation of glycoalkaloid levels based on potato varieties has also been a subject of research with some varieties accumulating higher glycoalkaloid levels than others under similar storage conditions (Valcarcel et al., 2014).The high commercial and subsistence use of Shangi, Dutch Robjin and royal varieties of potato in Kenya make them of great importance in terms of safety and nutrition. Establishing proper storage conditions of these varieties is, therefore, important in ensuring their safe utilization.

## 5.2 Materials and methods

### 5.2.1 Sample collection

Three potato varieties, Dutch Robjin, Royal and Shangi were used in this study. Dutch Robjin was obtained directly from a farmer in Bomet while Shangi and Royal were purchased from traders in Nairobi who had obtained them directly from farmers the same day.

### 5.2.2 Experimental design

Randomly selected samples of three potato varieties, Dutch Robjin, Royal and Shanigi, were subjected to different storage conditions of temperatures (5, 10 and 25 $^{o}$C) and storage in the presence of light and in darkness. The samples were stored for a period of twelve weeks with sampling after every four weeks for analysis of moisture content and glycoalkaloid levels. Obtained data was analyzed as two-factor experiment with potato variety and storage condition factors in a completely randomized design.

### 5.2.3 Analytical methods

#### 5.2.3.1 Determination of moisture content

Moisture content of different potato varieties was determined as per AOAC (2005) method number 930.15. The oven used was memmert 40500-IP20 (Schutzart, Germany). Triplicate samples of both whole and flesh potato samples of different varieties were subjected to moisture analysis at baseline and after every four weeks for a period of twelve weeks.

#### 5.2.3.2 Determination of glycoalkaloids

The levels of glycoalkaloids were determined by high pressure liquid chromatographic methods using Waters HPLC (Waters 2695- Waters corporation, USA) and detection set at a wavelength of 202 nm using photodiode array detector (Waters 2996, USA). Potato variety from same storage condition and period were sub-divided into two sets. One set was peeled and chopped into 5 mm pieces while another was chopped without being peeled. Twenty grams (20 g) of each set were oven dried to a constant weight at 135 $^{o}$C. The dry samples were ground and packaged in sealed plastic bottles and stored frozen at -20$^{o}$C before analysis.

##### 5.2.3.1 Extraction of glycoalkaloids

A 2 g sample was mixed with 20 ml extraction solution comprising of water, acetic acid and sodium hydrogen bisulfite (100 + 5 + 0.5, v/v/w) and shaken for 15 minutes by Burrell vertical shaker (Burrel Corp, Pittsburg, UK). Clarification of the mixture was then done by centrifugation for 30 min at 800*g* using Labofuge A (Heraeus, Germany). The extraction was done in triplicates.

#### 5.2.3.2 Cleaning of extract

Five ml (5 ml) acetonitrile followed by 5 ml extraction solution were used in conditioning Solid Phase Extraction (SPE) columns (Strata, Phenomenex). Into these columns, 10 ml of the supernatants were passed through the SPE columns at a controlled pressure after which SPE 4 ml wash solution (15% acetonitrile) was used to wash glycoalkaloids. This was followed by elution with 4 ml LC mobile phase (60% acetonitrile in 0.01M phosphate buffer) at a rate of 1–2 drops/s. The final volume collected was adjusted to 5 ml with LC mobile phase filtered through a 0.45 µm filter into vials and frozen ready for injection.

#### 5.2.3.3 Chromatographic analysis

The HPLC instrument (Waters-2595, USA) was fitted with stainless steel LC column—250 ×4.6 mm, packed with Hypersil ODS (Shandon Southern Products Ltd., Astmoor, UK), 5 µm particle size, C18 phase. The operating conditions included a flow rate of 1.5 ml/min, injection volume of 50 µl, run time of 15 minutes, column temperature of 40 °C and wavelength detection set at 202 nm. Glycoalkaloids were calculated based on external calibration curves generated from standards stock solutions and expressed as mg GAS/kg on dry weight basis.

### 5.2.4 Statistical Analysis

The data were analyzed using Genstat version 15 software. Descriptive statistics in terms of mean, standard deviation and standard error were generated for moisture content and glycoalkaloid levels. Test for significant differences in the means was performed using two way ANOVA at $p<0.05$. Means that were statistically different were separated using Fischers LSD test ($p \leq 0.05$).

## 5.3 Results and discussion

### 5.3.1 Influence of storage condition and variety of potato on levels of glycoalkaloids in potatoes

Results showed that significant ($p<0.001$) variations existed in the α-Solanine, α-chaconine and total glycoalkaloid levels of potatoes based on the period of storage, storage condition and variety for both the flesh (peeled) and whole potato (unpeeled) as shown in **Table 5.1**. An interaction between storage conditions (temperature, light and dark) and potato variety resulted in significant ($p>0.05$) variations in the α-chaconine and total glycoalkaloid levels in the potato flesh only. There was significant ($p<0.05$) variation in moisture content of whole potato and flesh based on the samples. The moisture content of the potato flesh varied with both potato variety and storage conditions. There was also variation in the ratio of α-Solanine to α-chaconine in the whole potato and flesh potato based on the period of storage. There was a weak negative ($r=-0.21$) and insignificant ($p>0.05$) correlation between moisture content and total glycoalkaloid levels meaning that the moisture content of the potato has no influence on the glycoalkaloid levels.

**Table 5.1: Analysis of variance for attributes of different varieties of potatoes**

| Source of variation | Mean square values | | | | |
|---|---|---|---|---|---|
| | Whole potato ( unpeeled) samples | | | | |
| | α-Solanine (a) | α-chaconine (b) | Total glycoalkaloids | Ratio (a:b) | Moisture |
| Period of storage | 12860080** | 20768393** | 65874166** | 1.1601 | 16.508 |
| Potato variety | 1138113** | 2087362** | 4816600** | 0.7854 | 162.932* |
| Storage conditions | 906168** | 2710269** | 5198053** | 2.2568** | 19.573 |
| Potato variety x Storage conditions | 36825 | 245857 | 317008 | 0.3441 | 13.716 |
| Error | 53974 | 228422 | 314640 | 0.3105 | 8.716 |
| | Flesh potato (peeled)samples | | | | |
| Period of storage | 5295930** | 12307895** | 33641807** | 0.3245 | 8.554 |
| Potato variety | 754372** | 1856443** | 4828104** | 1.9903* | 107.826** |
| Storage conditions | 360290** | 1851276** | 3483790** | 1.4418* | 45.306** |
| Potato variety x Storage conditions | 81180 | 598566* | 993640* | 0.7437 | 14.193 |
| Error | 62738 | 177014 | 358892 | 0.4665 | 9.083 |

**statistically significant at $p<0.001$, *statistically significant at $p<0.05$.

### 5.3.2 Variation of moisture content with storage

The whole potato Royal variety had the highest moisture content ($p \leq 0.05$) of the three varieties as shown in **Table 5.2.** The moisture contents of the potatoes varieties averaged between 73.83-77.41%. Storage of any of the potato varieties at 5 $^{o}$C resulted in the least loss in moisture content, averaging at 22.47%. Storage period had insignificant effect ($p>0.05$) on the moisture content of the potatoes. The values obtained in this study were lower than the 80.8% moisture content in some potato varieties as reported by Zhang *et al.* (2018). Different potato varieties are known to have varied moisture contents (Imungi, 1987). However, the range of moisture contents found in this study agrees with the values obtained in another study by Sablani and Mujumdar (2006) who reported moisture content in potatoes as 63.2-86.9%. The levels of moisture in potatoes tend to determine the use these potatoes can be put to, with potatoes with lower moisture content being preferred as they give higher yields of products such as French fries while those with higher moisture content are mostly used for soups and salads (Imungi, 1987). Contrary to the findings in this study, Golmohammadi and Afkari-Sayyah (2013) found that storage of potatoes significantly results into moisture loss in potatoes. However, moisture loss in food products is greatly dependent on storage conditions with food products stored in lower temperatures showing high retention of moisture (Kaur, Singh, & Ezekiel, 2008), thus the effect of storage period may be masked by this which is a known disadvantage of factorial designs (Collins, 2010).

**Table 5.2: Moisture content of potato flesh under different storage conditions**

| **Potato variety** | **Storage conditions** | | | | | **Averages** |
|---|---|---|---|---|---|---|
| | **Dark** | **Light** | **25$^oC$** | **10$^oC$** | **5$^oC$** | |
| Dutch Robjin | $74.01 \pm 5.54^a$ | $73.41 \pm 0.80^a$ | $75.74 \pm 1.10^a$ | $76.45 \pm 1.24^a$ | $78.72 \pm 4.84^a$ | $75.67 \pm 3.74^b$ |
| Royal | $77.43 \pm 0.27^a$ | $76.56 \pm 5.65^a$ | $78.78 \pm 1.48^a$ | $77.54 \pm 0.87^a$ | $76.22 \pm 1.61^a$ | $77.41 \pm 2.98^c$ |
| Shangi | $74.39 \pm 0.70^a$ | $71.17 \pm 2.90^a$ | $75.61 \pm 3.45^a$ | $72.51 \pm 0.99^a$ | $76.47 \pm 3.22^a$ | $73.83 \pm 3.04^a$ |
| Average | $75.28 \pm 3.46^{AB}$ | $73.71 \pm 4.19^A$ | $76.71 \pm 2.63^{BC}$ | $75.38 \pm 2.37^{AB}$ | $77.53 \pm 3.88^C$ | |

Values with different uppercase letters across a row or different lowercase letters along a column are significantly different at $p<0.05$.

### 5.3.3 Glycoalkaloid levels under different storage conditions

The glycoalkaloid levels of both the flesh potato (peeled) and whole potato (unpeeled) increased with increasing period of storage (**Figures 5.1, 5.2 and 5.3**). Upon four weeks of storage, the glycoalkaloid levels were beyond 1000 mg/kg for whole potatoes of all the varieties whereas in the flesh such levels were attained after eight weeks of storage of all the varieties. Glycoalkaloid levels below 200 mg/kg fresh weight (1000 mg/kg dry weight assuming an average moisture content of 80% in potatoes) has been set as the safe levels for potatoes meant for consumption (Valcarcel et al., 2014). The high total glycoalkaloid levels in whole potatoes as compared to the flesh potatoes could be explained by the presence of peels in the whole potatoes; higher accumulation levels of glycoalkaloids in the peels as compared to the flesh is a characteristic of the potatoes (Eltayew, Al-sinanp, & Khan, 2003). Glycoalkaloid accumulation is subject to abiotic factors and is usually independent of the levels in the potato at harvest (Griffiths, Bain, Finlay, & Dale, 1997). The flesh potatoes at baseline (week 0) had acceptable levels of total glycoalkaloids and hence would raise less food safety concerns. Similar findings were recorded by Kirui *et al.*(2018) in their evaluation of freshly harvested potato varieties in Kenya. Concerns would, therefore, be on the storage and postharvest handling practices of these potatoes.

Royal variety accumulated significantly ($p<0.05$) lower glycoalkaloid levels both in the whole and peeled potatoes as compared to the other two varieties of potato (**Table 5.3 and 5.4)**. Dutch Robjin and Shangi varieties whole potato and potato flesh averaged glycoalkaloid levels above the safety limit of 1000 mg/kg under different storage conditions. Variation in levels of total glycoalkaloids was also noted in other studies (Aziz *et al.*(2012);Eltayew *et al.*(2003). Aziz *et al.*(2012) in their study recorded glycoalkaloid levels higher than the safe levels in some varieties too. Consumption of such potatoes would most likely induce food poisoning, thus should be avoided. In another study, Nahar *et al.*(2017) reported genetic influence as being the factor inducing variations among different potato varieties.

Storage of the potatoes at a temperature of 10 $^{o}$C or under exposure to light resulted in significantly ($p<0.001$) higher glycoalkaloid levels. The two storage conditions had significantly ($p<0.05$) higher accumulation for α-chaconine than for the α-solanine. Storage in the darkness and at 5 $^{o}$C resulted in lower levels of glycoalkaloid accumulation; lower than 1000 mg $kg^{-1}$ dry weight, thus safe for consumption. These findings are in agreement with the findings by Percival (1999) and Sengul *et al.* (2004) where less accumulation of glycoalkaloids was reported for storage in darkness as compared to storage in light. Similar findings were reported by Kozukue and Mizuno (1990) where varieties of potatoes stored at a lower temperature of 4 $^{o}$C did not show signs of greening whereas those stored at 10$^{o}$C developed some greening, a clear indication of accumulation of glycoalkaloids. The study also found that light induces greening in these potatoes. Similarly, Edwards and Cobb (1997) in an earlier study reported the same. Greening in potatoes is due to the development of chlorophyll and this has a positive correlation with the accumulation of glycoalkaloids (LAURA Grunenfelder, 2005).

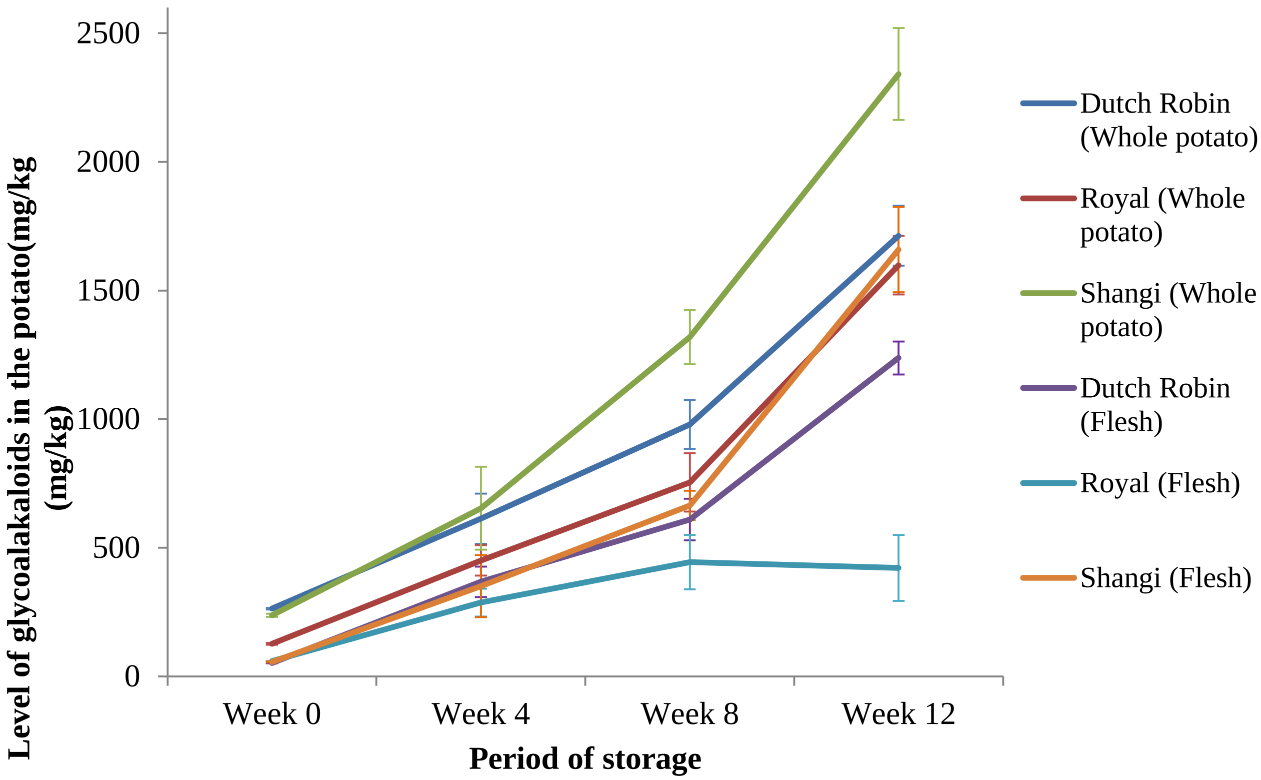


**Figure 5.1: α-Solanine levels in different potato varieties over different periods of storage.** The bars indicate standard error of the mean.

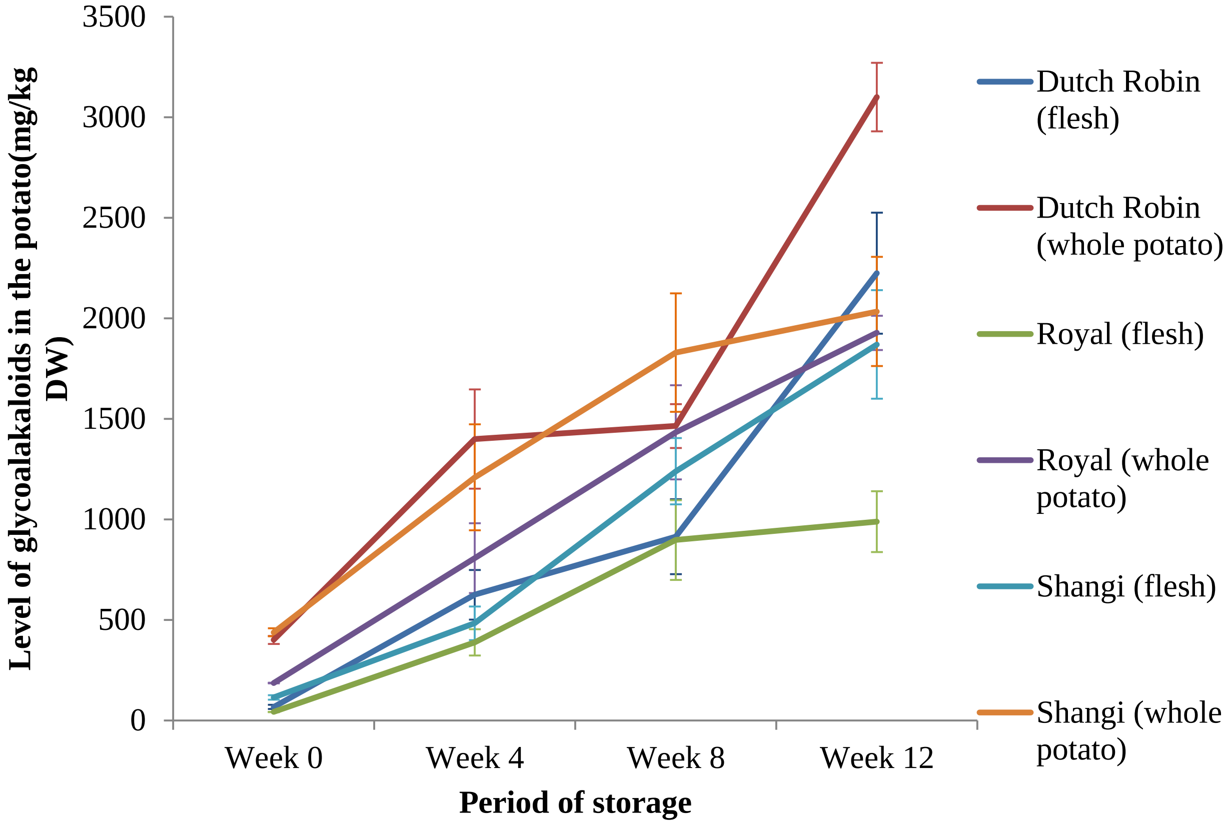


**Figure 5.2: α-Chaconine levels in different potato varieties over different periods of storage.** The error bars indicate standard error of the mean.

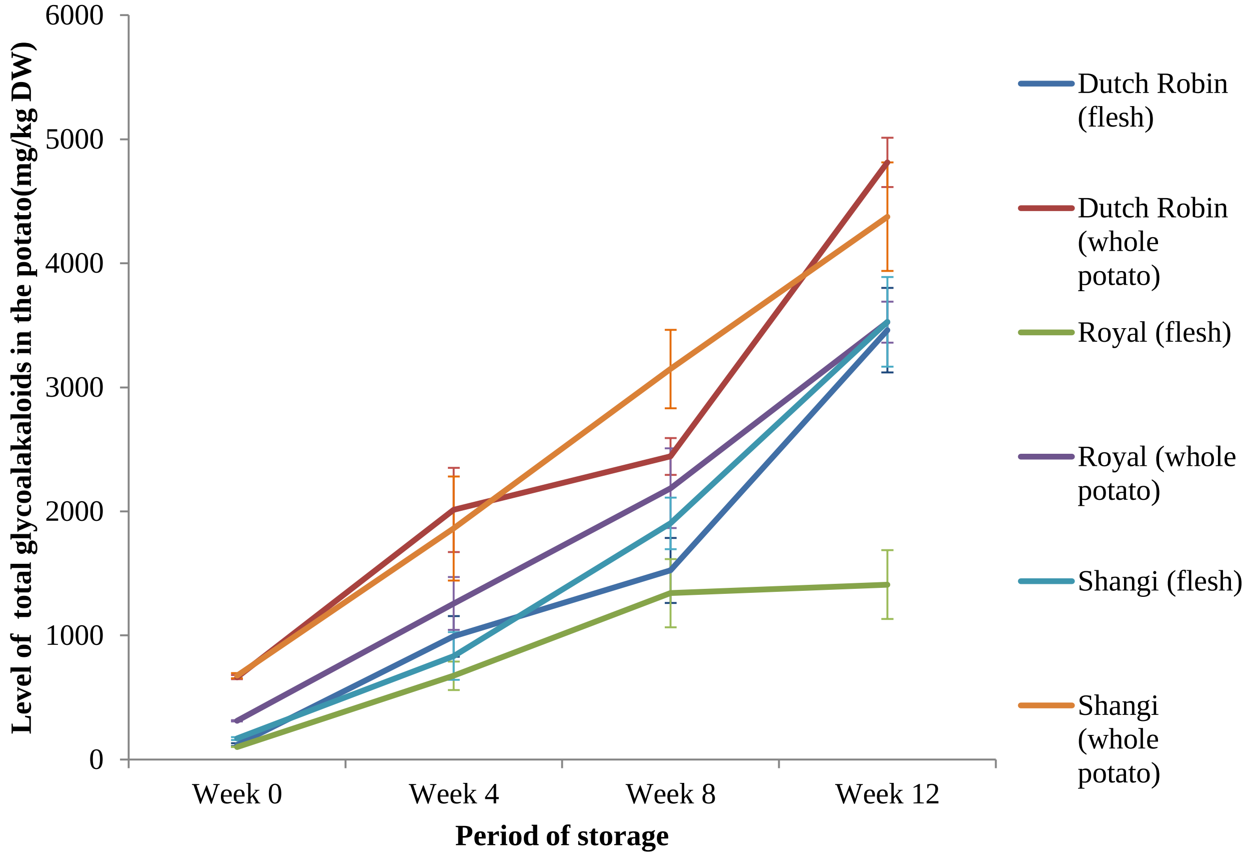


**Figure 5.3: Total glycoalkaloid levels in different potato varieties over different periods of storage.** The error bars indicate standard error of the mean.

**Table 5.3: Glycoalkaloid levels in whole potatoes (mgkg-1 dry weight)**

| Variety | Dutch Robjin | | | | Royal | | | | Shangi | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Storage | α-Solanine A | α-chaconine B | Tota A+B | Ratio A/B | α-Solanine A | α-chaconine B | Total A/B | Ratio A+B | α-Solanine A | α-chaconine B | Total A+B | Ratio A/B |
| **Dark** | 1003.2±640.5$^{b}$ | 1536.2±423.0$^{c}$ | 2821±1832$^{b}$ | 1:2.0$^{bc}$ | 1003.2±640.5$^{d}$ | 1536.2±423.0$^{e}$ | 1426±1206$^{b}$ | 1:2.0$^{c}$ | 1003.2±640.5$^{b}$ | 1536.2±423.0$^{b}$ | 2821±1832$^{c}$ | 1:2.0$^{bc}$ |
| **Light** | 1536.2±423.0$^{d}$ | 2581.0±866.0$^{e}$ | 4117±1176$^{d}$ | 1:1.7$^{ab}$ | 1003.2±709.9$^{d}$ | 1323.0±868.7$^{de}$ | 2326±1552$^{c}$ | 1:1.4$^{b}$ | 1249.5±1052.6$^{c}$ | 1439.0±958.7$^{b}$ | 2689±1974$^{c}$ | 1:1.5$^{a}$ |
| **25°C** | 1216.3±657.7$^{c}$ | 1486.0±550.1$^{b}$ | 2702±1177$^{b}$ | 1:1.5$^{a}$ | 644.9±455.3$^{c}$ | 929.0±708.5$^{b}$ | 1574±1161$^{b}$ | 1:1.4$^{b}$ | 912.5±780.1$^{b}$ | 920.0±442.4$^{a}$ | 1833±1179$^{a}$ | 1:1.5$^{a}$ |
| **10°C** | 1028.4±521.4$^{b}$ | 2188.0±905.7$^{d}$ | 3217±1425$^{c}$ | 1:2.2$^{c}$ | 435.2±261.4$^{b}$ | 1273.0±890.8$^{c}$ | 1708±1138$^{b}$ | 1:2.6$^{d}$ | 587.8±540.1$^{a}$ | 1473.0±620.7$^{b}$ | 2061±258$^{b}$ | 1:2.2$^{c}$ |
| **5°C** | 539.4±337.8$^{a}$ | 1181.0±1128.5$^{a}$ | 1720±1458$^{a}$ | 1:1.9$^{b}$ | 172.4±54.3$^{a}$ | 198.0±17.9$^{a}$ | 370±71$^{a}$ | 1:1.2$^{a}$ | 640.6±491.6$^{a}$ | 974.0±602.2$^{a}$ | 1614±1082$^{a}$ | 1:1.8$^{ab}$ |
| **LSD** | 147.9 | 304.2 | 357.0 | 1:0.35 | 147.9 | 304.2 | 357.0 | 1:0.35 | 147.9 | 304.2 | 357.0 | 1:0.35 |
| **Averages*** | 1002.9±593.6$^{Ac}$ | 1772.±1065.1$^{Bb}$ | 2775±1587$^{C}$ | 1:1.9$^{Da}$ | 629.2±551.5$^{Aa}$ | 969.0±771.2$^{Ba}$ | 1598±1274$^{B}$ | 1:1.62$^{B}$ | 885.5±804.3$^{Db}$ | 1141.±886.9$^{Da}$ | 2026±1593$^{D}$ | 1:1.6$^{Da}$ |

Values with different lowercase letters in the superscripts along a row except for averages* where values with similar uppercase letters preceding a different lowercase letters in the superscript are significantly different at $p<0.05$.

**Table 5.4: Glycoalkaloid levels of flesh potatoes (mg kg$^{-1}$ dry weight)**

| Variety | Dutch Robjin | | | | Royal | | | | Shangi | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Storage | α-Solanine A | α-chaconine B | Total A+B | Ratio A/B | α-Solanine A | α-chaconine B | Total A/B | Ratio A+B | α-Solanine A | α-chaconine B | Total A+B | Ratio A/B |
| **Dark** | 641.8±551.7$^{b}$ | 714.7±696.6$^{b}$ | 1356±1238$^{b}$ | 1:1.1$^{a}$ | 346.8±309.7$^{cd}$ | 571.6±430.5$^{b}$ | 918±723$^{c}$ | 1:1.6$^{b}$ | 433.7±121.2$^{b}$ | 656.6±190.8$^{a}$ | 1090±388$^{b}$ | 1:1.7$^{a}$ |
| **Light** | 1034.7±398.8$^{d}$ | 1805.7±1305.3$^{d}$ | 2840±1701$^{c}$ | 1:1.6$^{b}$ | 424.3±357.3$^{d}$ | 564.7±434.3$^{b}$ | 989±787$^{c}$ | 1:1.4$^{b}$ | 777.7±317.4$^{c}$ | 1031.4±972.6$^{b}$ | 1809±725$^{c}$ | 1:1.6$^{a}$ |
| **25$^{o}$C** | 703±407.4$^{bc}$ | 951.7±485.1$^{c}$ | 1655±887$^{b}$ | 1:1.5$^{ab}$ | 167.1±93.8$^{ab}$ | 234.9±166.1$^{a}$ | 402±249$^{b}$ | 1:1.3$^{b}$ | 428.7±258.8$^{b}$ | 594.6±485.6$^{a}$ | 1023±1008$^{b}$ | 1:2.0$^{a}$ |
| **10$^{o}$C** | 802.9±326.5$^{c}$ | 2073.9±877.2$^{e}$ | 2877±1192$^{c}$ | 1:2.6$^{c}$ | 259.1±172.4$^{bc}$ | 601.9±126.3$^{b}$ | 861±183$^{c}$ | 1:1.7$^{b}$ | 262.1±80.2$^{a}$ | 570.5±217.3$^{a}$ | 833±137$^{a}$ | 1:2.0$^{a}$ |
| **5$^{o}$C** | 326.5±365.5$^{a}$ | 461.1±518.7$^{ab}$ | 788±183$^{a}$ | 1:1.4$^{ab}$ | 118.8±68.9$^{a}$ | 107.0±74.9$^{a}$ | 226±144$^{a}$ | 1:0.8$^{a}$ | 433.5±432.6$^{b}$ | 577.3±491.7$^{a}$ | 1011±924$^{b}$ | 1:1.9$^{a}$ |
| **LSD** | 159.4 | 267.8 | 381.3 | 1:0.43 | 159.4 | 267.8 | 381.3 | 1:0.43 | 159.4 | 267.8 | 381.3 | 1:0.43 |
| **Averages*** | 657.6±459.6$^{Ac}$ | 1114.3±987.3$^{Bc}$ | 1772±1405$^{Cc}$ | 1:1.6$^{Dab}$ | 280.4±258.2$^{Aa}$ | 441.5±449.4$^{Ba}$ | 722±678$^{Ca}$ | 1:1.4$^{Da}$ | 492.7±589.7$^{Ab}$ | 714.0±758.8$^{Bb}$ | 1207±1304$^{Cb}$ | 1:1.8$^{Db}$ |

Values with different lowercase letters in the superscripts along a row except for averages* where values with similar uppercase letters preceding a different lowercase letters in the superscript are significantly different at $p<0.05$.

## 5.4 Conclusion

Potato that has been stored exposed to light and in elevated temperatures tends to accumulate high levels of glycoalkaloids regardless of the variety of the potato. Low temperature storage and storage in the dark leads to low accumulation of glycoalkaloids hence less food safety concerns. However, it is not definite that storage in these latter conditions would assure absolute safety from glycoalkaloids as storage beyond eight weeks even under these conditions would result into accumulation of glycoalkaloids beyond acceptable levels. Considering the high consumption levels of Shangi and Dutch Robjin varieties in the country and given that they accumulate higher levels of glycoalkaloids during storage, they could pose a food safety risk in the long term. It is, therefore, recommended that strategies be put in place to educate all the potato value chain players, from production to consumption on appropriate post-harvest handling and storage of potatoes for consumer safety.

# GENERAL CONCLUSION AND RECOMMENDATIONS

## 6.0 General conclusion

Potato post-harvest handling practices among the potato traders in open air markets in Nairobi is poor which may impact negatively on the quality of the potatoes especially in terms of safety. More than half of the potatoes on the market are exposed to unfavourable temperature and light conditions as seen through the direct exposure of the tubers to sunlight. This means potato consumers in Nairobi may be experiencing long term exposure to these toxins due to buying of greening, bruised or sprouting potatoes for home consumption or consuming of potato products made from these potatoes. Furthermore, presence of low level of knowledge on the health effects of consuming greened, bruised or sprouting potatoes leads to poor perception of potato safety among the traders.

Glycoalkaloids levels in commercial potatoes traded in open-air markets and supermarkets did not exceed the recommended safety levels. However, the supermarkets samples had slightly higher levels of GAs thus posing a food safety risk to the consumers.

Low temperature storage, storage in the dark and storage for shorter periods of time results in low accumulation of glycoalkaloids hence these conditions are deemed appropriate to enhance food safety.

## 6.1 General recommendations

There is need to create awareness among potato traders and handlers along the potato chain to ensure that tubers are not exposed to factors that increase glycoalkaloid levels. Since this study sampled only three varieties in the Kenyan market, it is recommended that further studies using more available varieties be conducted to come up with more generalizable findings.

Furthermore, there is need to conduct further studies to shed more light on why supermarket samples have higher levels of glycoalkaloids compared to open air samples. This will be helpful in formulate necessary strategies for sales of potato in supermarkets. It is essential that consumers and potato handlers select potato cultivars with minimal glycoalkaloids accumulation rates in order to ensure that there is minimum glycoalkaloids intoxication even with storage.

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## APPENDIX: SURVEY QUESTIONNAIRE

## ASSESSMENT OF POST-HARVEST HANDLING AND STORAGE PRACTICES AMONG POTATO TRADERS IN NAIROBI, KENYA

I am a Master of Science (MSc.) Student at the University of Nairobi conducting a research on **Glycoalkaloids in Commercial Kenyan Potato Varieties: Effect of Postharvest Handling and Storage Conditions.** This survey is aimed at assessing the post-harvest handling and storage practices among potato traders and how this affects the glycoalkaloids levels of potatoes. This will form a basis for consumer health protection and formulation of appropriate strategies for the prevention and control of glycoalkaloids along the potato value chain in Kenya. Your honest responses will be used for research purpose only and shall be treated with utmost confidentiality. Your cooperation and participation is highly appreciated.

**Questionnaire No……………** **Date of interview……………………….**

1. **General Information**

Name of sub-county……………………………………………………

Name of market………………………………………………………….

2. **Respondent information**

Gender…………………………………………………………………………….

Age…………………………………………………………………………………

Education level………………………………………………………………….

3. **Variety (s) of potatoes sold**
    1. …………………………..
    2. …………………………..
    3. …………………………..
    4. …………………………..

## 4. Information on post-harvest handling and storage (*please tick where appropriate)*

4.1 Where do you get your supply of potatoes from?

[a] Own production [b] Buy directly from farmer [c] From other retailers(middle men)

4.2 Approximately how long does it take you to get the potatoes from the point of supply to the market? ....................................................................

4.3 i) How do you transport the potatoes from the point of supply to the market?

[] Vehicle e.g. lorry, pickup [] hand-pulled cart [] other (specify)

ii) If a vehicle/hand-pulled cart is used what is the design of its back?

[] Open back [] Closed back

4.4 How do you store potatoes?

[] cool dry place [] in piles [] in a dark room [] in a room with enough light

4.5 How long do you store your potatoes until the next supply?

[] 1-2 wks [] 1 month [] over one month [] other (specify)……………………

4.6i) Are there factors you consider when storing potatoes?

[] Yes [] No

ii) If yes above, please list them.

4.7 Are the potatoes exposed to sunlight? (**This question is to be answered by interviewer by observation**) [Yes] [No]

Include any comments here regarding your observation above.

4.8 In your opinion what do you think "greening" in potatoes indicates?

4.9 What do you do to potatoes that show any sign of "greening"/damage?

**5. Knowledge of effects of glycoalkaloids on health**

5.1 Do you consider consumption of "greened" potatoes injurious to health?

5.2 Have you/your friend/family member at any given time ever complained of having been affected health wise (shown symptoms) after consuming "greened" potatoes?

[] Yes [] No

5.3 Any comments you would like to share concerning post-harvest handling and storage of potatoes?

**Thank you for your cooperation.**