PHYSICO-CHEMICAL PROPERTIES AND STORABILITY OF SELECTED IRISH POTATO VARIETIES GROWN IN KENYA

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Physico-chemical properties and storability of selected Irish potato varieties grown in Kenya

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other university

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DEDICATION

I dedicate this work to my parents; Joseph Gikundi and Jenerosah Nyoroka.

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LIST OF ABBREVIATIONS AND ACRONYMS

FAO	Food and Agriculture Organization
MoA	Ministry of Agriculture
CIP	International Potato Center
NPCK	National Potato Council of Kenya
CIS	Cold Induced Sweetening
DWB	Dry weight basis
FWB	Fresh weight basis
HPLC	High Performance Liquid Chromatography
RH	Relative Humidity
RT	Room Temperature

ABSTRACT

Potato is the second most important food crop after maize in Kenya. It is valuable as it yields more nutrients per unit area and time than any other crop. Potato is a short-duration crop, easy to propagate, versatile in use, and a good source of nutrients. While different potato varieties do exist, the nutritional value, storability, and suitability of each variety for domestic and industrial application is not well documented. This study aimed to characterize the physical properties, nutrient content, and storability of three popular Kenyan potato varieties (Shangi, Dutch Robjin, and Unica). The three potato varieties were obtained from Jaconta farms ltd in Ol Kalou, Nyandarua County where they were all cultivated under the same conditions in one season. Physico-chemical characteristics were determined using standard methods and procedures. Tuber storability was evaluated at room temperature and relative humidity (RH), 10°C/75% RH, 10°C/ ambient RH, and 7°C/75% RH. Parameters analyzed for tuber storability included weight loss, sprouting, greening, rotting, and simple sugars. The results for physical characteristics revealed that Unica, Shangi, and Dutch robjin had tuber lengths above 50mm recommended for French fry processing. Dutch robjin and grade two tubers of Shangi and Unica varieties would be suitable for crisp processing as they had widths ranging between 40-60mm. Shangi and Unica were oval in shape making them suitable for French fry processing while Dutch robjin was round in shape and would thus be suitable for crisp processing. All varieties had specific gravity ranging between 1.08±0.01 and 1.12±0.02 for both grades hence suitable for processing. All the varieties had deep eyes (>0.6mm). There were significant differences in the nutrient content among the three varieties with Dutch Robjin having the highest content of carbohydrates (20.43±1.03%, P=0.0003), crude fibre (1.11±0.15%, P=0.0246), total ash (1.10±0.03%, P=0.0004), iron (0.87±0.05mg/100g, P=0.0028), thiamine (0.04±0.01mg/100), niacin (0.93±0.09mg/100, P=0.0439), pyridoxine (1.92mg/100g, P=0.0001) and folic acid (34.62±1.06 µg/100g, P<0.0001). Reducing sugar content across the three varieties differed significantly (P= 0.0083) and increased during storage, with Shangi variety exhibiting the highest accumulation. Potato storability varied across the storage conditions and varieties. The degree of change in tuber physical quality was highest at room conditions and least at 7°C/75%RH. Shangi generally had the highest rate and extent of change in physical quality as indicated by the rate of sprouting, weight loss, greening, and rotting under all the storage conditions while Unica had the best storability attributes. Storage at 7°C/75%RH best preserved the tuber physical characteristics increasing the storability of Shangi from 2 weeks to 3 months. These findings indicate that Shangi, Unica, and Dutch robjin varieties differ in terms of physical, nutritional, and storability properties. The physicochemical properties of these varieties such as tuber weight, greening and simple sugars concentration are influenced by different storage conditions.

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Potato (*Solanum tuberosum* L.) is one of the world's major food crops, ranking third among the most important food crops worldwide after rice and wheat in terms of production and area under cultivation (Devaux *et al*., 2021). It is a key part of the global sustainable food system, possessing a unique combination of characteristics such as high yield, low cost, nutritious and palatable food (Azad *et al*., 2017). Potato is valuable to the Kenyan population as it is a major source of nutrition and livelihood for many families (Ministry of Agriculture, 2016). The crop yields more food per unit area and time than any other food crop and is suitable for inter-cropping systems which are prevalent in Kenya (Azad *et al*., 2017; Campos and Ortiz, 2020; Ghebreslassie, 2017). Furthermore, its ability to thrive in high-altitude areas where crops such as maize have no comparative advantage makes potato a very important food and cash crop (Janssens *et al*., 2013). Owing to its high productivity per unit area and versatility in utilization, potatoes have a high potential for improving nutrition and enhancing food security, employment, and higher farm incomes in Kenya (Ministry of Agriculture, 2016).

Generally, the production, consumption, and processing of potatoes especially in developing countries is growing, spurred by the steady rise in population, urbanization, and expansion of the fast-food industry (Devaux *et al*., 2021; Kyalo, 2014). According to FAOSTAT, the global production of potatoes is estimated at approximately 370 million metric tonnes annually (FAO, 2021). In Kenya, potato is the second most important food and cash crop after maize with production ranging between 2-3 million tonnes annually (Ministry of Agriculture, 2016). Kenya is the third biggest producer of potatoes in Sub-Saharan Africa, immensely contributing to national food and nutritional security (FAO, 2021; Muthoni and Nyamongo, 2009). The increasing demand for potatoes is supported by changing eating habits and preferences in support of potato and potato products such as bhajia, French fries, and salads (MoA, 2016).

Potatoes are a good source of macronutrients (carbohydrates, protein, fiber) and micronutrients (vitamins such as folate, niacin, and minerals such as iron, zinc, potassium, and phosphorous) (Bonierbale *et al*., 2010; FAO, 2008). Additionally, potatoes are a rich source of antioxidants including carotenoids, ascorbic acid, and phenolic substances (Bonierbale *et al*., 2010). However, studies have demonstrated variations in the nutritional composition and physical properties of potato tubers due to factors such as variety, climate, soil, agronomic practices, tuber maturity, cooking, and storage conditions (Bonierbale *et al*., 2010; Leonel *et al*., 2017; Salaman, 2014). Recent insight into the nutrient quality of potatoes reveals that substantial compositional variations exist between different potato cultivars (Leonel *et al*., 2017; Ngobese *et al*., 2017). Compositional variations are of prime concern as they influence the quality of cooked and processed potato products (Brunton *et al*., 2007).

Physical tuber characteristics such as eye-depth and storability attributes have also been found to vary significantly with variety (Ooko, 2008). These variations are important as they determine the quality and utilization of potatoes. Physical characteristics such as eye-depth and shape determine peeling and trimming efficiency during processing, subsequently the product yield (Brunton *et al*., 2007; Ooko, 2008). The storability of potato tubers influences availability of quality tubers all-round the year. Studies indicate that some varieties have longer tuber dormancy and less sprouting than others (Gautam *et al*., 2016). Depending on varietal characteristics, some varieties have dormancy periods of as long as 15-27 weeks, while others last only a few weeks (Benkeblia *et al*., 2008). Varieties like Kenya Mpya and Sherekea have a dormancy period of 75 to 90 and 80 to100 days respectively (Onditi and Nderitu, 2012)

In terms of utilization, potato is one of the most versatile and adaptable crops. Potatoes can be prepared in many ways including baking, steaming, roasting and boiling. They can also be processed into a variety of products at the industry level (Kibar, 2012). Some of the common dishes consumed in Kenya include French fries, potato crisps, and traditional dishes such as *mukimo* which is prepared by mixing potatoes with vegetables and cereals such as maize or legumes such as beans (Muthoni and

Nyamongo, 2009; Ogolla *et al*., 2015). Following the rapid expansion of fast-food restaurants and snack bars especially in urban areas, the most commonly consumed potato products in Kenya are French fries, followed by potato crisps (Abong *et al*., 2009; Ogolla *et al*., 2015). Other edible potato products include potato starch, alcohol, baby food, and animal feed (MoA, 2016). In addition to food products, potatoes are used in the manufacture of non-food materials such as fertilizers, pharmaceutical products, glue, and detergents (Abebaw, 2020; Javed *et al*., 2019; Survase and Singhal, 2009). Potatoes are also utilized in the pharmaceutical industry, for instance in the production of weight loss supplements (Donnelly and Kubow, 2011).

Despite the numerous benefits of Irish potatoes in Kenya, there is limited information regarding the nutritional attributes, physical properties, and effective storage practices of new and existing potato varieties.

1.2 Problem statement

In spite of its nutritional, economic, and industrial benefits, potato's potential is underexploited in terms of utilization at both the industry and household level. There is insufficient information regarding the nutritional value of the different potato varieties grown in Kenya. Additionally, there is limited information on the link between physical properties and the storability and utilization of different varieties, which contributes to losses during processing, inadequacy in supply, and low-quality tubers and potato products (Abong' and Kabira, 2011). Many processors experience losses due to challenges in grading, mixing of varieties, and storage (Ministry of Agriculture, 2016). Additionally, processors run out of supplies as they rely on one processing variety because other varieties have barely been tested for suitability to their requirements (Ministry of Agriculture, 2016).

Based on previous studies, significant variations exist in the nutrient profile, physical characteristics, and storability attributes across varieties (Abong *et al*., 2009a; Brunton *et al*., 2007; Leonel *et al*., 2017; Salaman, 2014). As a result, different varieties are suitable for specific uses. While new varieties are continually being introduced in Kenya, their nutritional value and suitability for domestic and industrial use are often overlooked (Abong *et al*., 2009b). Generally, a lot of focus has been on investigating and breeding varieties with better agricultural traits such as disease resistance and high yields (Abong *et al*., 2009b; Navarre *et al*., 2009). Consequently, there is limited information concerning the nutritional, physical, and storability attributes of Irish potatoes, which are to a great extent subject to varietal differences. This contributes to poor knowledge and linkage between farmers' interests as well as consumers' and processors' needs with regards to variety and use (Komen et al., 2017).

Due to the bulky and perishability nature of potatoes, high post-harvest losses are experienced (FAO, 2013). According to FAO, (2013), most farmers and processors in Kenya practice poor potato tuber storage techniques or no storage at all. Most farmers harvest their crops after identifying buyers and sell immediately after harvest, mainly due to poor storage systems and lack of knowledge in the effect of storage conditions on the quality of potatoes (FAO, 2013). Consequently, big gluts and low prices are experienced during harvests, with subsequent shortages and high prices later (Abong *et al*., 2015). Potato processors in Kenya complain of inconsistent supply of quality raw material round the year resorting to importation of potatoes for processing (Abong' and Kabira, 2011; Kaguongo *et al*., 2014). There is scarce information on effective potato storage methods and conditions that can minimize post-harvest losses and retain the quality of tubers for future use.

1.3 Justification

Potato is an important food and cash crop in Kenya, contributing largely to the country's economy and food security (Laititi, 2014). It is the second most valuable crop after maize in terms of production and consumption (Nderitu *et al*., 2014; Ogolla *et al*., 2015). Approximately 800,000 people benefit directly from potato farming while approximately 3.3 million people get income through employment in the potato value chain (MoA, 2016). The demand for potatoes, therefore, is increasing steadily, mainly due to the rapid growth in population, urbanization, and expansion of the fast-food industry (Kyalo, 2014). Additionally, potatoes have been targeted as one of the priority crops in strategies aimed at achieving the food security component of the Kenyan government's big four agenda (Mbego, 2019). The crop has immense potential for addressing food insecurity in Kenya due to its excellent attributes including tremendous yields per unit area compared to other crops and good nutritional value (Hussain, 2016). These attributes make potato an ideal crop to reduce the pressure on maize which has been subject to over-reliance as the predominant staple in Kenya (FAO, 2013; Zhang *et al*., 2017).

Other than food products, potatoes have the potential for non-food applications including the manufacture of animal feed, and the textile industry (Bradshaw and Ramsay, 2009; MoA, 2016). In addition to high productivity, nutritional value, and versatility in use, potato tubers can be stored following harvest (Hussain, 2016). To improve potato storage practices and enhance a steady supply of quality tubers even during the offseason, it is vital to evaluate the tubers' storability and explore efficient storage conditions for the various potato varieties.

The findings of this study will contribute to guiding potato consumers and processors in selecting varieties that possess suitable traits for their diverse needs. This will subsequently contribute to improving efficiency in processing and quality of the end product. Information on the storability of different varieties under different conditions will be valuable to farmers, processors, and primary consumers in terms of selecting appropriate potato storage depending on the intended end-use. Additionally, this study will contribute to the body of knowledge and research on different varieties of Irish potatoes grown in Kenya.

1.4 Study objectives

1.4.1 Overall objective

To characterize the physical, nutritional, and storability attributes of three potato varieties (Shangi, Unica and Dutch robjin) grown in Ol Kalou- Nyandarua county, Kenya.

1.4.2 Specific objectives

1. To determine the main physical attributes of three popular potato varieties (Shangi, Dutch Robijn, and Unica) grown in Nyandarua county, Kenya
2. To determine proximate content and micronutrient content of three popular potato varieties (Shangi, Dutch Robijn, and Unica) grown in Nyandarua county, Kenya
3. To determine the main simple sugars in three popular potato varieties (Shangi, Dutch Robijn, and Unica) grown in Nyandarua county, Kenya, and their changes under different storage conditions
4. To evaluate the storability of three popular potato varieties (Shangi, Dutch Robijn, and Unica) grown in Nyandarua county, Kenya under different storage conditions

1.5 Hypotheses

a) Popular potato varieties grown in Kenya do not differ in their main physical attributes
b) The potato varieties do not vary in proximate content and micronutrient content
c) The potato varieties do not vary in content of simple sugars and their changes during storage
d) The potato varieties do not differ in storability under different storage conditions

CHAPTER TWO

REVIEW OF LITERATURE

2.1 Introduction

Potato (*Solanum tuberosum* L.) belongs to the family Solanaceae. Potatoes are planted by vegetative propagation, yielding harvestable tubers below ground (Ekin, 2011). The potato is an enlarged portion of an underground stem that acts as the food reservoir for the plant during its growth cycle (Ooko, 2008). The tuber is characterized by apical and axillary buds (commonly known as eyes) which are usually dormant when the tuber is growing, and remain so for some time after harvest (Daniels-lake, 2013). The dormancy duration is variety dependent, controlled by endogenous plant growth regulators and genetic factors, but also tuber maturity at harvest and environmental conditions during storage (Daniels-lake, 2013). The plant also bears flowers of different colors which are reported to be related to the tuber skin colors. Generally, varieties with white flowers are associated with white skin-colored tubers while pink, red, purple, or blue flowers are linked to tubers with pinkish -reddish skin colors (Gautam *et al*., 2016).

Potato is one of the oldest food crops known to mankind, providing nutrition to countries across the world since its origin in Peru, hundreds of years ago (Niekerk, 2015; Singh *et al.*, 2012). The crop was brought to Europe in the 16th century by Spanish explorers from where it spread throughout the globe (Gibson and Kurilich, 2013). Although the crop was originally domesticated to mountain highlands, it has been adapted to a broad range of climatic and growing conditions including tropical lowlands and temperate regions (Daniels-lake, 2013). Potato is currently the world’s largest non-cereal food crop and third in line among the most important foods contributing to human nutrition after rice, wheat, and maize (Gibson and Kurilich, 2013).

Potatoes are cultivated in more than 80% of countries across the world, with demand and consumption increasing especially in developing countries (Devaux *et al*., 2021).

More than 1.3 billion people worldwide consume potatoes as a staple food. The crop's versatility coupled with the notable increase in production over the last two decades is unparalleled (Devaux *et al*., 2021). Global statistics show that the production of potatoes is shifting towards developing countries, with significant growth in production observed mainly in Asia, and Africa (especially in East Africa) (Devaux *et al*., 2021). Some of the reasons attributed to the increasing popularity of potatoes include; their ease of cultivation, versatility in use, high yields, and affordability among others (Niekerk, 2015). Potatoes are a short-duration crop, easy to propagate and seeds can be replanted (Hussain, 2016). They have high productivity per unit area and are a good source of nutrients, playing a significant role in the food and nutritional security of many countries. Tuber quality is influenced by varieties, growth conditions, cultivation practices, crop management, and storage practices (Ekin, 2011). Each potato cultivar has unique physical tuber characteristics and nutritional composition and is therefore suited to different consumption, processing, and propagation purposes (Ekin, 2011).

2.2 Potato production

Globally, approximately 370 million metric tonnes of potatoes are produced annually, with the region of Asia leading in production followed by Europe, the Americas, and Africa (FAO, 2021). China is the leading potato producer worldwide, with an estimated production of 90 million metric tonnes. In Africa, Egypt is the leading producer of potatoes **(Table 2.1)** with production estimated at 5.1 million tonnes while Kenya is the fourth largest potato producer in Africa(FAO, 2021). The total area under potato farming in Kenya is estimated to be 212, 976 ha with an average production of 2 million metric tons annually (FAO, 2021). Potato is an important food and cash crop in Kenya. It is the second most important crop after maize in terms of production and consumption (Mburu *et al*., 2020).

Table Error! No text of specified style in document.**.1: Top twenty potato producing countries in Africa (metric tonnes)**

Country	**Production (Metric tonnes)**
Egypt	5,078,374
Algeria	5,020,249
South Africa	2,505,775
Kenya	2,000,000
Morocco	1,956,711
Nigeria	1,396,892
Malawi	1,219,366
Tanzania	1,013,408
Rwanda	973,408
Ethiopia	924,528
Sudan	465,927
Angola	455,249
Tunisia	440,000
Burundi	376,441
Cameroon	363,556
Libya	359,457
Mali	303,257
Mozambique	297,812
Madagascar	250,000
Niger	198,392

Source: (FAOSTAT, 2019)

The potato has many advantages with respect to production and nutrition that make it an ideal complement to maize which is the predominant food security crop in Kenya. Potatoes have short growing periods of 3-4 months, enabling year-round production with at least two seasons per annum (Mburu *et al*., 2020; Muthoni and Nyamongo, 2009). Additionally, due to the rapid shrinkage of arable land on account of population growth and urbanization, there is a high demand for crops that can produce more food, nutrients, and cash per unit area and time (FAO, 2013). Potatoes fit these criteria as they supply more food, more quickly and on less land than any other major food crop (Gibson and Kurilich, 2013). Moreover, the potato has been targeted as one of the priority crops in strategies aimed at achieving the food security component of the Kenyan government's Big-Four agenda (Mbego, 2019).

The crop is cultivated by approximately 800,000 farmers, and an estimated 2.5million people are employed in the potato sub-sector (CIP, 2016). Potato, therefore, plays a substantial role as a source of food and nutritional security, and livelihood to many Kenyans. Cultivation of potatoes in Kenya is concentrated in the high altitude areas (1500-3000 meters above sea level) of Central, Eastern, and Rift valley regions of Kenya, where other crops such as maize do not have a comparative advantage (Janssens *et al*., 2013). However, some new varieties can also do well in areas with altitudes below 1500 meters above sea level (National Potato Council of Kenya, 2017). There are five major potato growing zones in Kenya based on varieties grown, geographic location, and cultivation practices (Kaguongo *et al*., 2008). They include; Mt. Kenya region (Meru, Nyeri), Aberdares and Eastern Rift Valley region (Nyandarua, Kiambu and Nakuru counties), Mau region comprising Narok and Bomet counties, Mt. Elgon region (Elgeyo-Marakwet and Uasin-Gishu county) and other highlands such as Taita-Taveta in the South Eastern Kenya (Kaguongo *et al*., 2008; National Potato Council of Kenya, 2017). **Figure 2.1** shows the major potato producing counties in Kenya.

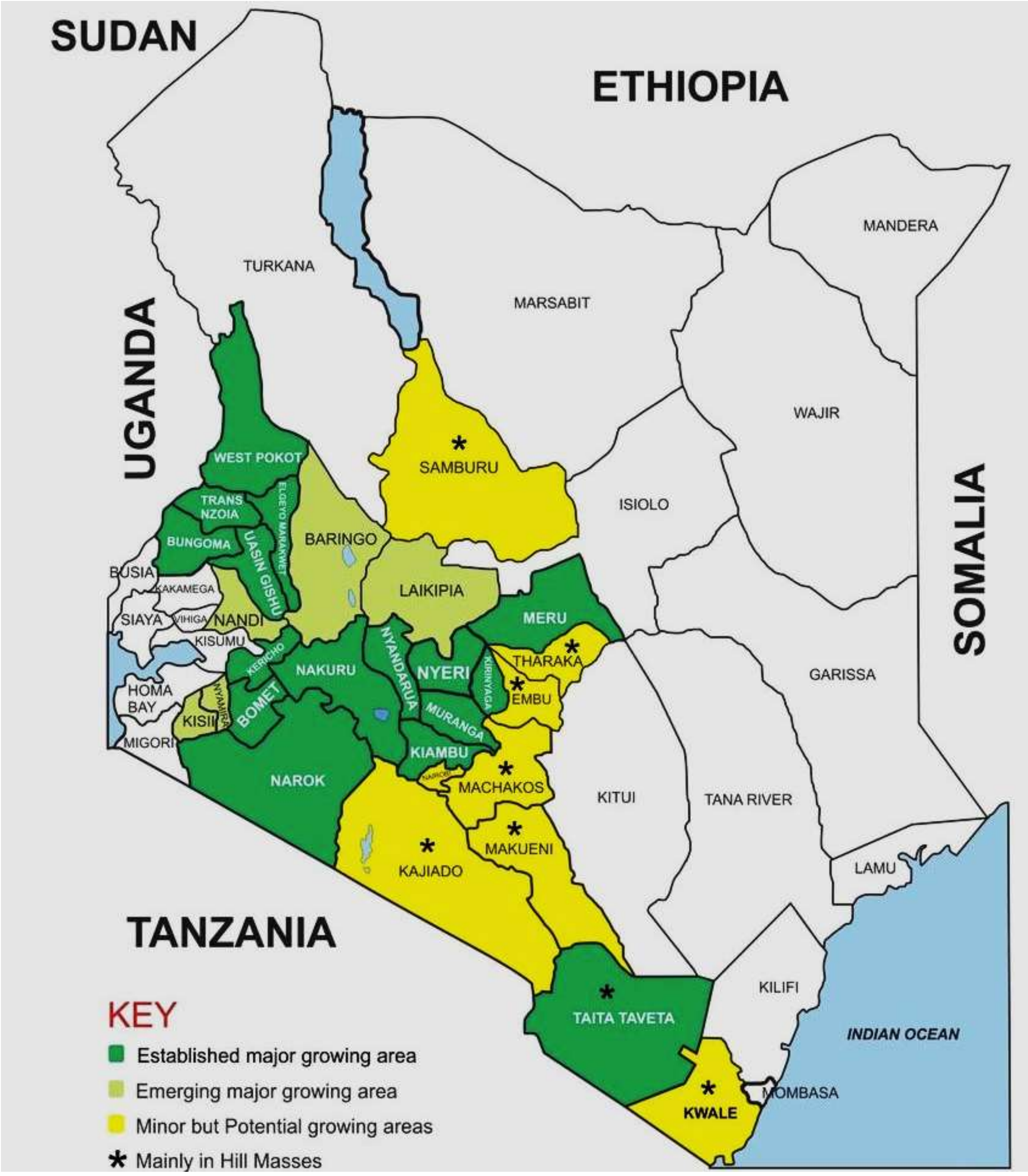

Figure 2.1: Major potato-producing counties in Kenya (Ministry of Agriculture, 2016).

2.3 Varieties of potatoes grown in Kenya

Currently, there exist more than fifty improved and local potato varieties in Kenya (National Potato Council of Kenya, 2017). Different varieties are popular for specific uses, as they vary in attributes such as shape, color, size, and rate of maturity. Some of the main varieties grown and consumed in Kenya include; Shangi, Tigoni, Dutch Robjin, Kenya mpya, and Asante (Kaguongo *et al*., 2014).

Shangi is the most cultivated potato variety in Kenya with an estimated area under cultivation of more than 80% (CIP, 2016). The variety constitutes 42% of all varieties traded in Kenya (Janssens *et al*., 2013). It is mainly used for French fries and homemade dishes (NPCK, 2017). The tuber cooks fast, thereby saving on energy, costs, and time (Kaguongo *et al*., 2014). Other benefits of Shangi include early maturity (≤ 3months) and high productivity (Abong *et al*., 2015). Shangi does well in Nyandarua, Kiambu, Meru, Laikipia, Nyeri, Uasin-Gishu, Taita-Taveta, Bomet, Narok, and Kisii counties (NPCK, 2017).

Dutch Robjin is the most preferred variety for crisp processing in Kenya (Infonet Biovision, 2019; Kaguongo *et al.*, 2014). Its adoption and area under cultivation are increasing steadily owing to its good attributes including long tuber dormancy, moderate resistance to drought, and medium maturity (Abong *et al*., 2015; NPCK, 2017). The variety grows at a high altitude of between 1800-2600m above sea level, and the best growing area is Bomet county. Others counties include Nyandarua, Nyeri, Meru,Trans-Nzoia and Nakuru (NPCK, 2017).

Tigoni variety is popular for both table use (mashing, roasting, boiling, baking and stewing) and industrial processing especially of frozen chips (Abong *et al*., 2015; Gachango *et al*., 2008). However, Tigoni variety rapidly turns green after harvest, has poor storability under ambient conditions and is highly susceptible to late blight disease (Abong *et al*., 2009).

Unica is a relatively new variety, having been released in 2016. The variety is rapidly gaining popularity due to its positive attributes which include a yield potential of more than 45 tonnes/hectare and early maturity (2.5-3.5 months) (Sinelle, 2018). Unica is also resistant to viral and fungal diseases and is versatile in use (NPCK, 2017). The tubers are used for table use, crisp and French fry processing and are rich in iron, zinc and vitamin C (NPCK, 2017). **Figure 2.2** shows some of the main varieties cultivated and consumed in Kenya.

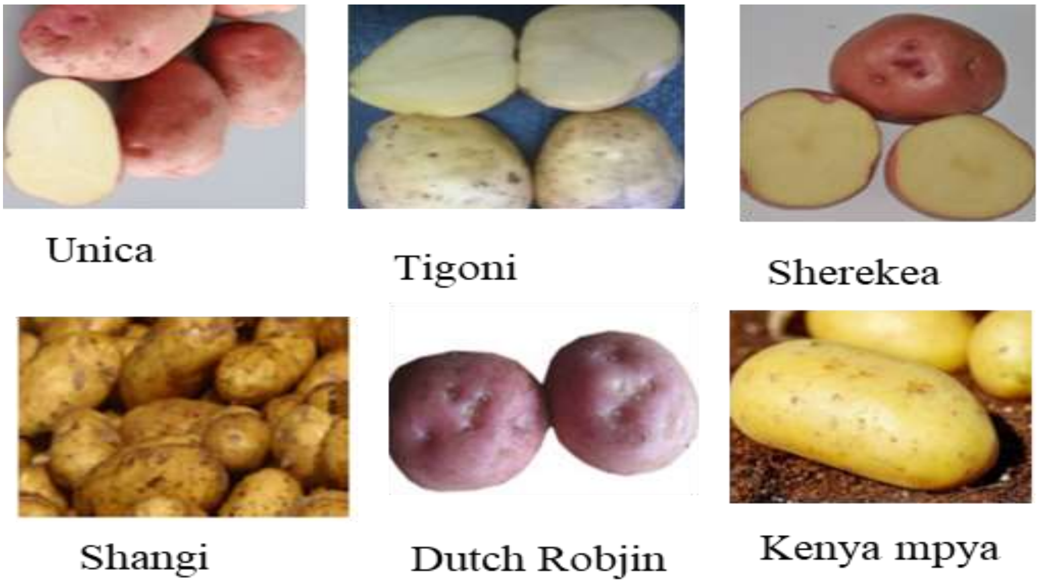

Figure 2.2: Some common potato varieties in Kenya (National Potato Council of Kenya, 2017)

2.4 Physical characteristics of potato tubers

The physical characteristics of potatoes are one of the major factors to consider during grading, handling, processing, and packaging (Abedi *et al*., 2019; Tabatabaeefar, 2002). Parameters such as eye-depth, average weight, shape, size, specific gravity, greening, and sprouting determine the suitability of tubers for processing of different potato products (Rahman *et al*., 2017; Subía, 2013). Furthermore, physical appearance substantially influences consumers' or processors' purchasing decisions (Tsegaye, 2019). These traits differ across varieties and a single variety cannot be relied on to meet the demands of the expanding fast food market (Abong *et al*., 2010). In Kenya, during the preparation of potatoes for cooking and processing, tubers are usually peeled, and losses as much as 20% may occur depending on age, eye-depth, shape, and extent of skin removal of the tubers (Ooko, 2008). Physical characteristics are therefore critical when choosing varieties for cultivating and processing.

2.4.1 Weight

Weight is one of the key components that estimate the yield of potatoes after harvest. It is also one of the most important tuber traits because potatoes are usually sold based on weight. Marketable tuber yield is determined by total tuber weight (Aliche *et al*., 2019). Additionally, weight is sometimes used to grade potatoes. For instance, according to Gericke, (2018), potato tubers in South Africa are graded as small (50-100g), large – medium (150-250g) and large (>250g). Tuber weight has been reported to differ significantly with variety (Rahman *et al*., 2017).

2.4.2 Shape and size

Tuber shapes and sizes are important characteristics to consider during the selection of potatoes for processing. Shapes of tubers can be described as round, oblong, elongated, and oval long (Lindqvist-Kreuze *et al*., 2015). Tuber shape is a vital property as it determines trimming and peeling efficiency during the preparation and processing of potatoes. Tubers that are round in shape are preferred for processing crisps as they have been found to easily yield the desired crisp diameters (Abong *et al*., 2010).

Tuber size and shape are important parameters as they are used to sort potato tubers after harvest into various grades depending on use (Tabatabaeefar, 2002). Knowledge of size parameters such as length and width are also valuable in designing sorting equipment, predicting the surface required during the application of chemicals such as sprout inhibitors, and calculating the sphericity or shape factor of tubers (Abedi *et al*., 2019).

Tuber size also affects peeling and recovery, with small tubers exhibiting higher losses than large ones (Araújo *et al*., 2016; Ooko, 2008). Large and long tubers of more than or equal to 50 mm are suitable for French fry processing. They result in low peeling losses and higher yields of French fries which is beneficial to fast-food restaurants (Araújo *et al*., 2016). However, extremely large tubers are undesirable for crisp processing because tuber size affects crisp size and subsequently, post-processing handling and packaging. Tubers larger than 60mm have been observed to yield fragile crisps that break easily during packaging and distribution (Abong *et al*., 2010).

Tuber shape and size are significantly subject to varietal differences (Alamar *et al*., 2017; Ooko, 2008). In a study of ten different varieties of potatoes produced in the Czech Republic, Bubeníčková *et al*. (2011) found that the main dimensions (length, width, and thickness) varied for individual potato varieties. Similarly, variation in diameters between 41.7-93mm was observed of four Iranian potato varieties (Tabatabaeefar, 2002).

2.4.3 Flesh and skin color

Appearance in terms of color is a very important attribute in influencing consumers' first impression of agricultural produce. Flesh and skin color are a result of anthocyanins and carotenoids which are responsible for pink and yellow/white colors respectively (Ooko, 2008). Flesh and skin colors differ according to variety ranging from white cream to purple (de Oliveira *et al*., 2020; Subía, 2013). They are important attributes as they affect the color of finished products. For instance, tubers with a pale yellow or cream white color have been observed to yield slight golden-colored products that are desirable in fries and crisps (Ooko, 2008). Similarly, a study conducted by de Oliveira *et al*. (2020) indicated that participants preferred yellow-colored potato varieties because they yielded attractive products with a stronger tonality after cooking. Colored potatoes may serve as a potential source of anthocyanin and carotenoid pigments as well as antioxidants (Jansen and Flamme, 2006). Purple and red-fleshed potatoes could be used as sources of natural colorants and antioxidants with added value for the food industry (Subía, 2013).

2.4.4 Eye-depth

Eye-depth is a key attribute of tuber quality. Deep eyes affect the appearance of tubers and increase peeling losses and processing costs (Subía, 2013). Shallow to medium eye-depth is appropriate for processing as losses during peeling and trimming are minimal, hence good product yields (Abong' and Kabira, 2011). Differences in eye-depth have been demonstrated to exist among potato varieties, hence varieties with shallow eyes are recommended during processing (Subía, 2013). In a study of 14 Ecuadorian varieties, seven varieties were reported to have shallow eyes, five had medium eyes while two varieties had deep eyes (Subía, 2013).

2.5. Specific gravity

Tuber-specific gravity is one of the most significant tuber traits extensively used to determine the suitability of potatoes for the processing industry. It is considered the quickest practical index to estimate the mealiness and total solids and dry matter quality of potatoes as it is highly correlated with the dry matter content (Wayumba *et al*., 2019). High specific gravity is desired in tubers for processing dehydrated and fried products as it influences chip crispiness and oil uptake during processing, thereby affecting the product yield (Mohammed, 2016). High specific gravity also enhances product flavor and low energy consumption during processing. Potatoes with low specific gravity on the other hand have been found to be suitable for canning because they are unlikely to disintegrate during processing (Gamea *et al*., 2009; Ndungutse *et al*., 2019). Varietal differences have been observed in the specific gravity of potato tubers (Lara and Malaver, 2019; Mohammed, 2016; Rahman *et al*., 2017; Sharkar *et al*., 2019).

2.4 Nutrient composition and health benefits of potatoes

Potatoes are sometimes referred to as a "hidden treasure" because they play a significant role in human health and nutrition over a lifetime of consumption (Zhang *et al*., 2017). Potatoes are often negatively perceived, with many consumers associating them with health conditions such as obesity and diabetes (Gibson and Kurilich, 2013; Niekerk, 2015). The reality, however, is that potatoes have relatively low energy density and can contribute substantial amounts of protein, dietary fiber, and micronutrients (Abong *et al*., 2009b; FAO, 2008a; Gibson and Kurilich, 2013). Fresh potato tubers are composed of 80% water and 20% dry matter, although these values vary depending on variety (FAO, 2008a).

It has been observed in past studies that the nutrient composition of potatoes, though readily influenced by growing conditions, is to a greater degree subject to varietal differences (Leonel *et al*., 2017; Mareček *et al*., 2016; Salaman, 2014). Compositional differences in potatoes are critical as they influence the cooking and processing quality of potato products (Arvanitoyannis *et al*., 2008). For instance, variety is one of the major factors that influence the level of simple sugars which subsequently determine the quality of fried potato products (Brunton *et al*., 2007). Varieties with high sugar contents and free amino acids are more likely to lead to formation of dark colored, commercially unacceptable products (Plata-Guerrero *et al*., 2009).

2.5.1 Macronutrients

2.5.1.1 Carbohydrate

Carbohydrates constitute almost 80% of the dry matter in potatoes (Navarre *et al*., 2009). Starch is the predominant carbohydrate in potatoes and acts as the plant's energy store (Camire *et al*., 2009; Mareček *et al*., 2013). Starch content in fresh potato tubers normally ranges between 10% to 25% some of which is resistant starch (not rapidly digested compared to normal starch) (Mareček *et al*., 2013; Simkova *et al*., 2013). Resistant starch is believed to confer health benefits such as increased satiety and glycemic control (Liang *et al*., 2019). Starch has a semi-crystalline structure composed of amylose and amylopectin on an average ratio of approximately 1:3 (Donnelly and Kubow, 2011). Amylopectin accounts for the starch crystallinity and is highly branched while amylose forms the amorphous component and is structurally linear (Ngobese *et al*., 2017). Amylose is digested slowly compared to amylopectin, resulting in a lower glycemic index. Therefore, varieties with a high amylose content are more preferred by diet-conscious consumers (Fajardo *et al*.,2013). Examples of such varieties include Range Russet and white pearl which are grown in the United Stated (Jansky and Fajardo, 2016)

2.5.1.2 Protein

Proteins form the second major component of dry matter in potato tubers (Leonel *et al*., 2017). Potato is said to be the second-largest supplier of protein per unit area cultivated (Campos and Ortiz, 2020; Casper, 2007). On a dry weight basis, potato has a considerable amount of protein that surpasses that of other root and tuber crops (Ekin, 2011). Additionally, potato protein is of a relatively high quality due to its amino-acid composition pattern that well matches the requirements of the human body (Ekin, 2011). Potato protein contains a high proportion of essential amino acids especially lysine which is deficient in cereals. It is however limited in sulfur-containing amino acids, bringing about mutual complementation when incorporated in a cereal diet (Ooko, 2008). Furthermore, compared to wheat, rice, and pulses like peas, potato protein has an outstanding biological value (the proportion retained for growth and/ or maintenance divided by the amount absorbed) of approximately 70% but varies across varieties (Camire *et al*., 2009; Campos and Ortiz, 2020; Lisieska *et al*., 2009; Ooko, 2008).

Differences in protein content exist across varieties as observed by various researchers. Variations in protein content were reported by Ngobese *et al*. (2017) among eight South African potato varieties with a range of 1.57% to 2.87% protein content (fresh weight basis). Similarly, Leonel *et al*. (2017) reported variations in protein content among five Brazilian potato varieties which ranged between 1.45 and 2.35% (fresh weight basis). **Table 2.2** shows the nutritional composition of different potato varieties grown in different regions.

Table Error! No text of specified style in document.**.2: Macronutrient composition of different potato varieties in g/100g**

Variety	Carbohydrate	Protein	Crude fat	Crude fibre	Ash	Reference
Tigoni (FWB)	19.28	1.91	0.09	1.22	0.95	Ooko, (2008)
Desiree (FWB)	17.33	1.92	0.13	1.11	1.07	
Kenya Karibu (FWB)	16.85	2.08	0.09	1.06	1.09	
UTD (FWB)	16.6	0.88	0.03	ND	ND	Niekerk, (2015)
Fianna (FWB)	21.8	1.75	<0.0001	ND	ND	
Favorita (FWB)	ND	1.55	0.03	0.27	0.74	Liang *et al*., (2019)
Neida 34 (FWB)	ND	2.71	0.06	0.37	1.12	
Agata (DWB)	ND	1.59	0.28	0.66	0.87	Leonel *et al*., (2017)
Atlantic (DWB)	ND	2.28	1.04	0.71	1.09	

ND: Not determined, FWB: Fresh weight basis, DWB: Dry weight basis

2.5.1.3 Fibre

The fibre content in potatoes is relatively low compared to other common vegetables (Leonel *et al*., 2017). In various studies, fibre content in potatoes has been found to differ considerably according to variety, with some cultivars having high and others very low levels of fibre **(Table 2.2**). Variations ranging between 0.43-0.80% of fiber content on a fresh basis were observed among five Brazilian varieties (Leonel *et al*., 2017). Similarly, a study on eight Kenyan varieties showed variations in fibre content between 1.79 % and 2.48% (Abong *et al*., 2009b). Fibre in potatoes is composed of mainly resistant starch and polysaccharides such as cellulose, hemicellulose and pectin in smaller quantities (Robertson *et al*., 2018). An average-sized raw potato tuber contains approximately 10g/100g resistant starch (fresh weight). However, upon cooking potato starch is gelatinized and becomes more digestible. The extent of digestibility is influenced by the method of cooking and water, with baked potatoes having the highest residual resistant starch and boiled potatoes the least (Robertson *et al*., 2018). According to Bonierbale *et al*. (2010), cooling of the cooked potatoes reverses the process of gelatinization, resulting in resistant starch. This happens through a process called starch retrogradation, whereby molecules of gelatinized starch reassociate into an ordered crystalline structure (Maurer, 2009). Resistant starch is desirable in the human diet as it confers health benefits such as prevention and control of digestive and metabolic conditions like diabetes (Nofrarías *et al*., 2009).

2.5.1.4 Fat

Potatoes are low in fat content (less than 2%) and are therefore a low-caloric product (Lisieska *et al*., 2009). This quantity of fat in potatoes is too low to have a significant nutritional impact, but has been reported to play a substantial role in potato palatability, promoting tuber cellular integrity and resistance to bruising and contributes to reducing enzymatic browning of tuber flesh (Ooko, 2008). Differences in fat content among varieties have been observed in previous studies (**Table 2.2)**. Leonel *et al*., (2017) found variations ranging from 0.25-1.04% in five potato varieties cultivated under similar conditions in Brazil. Similarly, Ooko, (2008) found slight variations of between 0.38% 0.53% (dry weight basis) in crude fat content among five Kenyan varieties.

2.5.2 Micronutrients

Potato contains considerable amounts of vitamins and minerals. Vitamins C and B complex are the major vitamins contained in potatoes (FAO, 2008b). One medium sized potato of 150g can provide almost half the daily adult requirement of vitamin C, but the vitamin is susceptible to degradation during processing and cooking (Ooko, 2008; Shinde *et al.*, 2018).

Potato also compares well to other vegetables in terms of vitamin B. The B vitamins present in potatoes include folic acid, niacin, pyridoxine, riboflavin and thiamine (Camire *et al*., 2009; Campos and Ortiz, 2020). Potatoes are particularly considered to be a good source of pyridoxine (vitamin B_6), with concentrations ranging between 0.45 to 0.68 mg/100g (fresh weight basis) (Mooney *et al*., 2013). The concentration of vitamin B_6 in cooked tubers (0.299mg/100g FW) has been reported to be higher than that of other staple crops such as maize (0.139mg/100g), rice (0.05mg/100g FW), cassava (0.051mg/100g FW) and wheat (0.034mg/100g FW) (Fudge *et al*., 2017). A 100g of cooked potato can deliver 17-23% of the recommended daily allowance of vitamin B_6 (1.3-1.7mg/day) for an adult (Burgos *et al*.,2020). Like vitamin C, vitamin B_6 is also influenced by factors such as light exposure and heat but is relatively stable during storage (Campos and Ortiz, 2020).

Potato is a moderate source of minerals including iron, potassium, phosphorous, magnesium, zinc and calcium, which form part of the ash content (Camire *et al*., 2009). Ash content in potatoes is approximately 3.5% on dry weight basis, and constitutes minerals essential to various body functions (Abong *et al*., 2009b). Moreover, potato minerals have potentially higher bioavailability relative to other plant sources (Beals, 2018; Camire *et al*., 2009). This is due to low concentrations of compounds such as phytates and oxalates that would limit mineral absorption (Ekin, 2011).

Large variations in mineral content of raw tubers and their processed forms have been observed across varieties according to various studies. Abong *et al*.(2009b), found significant variations in mineral content among eight Kenyan potato varieties. Iron and zinc contents ranged between 2.65-4.54 mg/100g and 1.77-2.90 mg/100g (Dry weight basis) respectively. Another study on five Brazilian varieties revealed variations in phosphorous contents, with the lowest-containing variety having 22.77g/100g and the highest one having 30.95mg/100g on fresh weight basis (Leonel *et al*., 2017). Managa, (2015) observed that iron and zinc varied significantly among 20 South African cultivars, with the average concentrations ranging between 12.88-66.1 mg/kg for zinc and 34.67-76.67mg/kg for iron. **Table 2.3** below shows some of the mineral contents of different potato varieties from different parts of the world.

Table Error! No text of specified style in document.**.3: Mineral contents (mg/100g) of various potato varieties from different parts of the world**

Variety	Iron	Zinc	Calcium	Phosphorous	Potassium	References
Tigoni (DWB)	3.57	1.77	43	142	100	(Ooko, 2008)
Desiree (DWB)	4.54	1.78	62	151	779	
Kenya Karibu (DWB)	4.31	2.76	92	200	1802	
Neida26 (DWB)	2.40	2.25	71.24	ND	2821.8	Liang *et al*., 2019)
Neida 29 (DWB)	3.10	2.88	42.19	ND	2474.1	
Caspar (DWB)	6.72	1.43	123	223	ND	(Ekin, 2011)
Melody	9.72	1.47	94	231	ND	
Electra (FWB)	2.91	0.29	10.2	47.7	348	Ngobese *et al*., 2017)
Fianna (FWB)	2.79	0.48	7.5	56.9	472	
UTD (FWB)	0.62	0.32	3.76	44.1	401	(Niekerk, 2015)
Fianna	0.87	0.47	5.57	65.6	527	
A-624	5.92	2.08	72	340	3000	(Tekalign and Hammes, 2005)
CIP-388453-3(A)	5.47	1.38	60	260	2250	

DWB: Dry weight basis, FWB: Fresh weight basis, ND: Not determined

2.5.3 Reducing sugars and Amino acids

Potato tubers contain simple sugars with sucrose being the main disaccharide while fructose and glucose are the major monosaccharides (Bonierbale *et al*., 2010). Very high content of reducing sugars in potato tubers causes browning in fried and baked potato products such as crisps, in a process called Maillard reaction (Galani *et al*., 2016; Wayumba *et al*., 2019). The Maillard process involves a reaction between reducing sugars and free amino acids at elevated temperatures (Ogolla *et al*., 2015). This reaction can lead to formation of dark bitter products and acrylamide, a potential carcinogen (Brunton *et al*., 2007). Reducing sugar content and free amino acids in potato tubers are therefore used in the processing industry to determine suitability of potatoes for processing of popular snacks such as French fries and crisps (Granda *et al*., 2005)

According to Mareček *et al*. (2013), simple sugars in potato tubers usually range between 0.5 to 2.0 % in content. In order to produce quality chips and French fries, the recommended content of reducing sugars in tubers should be below 0.5% of fresh tuber weight (Mehta *et al*., 2014). Factors that affect the sugar level in potato tubers include genotype, growing conditions, environmental factors, physiological maturity and storage conditions (Duarte-Delgado *et al*., 2016; Halford *et al*., 2012). Genetic variations have been demonstrated to have the most influence on reducing sugar content, and increase in sugar levels during storage has also been observed to be cultivar dependent (Abong *et al*., 2009a). Ooko, (2008), observed different levels of reducing sugar contents among Kenyan potato varieties with the highest having 0.37% and the lowest with 0.15% reducing sugars. Similarly, significant differences in reducing sugar content between 0.2% and 3.16% were observed by Yang *et al*., (2016), in eight potato varieties cultivated in Spain.

Potato also contains a diverse group of amino acids that constitute its protein content (Marwaha *et al*., 2005). Asparagine and glutamine are the most abundant amino acids in potato tubers (Brunton *et al*., 2007; Gökmen *et al*., 2007). The levels of reducing sugars and free amino acids (particularly asparagine and glutamine) in potatoes are of prime concern as they directly influence the color and taste of processed potato products (Abong *et al*., 2009a; Brunton *et al*., 2007; Mehta *et al*., 2014). Potato varieties containing high levels of these amino acids have been implicated in production of commercially unacceptable dark colored chips due to the Maillard reaction (Abong *et al*., 2010; Marwaha *et al*., 2005). The level of free amino acids, like reducing sugars in potatoes has been found to be subject to varietal differences and storage conditions (Gökmen *et al*., 2007; Marwaha *et al*., 2005). Variations between 251.8 mg/100g-443.8 mg/100g in asparagine content were observed across fourteen Swiss potato varieties while glutamine content ranged between 79.9-158.8mg/100g (Amrein *et al*., 2004). In another study, asparagine levels in seven potato cultivars were observed to vary between 1070 and 3240 mg/100g (dry weight) at harvest, and between 390-7710 mg/100g (dry weight) after storing the same cultivars at 2°C for three months (Silva and Simon, 2005). Zhu *et al*., (2010) also studied the amino acid composition of sixteen potato varieties and observed a range of 34.5 g/kg -8.9 g/kg (dry weight) in asparagine content and 45.8-10.6 g/kg in glutamine content. Variations in the levels of asparagine and glutamine in different potato varieties allows for the possibility of selecting low asparagine and glutamine varieties for processing purposes (Silva and Simon, 2005).

2.6 Utilization of potatoes

2.6.1 Domestic uses

Potatoes have a wide range of uses, one of them being as a vegetable for home-prepared dishes (International Potato Center, 2019). According to the International Potato Center, however, it is likely that less than 50% of potatoes cultivated across the world are consumed fresh. Most of the potatoes are processed into other food products, non-food products, animal feed or re-used as seeds for the next growing season. Fresh potatoes are traditionally used for food after cooking using different methods which include baking, boiling, mashing, stewing, roasting, potato salads and potato pancakes among others (CIP, 2019; Tesfaye *et al*., 2010). As foodstuff, fresh potatoes are versatile in that they can be served as the staple dish, as a vegetable accompaniment to the main dish or as one of several ingredients in a mixed dish (Daniels-lake, 2013). In Kenya for instance, potatoes are often eaten with beans in many rural households during the “hunger period” just before maize is harvested. Potatoes are also included as a vegetable in the basic Kenyan diet of maize and beans to add flavor and variety (Muthoni and Nyamongo, 2009).

2.6.2 Industrial applications

Global consumption of potatoes is shifting from fresh to value-added, processed products. Following the rapid population growth, increasing urbanization and changing lifestyles, there has been an increasing trend in potato processing in terms of quantity and range of products (MoA, 2016). Processing of potatoes adds value to the produce, increases their shelf life, convenience, reduces post-harvest losses and wastage and produces a wide range of products for different applications (MOA, 2016). Processing practices include peeling, slicing, chips and crisp making, powder production and starch production among others (MoA, 2016).

2.6.2.1 Food products

The major processed potato products in the world are potato chips (crisps), French fries and frozen fries (Bradshaw and Ramsay, 2009). Potato chips are thin potato slices (1-1.5mm) that have been deep-fried at approximately 180°C till dry and brittle, with a low moisture content to enhance the crispiness and stability of the product. French fries on the other hand are cut into thin strips, washed and partly dried to remove surface moisture then deep-fried around 180°C to a light golden colour (Bradshaw and Ramsay, 2009).

Other products include dehydrated potato flakes, chilled peeled potatoes and canned potatoes among others. Dehydrated potato flakes are used as ingredients in snacks, in retail mashed potato and even as food aid. Another dehydrated product; potato flour is used in the food industry for binding meat mixtures and as a thickening agent for soups and gravies (International Potato Center, 2019). Recently in Kenya, local and international fast-food eateries have been expanding their branch networks, with French fries being the most common product sold (Kaguongo *et al*., 2014). Other popular potato products in restaurants include potato stew and *mukimo* (a mashed vegetable dish) also known as *kienyeji* (Kaguongo *et al*., 2014). Potatoes can also be used to produce alcohol for human consumption (Daniels-lake, 2013). Some popular potato products are shown in **Figure 2.3.**

Figure 2.3: Common processed potato products in Kenya (AES-Foods, 2020; African Food Recipes, 2017)

2.6.2.2 Potato starch

Approximately 65-75% of potato dry matter is composed of starch which can be readily extracted in water (Bradshaw and Ramsay, 2009). Potato starch has a wide range of functional properties including encapsulation properties, gelling, thickening, coating and adhesion properties (Bradshaw and Ramsay, 2009). Potato starch is fine, has an excellent mouthfeel and has a bland taste making it preferable in a broad range of food applications. Furthermore, potato starch has higher viscosity than cereal-based starches and has a better advantage when used in instant soups and sauces. Potato starch properties are attributed to its unique structure which is composed of linear amylose (20-30%) and highly branched amylopectin (comprising the remaining fraction), and their organization within the polymer (Fajardo *et al*, 2013). After extraction, potato starch can be physically or chemically modified to suit different functions. The starch is used in a wide array of products including starch based edible films, as an ingredient to thicken, stabilize and improve the mouthfeel of canned foods such as pie- fillings, sauces and soups. Potato starch with freeze-thaw stability and resistance to retrogradation are applied in frozen foods (Neeraj 2020).

2.7 Pre-harvest and post-harvest factors affecting potato tuber quality

The quality of potatoes is established in the farm and can only be maintained during and after harvest (Alamar *et al*., 2017). Important external tuber quality traits include tuber size, and shape, color and resistance to mechanical stress during and after harvest. Internal tuber quality traits include dry matter and starch content, sugar content and tuber flesh color (Naumann *et al*., 2020). These characteristics are closely interrelated and genetically influenced. Some of the pre-harvest and post-harvest factors affecting the quality of potatoes are related to the environment, the plant, and to cultural practices adopted during cultivation. The main pre-harvest factors that influence potato tuber quality include fertilizer applied, tuber maturity at harvest, variety type and growing environment. Post-harvest factors include curing, storage conditions and processing methods (Chemeda *et al*., 2014).

2.7.1 Pre-harvest factors

2.7.1.1 Maturity

Potato tuber maturity influences not only the storability of potatoes but also their processing quality (Sabba *et al*., 2007). A study by Driskill *et al*. (2007) showed that maturity influenced the retention of processing quality of potato tubers during storage. Mature potatoes have better storability compared to immature potatoes, as they are less vulnerable to skinning injury, have lower respiration rates and weight loss and are less susceptible to diseases (Heltoft *et al*., 2017). Maturity of potatoes can be defined by chronological age (true age in terms of months), haulm or potato vine maturity, physiological maturity, physical maturity and chemical maturity (Bussan *et al*., 2009; Pinhero and Yada, 2016). Vine maturity involves a decrease in photosynthesis and movement of carbohydrates to the tuber, reducing the bulking rate and allowing tuber maturation to occur (Bussan *et al*., 2009). Physical maturation involves the formation of a mature and fully set periderm while physiological maturity is achieved when the maximum dry matter content is reached (Fernandes *et al*., 2015; Heltoft *et al*., 2017).

Chemical maturity is the most commonly used indicator in models for predicting potato quality. It involves the sugar concentration of the potatoes whereby sucrose maximum in young tubers and reduced when the above-ground plant enters senescence. Chemical maturity determines the levels of sucrose and dry matter, parameters that significantly influence the quality of potato products. When tubers are chemically mature, sucrose concentrations reach minimum levels while dry matter and starch contents reach maximum levels (Sabba *et al*., 2007). The recommended maximum sucrose concentration in tubers at harvest is 2.8mg/g fresh weight (Heltoft *et al*., 2017).

2.7.1.2 Variety

The quality of plant material or seed is a critical factor that determines the quality of the crop because most characteristics are controlled genetically. The response to water and nutrients by potatoes is dependent of the cultivar grown among other factors (Alva *et al*., 2012). Potato tuber quality has been reported to differ between and within varieties, making variety the most critical factor with respect to matching tuber quality with the intended market (Chemeda *et al*., 2014). Abbas *et al*. (2012) elucidated the dry matter content of potatoes is a strongly genetically governed attribute that differs significantly among varieties. Similarly, a study in Ethiopia shows that tuber dry matter and starch content is influenced by environment and potato genotypes (Habtamu *et al*., 2016). Tessema *et al*. (2020) reported significant variability in among potato varieties in terms of potato tuber attributes.

2.7.1.3 Cultural practices

All cultural practices directly affect the final quality of the produce. Sustainable agricultural practices such as irrigation and balanced fertilization improve not only the tuber yield but also potato marketing quality such as tuber size (Alamar *et al*., 2017). According to Naumann *et al*. (2020), internal and external tuber quality traits are linked to the nutrient status of the plant. Water and nitrogen are important inputs affecting the yield and quality of potatoes. Insufficient water during growth results in loss of grade, internal quality, yield, and inadequate utilization of other production inputs (Alva *et al*., 2012). With respect to nutrients, potato tuber quality requires both organic matter and nitrogen availability (Nesbitt and Adl, 2014). Nitrogen, Phosphorous and potassium are the most commonly used nutrients in potato cultivation (Koch *et al*., 2019). Increasing the supply of nitrogen can increase the proportion of large-sized tubers, a desirable attribute in tubers meant for processing (Zebarth and Rosen, 2007). However, high nitrogen supply might have a decreasing effect on potato starch content (Koch *et al*., 2019). According to Hopkins *et al*. (2014), adequate soil phosphorous is vital for early potato plant development, tuber set and yield and enhancement of tuber maturity. Phosphorous has also been reported to influence tuber size, with high phosphorous fertilization rates being implicated in decreasing the yield of large sized tubers (Koch *et al*., 2019). Fertilization of potatoes with potassium chloride (KCl) has a positive effect on the crude protein content of the tubers (Manolov *et al*., 2016). Other practices such as vine desiccation also significantly impact tuber quality as it induces both maturation of the tuber periderm and stolon release and can also influence tuber size in seed potato (Alamar *et al*., 2017).

2.7.2 Post-harvest factors

2.7.2.1 Curing

Curing entails the process of wound healing, suberization or lignification and development of new tissue beneath the surface of injured parts of a crop. Injury to tubers during and after harvest may occur through during mechanical harvest, lifting, transportation, and even grading despite all of the precautions taken (Pinhero and Yada, 2016). Weight loss and entry of microorganisms can occur through the injured skin, causing diseases and rot during storage. Curing minimizes water loss from tubers, increases resistance to decay and extends the storage life of potato tubers (Holcroft, 2018). There are various methods of curing which differ in cost of implementation and their efficacy. They include; pre-harvest in-ground curing, shed or barn curing, heap curing and evaporatively cooled structures. According to Pinhero and Yada, (2016), potato curing should be done at a temperature of 12-16°C and relative humidity ranging between 90 and 95% for two weeks. On the other hand, Tashome *et al*. (2021) recommends curing in a dark environment at a temperature range of 15-25°C for 4-15 days.

2.7.2.2 Storage conditions

After harvest, tuber quality management seeks to delay dormancy break and minimize weight loss and potato sweetening (Alamar *et al*., 2017). Senescent sweetening is an irreversible natural process that takes place due to tuber aging, and it leads to cellular breakdown. The cellular breakdown leads to depolymerization of structural and non-structural carbohydrates by hydrolytic enzymes. To slow this process, appropriate storage conditions are crucial (Alamar *et al.*, 2017). Storage conditions such as temperature, relative humidity and light significantly influence internal and external tuber characteristics.

Storage can lead to extensive changes in the chemical composition of potato tubers thereby affecting quality characteristics of the final products (Chemeda *et al*., 2014). For instance, storage of potatoes at high temperatures such as 10-20°C has been reported to increase starch content in tubers due to biosynthesis from reducing sugars (Chemeda *et al*., 2014). On the other hand, although cold storage is effective in inhibiting sprouting, it leads to quality loss due to cold-induced sweetening when sucrose is hydrolyzed to reducing sugars (Driskill *et al*., 2007). This is an undesirable trait in potatoes meant for processing as it negatively affects the end products of processing (Kumar, 2011). Temperature management during storage is therefore dependent on the intended end-use of the potato tubers. Suppressing sprout growth using gases such as ethylene has been reported to induce sucrose hydrolysis (ethylene-induced sweetening). Combining carbon dioxide and ethylene has also been found to negatively affect the color of fried potato products (Daniels-lake, 2013). Other storage conditions affecting tuber quality such as relative humidity, gas composition and light are discussed in **section 2.8**

2.8 Postharvest losses and management in potatoes

2.8.1 Post-harvest losses in potatoes

It is necessary to store potatoes for a considerable period after harvest to ensure constant supply to the market for direct human consumption, and for the processing industry (Azad *et al*., 2017). According to Benkeblia *et al*., (2008), 70% of the harvested potato crop in the world is stored for different periods depending on the demands of consumers and processors. Potato is mostly stored as fresh produce in a perishable form (Benkeblia *et al*., 2008).

Average post-harvest losses of potatoes globally are estimated to be 10-15% annually but can be as high as 30% in developing countries where efficient storage practices have not been fully adopted (Benkeblia *et al*., 2008). In Kenya, post-harvest loss of potatoes is estimated at 12.8% at the farm, 24.4% at the open market, 12% at the processing level, and 25% at the supermarkets (Kaguongo *et al*., 2014). On average, every season experiences approximately 19% loss of total production per hectare (Kaguongo *et al*., 2014). These losses are attributed to poor storage systems, poor packaging and lack of knowledge about factors that influence storability of potatoes (Nyankanga *et al*., 2018).

Most potato farmers in Kenya sell their produce after harvest, once they have identified buyers (Food and Agriculture Organization, 2013). This is mainly because most farmers lack resources and machinery for storage, forcing them to harvest only after they have identified buyers. Very few farmers practice on-farm storage of potatoes for future sale (FAO, 2013; Ooko, 2008). In establishments such as factories and restaurants, storage of potatoes is generally for short periods prior to processing (FAO, 2013). Most farmers store potato tubers under rustic conditions, including the use of sacks to store potatoes in their houses or multiple stores. Very few farmers exercise improved storage (FAO, 2013).

2.9 Factors influencing storability of potatoes

Temperature, relative humidity, gas composition, light and air circulation are factors that directly affect the quality and storage life of potato tubers (Eltawil *et al*., 2006). Temperature and humidity are the two main environmental factors involved when considering proper potato storage (Voss *et al*. 2015). Tuber dormancy, respiratory activity, sugar-starch relationship and disease spread are affected mainly by temperature (Muthoni *et al*., 2014). Sufficient ventilation and air circulation are also critical in maintaining uniform temperature and humidity among the potatoes (Voss *et al*., 2015).

2.9.1 Temperature

During storage of potatoes, optimal temperatures depend on the potato variety and intended end-use of the potatoes (Kibar, 2012). Too low or too high storage temperatures may reduce potato quality (Wustman and Struik, 2007). High storage temperature is accompanied by a rapid increase in the respiration rate of stored tubers while storing potatoes below 2°C leads to water loss, rotting and chilling injury of tubers (Wustman and Struik, 2007).

Although cold storage of potatoes has been found effective in inhibiting potato sprouting, many varieties accumulate simple sugars (sucrose, fructose and glucose) in a process called Cold Induced Sweetening (CIS). CIS is caused by the remobilization of starch polymers into sucrose following the inactivation of enzymes involved in glycolysis such as phosphofructokinase. The low storage temperature activates enzyme invertase which then hydrolyzes sucrose into fructose and glucose (Abbasi *et al*., 2016). While this is of negligible concern for tubers intended for seed or table use, it is highly problematic for processors of fried potato products.

The color and taste of processed potato products largely depends on the amount of simple sugars, primarily fructose and glucose, which is influenced by potato variety and tuber storage conditions (Wiberley-Bradford *et al*., 2014). During processes such as frying, the reducing sugars participate in a non-enzymatic Maillard reaction with free amino acids leading to production of bitter, dark brown-colored chips and fries. Such dark colored and bitter products are unacceptable to consumers and may also contain higher amounts of acrylamide, which has been declared a potential carcinogen (Galani *et al*., 2016).

Galani *et al*. (2016) found that storing potato tubers at 4°C resulted to a 31.6-fold increase in reducing sugars content. According to Mareček *et al*. (2013), potatoes stored at temperatures between 8-10°C did not accumulate reducing sugars. Similarly, a relatively low accumulation of reducing sugars was observed in potatoes stored at 7°C (98.33mg/100g after duration of storage) whereas the same tubers stored at 3°C resulted in a higher sugar concentration (134.07mg/100g) (Amjad *et al*., 2020). The tubers stored at 7°C had better chipping quality than those stored at 3°C. On the other hand, storing potatoes at higher temperatures of 10-12°C and 17-31°C in non-refrigerated heaps was observed to yield chips with acceptable color and crispiness (Mehta *et al*., 2014; Pinhero and Yada, 2016). However, while storing potato tubers at such high temperatures minimizes accumulation of simple sugars, it accelerates the rate of sprouting, weight loss, shriveling, disease proliferation and rotting of stored tubers (Daniels-lake, 2013; Wiberley-Bradford *et al*., 2014).

Temperature regimes for potato storage may differ significantly according to variety. Cold-induced sweetening is not only influenced by post-harvest storage conditions but tuber variety as well (Alamar *et al.,* 2017; Kibar, 2012; Mehta *et al.,* 2014). In a study on the effect of low-temperature storage (5°C) on 11 potato varieties cultivated in Slovakia for six months, a difference in the extent of reducing sugar accumulation, was observed. The highest accumulation was in variety Ramos which increased by 4.2-fold while variety Viola exhibited the least accumulation (1.4-fold) (Mareček *et al*., 2013). Similarly, Silva and Simon, (2005) found that two out of seven potato cultivars had very little reducing sugar content at harvest, but exhibited a substantial increase in the concentration of reducing sugars compared to the other cultivars which showed much less rise in sugar concentration during storage at 2°C. Temperature management therefore depends on potato variety and its intended use.

Generally, potatoes for processing are stored between 6-10°C to minimize accumulation of reducing sugars in the tubers while maintaining their physical quality, while those intended for fresh consumption can be stored between 4-10°C (Kibar, 2012). It is noteworthy that the reducing sugar content of tubers stored at low temperatures can be reduced by reconditioning (Mareček *et al*., 2013). Reconditioning entails storing the tubers at high temperatures prior to processing, to promote respiration leaving out only starch, thus reducing the content of simple sugars (Wayumba *et al*., 2019). A study by Marwaha *et al*. (2005) indicated that reconditioning potato tubers cold stored for 90 days at 20°C for three weeks lowered the reducing sugar content by 41%. According to Wayumba *et al*. (2019), tubers reconditioned at 22°C for twenty-one days following storage at 4°C yielded chips with acceptable color.

2.9.2 Relative humidity

Appropriate storage should minimize loss of moisture from potato tubers. Moisture loss during storage causes high susceptibility of tubers to mechanical damage, greater loss during peeling, unattractive appearance and reduced culinary quality (Pinhero and Yada, 2016). Maintaining high relative humidity is recommended for minimizing early storage tuber losses due to dehydration (Kibar, 2012). As reviewed by Gottschalk, (2011) and Wustman and Struik, (2007), relative humidity of at least 95% reduces water loss from potato tubers, thus minimizing total mass loss during storage.

In a study conducted for 42 days, tubers stored at a relative humidity between 30-35% were found to undergo higher weight loss compared to those stored at 60-65% and 90-95% (Singh and Ezekiel, 2003). However, some varieties exhibited higher weight loss at 60-65% and 90-95% beyond 35 days due to higher sprout growth (weight loss increases with sprout growth dure to elevated evaporative loss) (Singh and Ezekiel, 2003). Humidifiers such as high-pressure mist sprays and evaporators can be applied as a means for obtaining and maintaining a high relative humidity (Gottschalk, 2011).

2.9.3 Gas composition

Atmospheric gas composition is also believed to influence tuber dormancy and overall quality (Nyankanga *et al*., 2018). There has been a lot of interest in storing potatoes for fresh, processing and seed use, using controlled atmosphere. Controlled atmosphere (CA) entails continuous monitoring and adjustment of the carbon dioxide (CO_2) and oxygen (O_2) levels within storages or containers, and works better when coupled with temperature control (Kibar, 2012). The amount of CO_2 and O_2 in the storage atmosphere can influence sprouting, respiration rate, sugar content, rotting and processing quality of tubers (Kibar, 2012).

High CO_2 levels in storage can promote sprouting since elevated CO_2 increases the rate of photosynthesis. However, depending on the maturity of tubers and temperature in storage, high CO_2 concentrations can also inhibit sprouting (Daniels-lake, 2013). High amounts of CO_2 have also been reported to cause accumulation of reducing sugars and rotting of tubers as compared to storing in uncontrolled atmosphere (Thompson, 2010). Low oxygen levels during long-term potato storage has been observed to cause tuber decay (Kibar, 2012).

Storing tubers under 9.4% CO_2 with 3.6% O_2 at 5°C, for 25 weeks inhibited sprouting almost completely, and maintained healthy skin and low weight loss in all cultivars under storage (Gottschalk, 2011). On the other hand, tubers stored under CO_2 levels of 8-12% were observed to produce dark colored crisps (Thompson, 2010). Similar findings were reported by Daniels-lake, (2013) whereby 2-3% CO_2 had little effect on potato chip color, but a higher concentration of 13% resulted in increased levels of reducing sugars. Conflicting results have been reported by Mazza and Siemens, (1990) who found that tubers stored in as little as 0.5% CO_2 resulted in dark colored chips. On the other hand, Schouten, (1993) found that storage at 3, 6 and 9% CO_2 did not affect potato chip color of tubers suberized at 18°C. According to Daniels-lake, (2013) tubers exposed to 19% O_2 and 2% CO_2 resulted in darker chips and higher reducing sugar concentration than in the control tubers. Although there are conflicting results regarding the optimum CO_2 and O_2 levels for suitable potato storage, a maximum of 10% CO_2 and a minimum of 10% O_2 has been recommended (Thompson, 2010).

2.9.4 Light

Potato tubers turn green when exposed to light for long periods due to the accumulation of chlorophyll (Kibar, 2012). This process may lead to formation of compounds known as glycoalkaloids which could give the potatoes a bitter taste. Moreover, glycoalkaloids are potentially toxic if large amounts of green potatoes are consumed (Kibar, 2012). Grunenfelder, (2005) observed that the rate of chlorophyll development and greening in potato tubers increased rapidly with increasing light intensity. In the same study, there was a visible difference in color change between the varieties under study. Some potato varieties are more sensitive to light than others, thus varying in the rate of light-induced glycoalkaloid development (Bamberg et al., 2015).

As reviewed by Tanios *et al*. (2018), light intensities of 129, 560 and 969 lux(lx) were reported to cause chlorophyll concentrations of 73, 122 and 153 $\mu g/100cm^2$ respectively on tuber surfaces (Tanios *et al*., 2018). Olsen *et al*. (2017) investigated the impact of light source on greening of potato tubers, and found that chlorophyll concentration was lowest in tubers stored in the dark (69.8 mg/g fresh weight) compared to tubers exposed to other various light sources such as fluorescent (1005.2 mg/g) and fiber optic (994.8mg/g).

These reports indicate that manipulating light regimes across all stages of the supply chain could aid in mitigation of tuber greening. The process of greening in potatoes is irreversible, therefore prevention of the process is imperative in preserving the aesthetic quality and safety of potatoes. The most basic greening prevention recommended is minimizing light exposure, but optimal temperature and moisture during storage are also important measures.

2.10 Sprouting and greening during storage

2.10.1 Sprouting of potatoes

Sprouting is one of the most critical physiological processes that influence the quality of potatoes after harvest (Benkeblia *et al*., 2008). Sprouts are undesirable as they diminish the appearance of potatoes and indicate breakdown of the dormancy of the tuber (Abong *et al*., 2015). Dormancy in potatoes refers to a physiological state characterized by temporary growth arrest of tubers after maturation, when the tubers attain their final sizes (Aksenova *et al*., 2013). During dormancy, tubers do not sprout even if placed under optimum growth conditions (Mani *et al*., 2014). Knowledge of dormancy duration provides insight into how long potatoes will last in storage before sprouting begins and selecting varieties for long or short-term storage (Mani *et al*., 2014).

The process of sprouting is accompanied by other biochemical and physiological alterations including remobilization of storage compounds (mainly starch and protein), water loss and shrinkage, increase in glycoalkaloid levels and accumulation of undesirable reducing sugar content (Pinhero and Yada, 2016). Sprout growth also promotes physiological aging thereby negatively affecting the appearance of tubers (Pinhero and Yada, 2016). Sprouts should, therefore, be very little or none in tubers, as they reduce the suitability of tubers for consumption and processing (Ooko, 2008).

The dormancy period and rate of sprouting has been observed to vary among different varieties (Abong *et al*., 2015; Mani *et al*., 2014). Murigi, (2016) investigated the sprouting rates of three Kenyan potato varieties and reported that sprouting ensued within three weeks for one variety (Shangi) while the other two (Asante and Kenya Mpya) started sprouting after ten weeks of storage. Similarly, Azad *et al*. (2017) reported a significant difference in sprouting rate of six potato varieties cultivated in Bangladesh after storage for five months.

Sprout growth is lower at low temperatures (below 5°C) and increases with higher temperatures with an optimum of 20°C beyond which sprouting rate decreases (Pinhero and Yada, 2016). Other factors that favor sprout growth during storage are high relative humidity and high carbon dioxide concentrations (Muthoni *et al*., 2014). Sprout management techniques such as low temperature storage, chemical treatments and controlled atmosphere are required to maintain the quality of potatoes after harvest (Pinhero and Yada, 2016). Although chemical treatments are widely used for sprout inhibition, increased awareness and concerns about the environment and consumer health safety call for alternative non-chemical or organic sprout control methods (Pinhero and Yada, 2016).

2.10.2 Greening of potatoes

One of the major causes of tuber quality loss is greening (Tanios *et al*., 2018). Greening entails a process where amyloplasts in the outer layers of the tuber are transformed into chloroplasts. The chlorophyll formation occurs concurrently with accumulation of glycoalkaloids (Although the biosynthesis of the two compounds is independent) that are toxic to animals and humans (Olsen *et al*., 2017). Glycoalkaloids are mainly glycosides of solanidine which might cause a bitter taste upon cooking at concentrations of 15-20mg/100g (Pinhero and Yada, 2016). Additionally, the green pigmentation renders potatoes undesirable and unacceptable because skin quality is one of the primary factors that influence consumer purchase (Olsen *et al*., 2017). **Figure 2.4** shows tubers that have greened due to accumulation of chlorophyll. In a survey across the UK, it was found that 56% of the households would not purchase potatoes exhibiting evidence of greening while 40% said they would discard uncooked green tubers (Tanios *et al*., 2018).

Tuber greening occurs when tubers are exposed to light intensity as low as 3-11W/m^2 and is also affected by temperature and stage of maturity (Pinhero and Yada, 2016). Greening is high in immature tubers and those stored in light and high temperature (Ooko, 2008). Although tuber greening is influenced by environmental factors, variability among varieties has also been observed (Bamberg *et al*., 2015; Subía, 2013). Chang, (2013) observed a significantly higher susceptibility to glycoalkaloid and chlorophyll accumulation in one American potato variety compared to the other two varieties under the study after light exposure.

Due to the toxic nature and off-flavor effects of glycoalkaloids, a maximum threshold of 200mg/kg fresh weight has been recommended by the Food and Drug Administration (Friedman, 2006; Tanios *et al*., 2018). According the potato standards in the Kenya subsidiary legislation, greenish tubers should not comprise more than 4% of the total weight of the unit (The Crop Production and Livestock Act, 2005).

Figure 2.4: Potato tuber greening due to chlorophyll accumulation (Tanios *et al*., 2018)

2.11 Potato storage technologies

2.11.1 Clamps

Clamps comprise a pile of potatoes that are covered with straw and soil as shown in **figure 2.5** (Kibar, 2012). A trench is dug in the ground into which tubers are placed on a bed of straw of 1-1.5 metre width (Wasukira *et al*., 2017). The floor of the trench is fitted with a ventilating duct in the center of the heap which is then covered with straw and some soil to protect it against pests and the weather (Wasukira *et al*., 2017). This method is effective in low temperature areas such as the mountains and high plateaus in the tropics. However, chemical sprout inhibitors are required if the tubers are to be stored for longer than their natural dormancy period (Kibar, 2012).

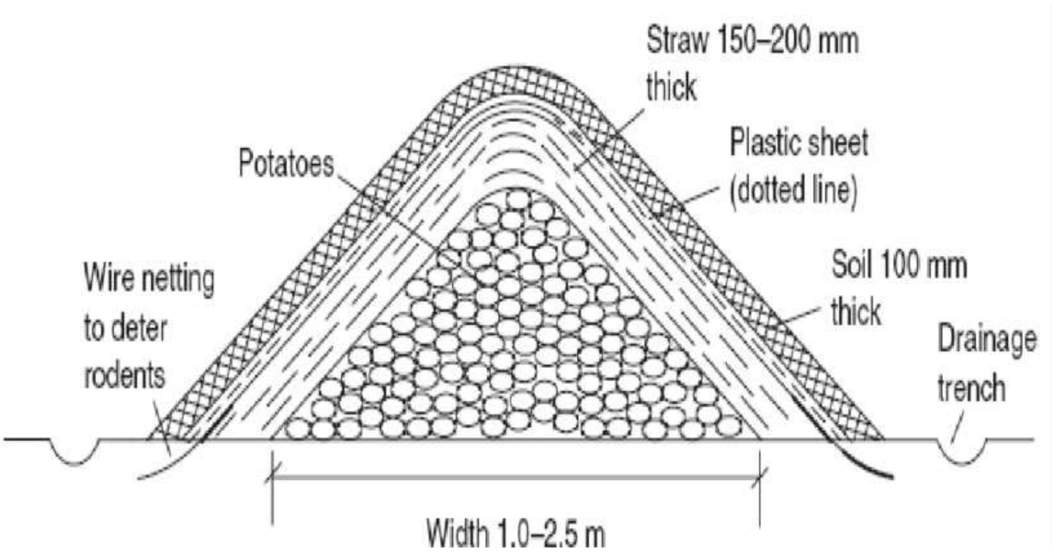

Figure 2.5 : Potatoes stored in a clamp (Hajdukiewicz, 2014).

2.11.2 Pit storage

In pit storage, rectangular pits (roughly 4.5meters by 3.6 meters by 14 meters) or circular pits (approximately 4.2m in diameter) are dug into the ground (Wasukira *et al*., 2017). Potatoes are placed in the pits and covered with 0.3 meters thick straw from wheat, barley, or grasses (Wasukira *et al*., 2017). Pit storage has been found to promote a reduction in reducing sugar content of tubers due to the reconditioning effect of high temperature but could trigger sprouting which is undesirable (Mehta *et al*., 2014). In these systems, water loss is minimal. However, due to little or no ventilation, the tubers may be overwhelmed by adverse weather conditions and are susceptible to diseases and pests (Daniels-lake, 2013).

2.11.3 Cold stores

Cold stores are large-sized structures with a refrigeration system and the capacity to hold a high tonnage of produce (Eltawil *et al*., 2006). The heat produced by the potatoes is transmitted to the air then to the evaporator which in turn expels it in the normal mechanical refrigeration cycle. The cooling of the air and subsequently the tubers is accelerated by the presence of electric fans fitted across the evaporator coil (Eltawil *et al*., 2006). The overall refrigeration capacity of the cold store and the speed of air passing over the produce and the evaporator determines the time taken for the potatoes to reach the optimum storage temperature. This mode of storage has been reported to lower sprouting rates and other storage losses (Gottschalk, 2011).

2.11.4 Outside air cooling

Outside air cooling stores are insulated, equipped with a ventilation system (Kibar, 2012). During cool weather, potatoes are ventilated with air from outside, and during hot weather when the temperature is high, outside air is prevented from entering. Therefore, the temperature in the storage can be maintained at an equal level or higher than the minimum air temperature outside (Kibar, 2012).

2.11.5 Evaporative cooling storage

Evaporative cooling involves a natural process whereby evaporation of water produces a cooling effect on materials moistened with water (Eltawil *et al*., 2006). Air is passed through the storage over moistened potatoes and the temperature of the air drops due to evaporation of water, bringing about a cooling effect (Marwaha *et al*., 2005). Evaporatively cooled stores have higher temperatures than cold stores and may result in tubers with relatively acceptable sugar content. The disadvantages of this method include; sprouting and high weight losses, high relative humidity in the store which accelerates the development of storage diseases, and the cooling effect is reduced during humid periods (Kibar, 2012).

2.11.6 Controlled atmosphere storage

In this system, sealed storage rooms are equipped with a carbon dioxide (CO_2) control system designed to maintain the levels of CO_2 (Eltawil *et al*., 2006). The CO_2 level is maintained by regulating airflow into a scrubber or controlling the outflow into the storage room, and sensors are installed to monitor the CO_2 (Gottschalk, 2011). The main reagents that are commercially applied for CO_2 absorption include water hydrated lime, molecular sieves and activated charcoal (Eltawil *et al*., 2006). This technique is however not yet well accepted as it is expensive to install and maintain in practical terms (Gottschalk, 2011).

2.12 Conclusion

Potato is an economically and nutritionally important crop across the world (Zaheer and Akhtar, 2016). In Kenya, the value of potato is increasing steadily, given that it provides food security and income to many inhabitants (Ministry of Agriculture, 2016). Potato is second to maize in terms of production and use, and produces more edible energy and protein than any other crop per unit time and land (Abong *et al*., 2009). Moreover, the crop has high water use efficiency, thus able to survive periods of water shortage (Ministry of Agriculture, 2016). Following its positive attributes, potato provides an ideal complement to maize which is the predominant staple in Kenya.

Potato tubers are rich in both macronutrients and micronutrients, which have been reported to vary considerably with variety. In addition to nutritional benefits, potatoes can be processed into a wide array of food and non-food products, creating more income generation opportunities in the value chain and expanding potential for value addition. Both physical and nutritional traits of potato tubers have been reported to differ according to variety, meaning that different varieties are suitable for different applications.

Storability of potato tubers has also been reported to vary depending on variety. Some varieties exhibit longer dormancy periods than others. Environmental conditions during storage of potatoes influence their keeping quality post-harvest and availability even during off season, necessitating research on optimal storage conditions. Based on the literature reviewed, the most critical evaluation criteria for quality of potato tubers are their physical and nutritional attributes. Since no single variety is appropriate for all applications, it is necessary to characterize different potato varieties to facilitate the process of matching tuber quality with the intended use, thereby optimizing cooking and processing performance.

Establishing physical, compositional and storage characteristics of different Kenyan varieties will be a useful guide to selecting potatoes for culinary and industrial usage. Additionally, exploring effective storage conditions that will maintain quality of tubers after harvest will contribute to enhancing consistency in availability of sufficient quality and affordable raw materials for potato consumers and processors.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study design

This study entailed a comparative assessment of three potato varieties namely; Shangi, Unica and Dutch robjin which were cultivated under the same geographic conditions and agronomic practices. The study was experimental and a completely randomized design was used with three replicates. Four main components were evaluated as outlined in **Figure 3.1.** They included: physical tuber characteristics, nutrient composition, simple sugar content before and after storage and storability of the three varieties at varied storage conditions. Under physical characteristics, six parameters; tuber weight, size, shape, eye number and depth, specific gravity and skin and flesh colors were evaluated. Four main parameters were characterized under nutrient composition; proximate content, minerals, vitamin B complex and simple sugars. For storability, the parameters evaluated included changes in simple sugars, weight loss, sprouting rate, greening rate and rotting incidence. Tubers for analysis were picked randomly. Thirty tubers of each variety were picked for physical attributes evaluation. Nutrition analyses were conducted in triplicate and approximately three kilograms of tubers in duplicates were used for evaluation of storability.

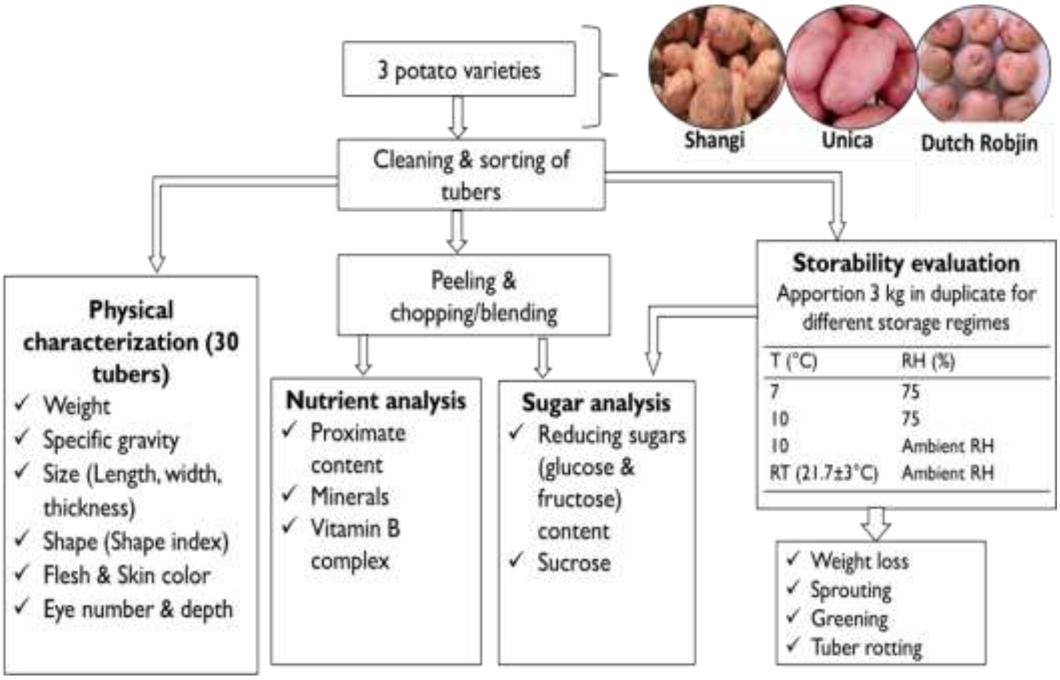

Figure 3.1: Flow diagram for comparative analysis of the physical, nutritional and storability attributes of three Irish potato varieties.

Key: RT- Room temperature, RH- Relative humidity, Ambient RH- Relative humidity of the ambient air

3.2 Materials

The three potato varieties (Shangi, Unica and Dutch Robjin.) were obtained from Nyandarua County and transported to the Food Science and Technology Laboratories of Jomo Kenyatta University of Agriculture and Technology (JKUAT) for analysis. The varieties were cultivated by a potato farmer and seed multiplier in Ol Kalou (Jaconta farms limited in Kariamu center) Nyandarua county under similar standard agronomic conditions and cultural practices including ridging, weeding and pest control. The tubers were harvested after three months (October - December 2019) and approximately 50kg of each variety was transported in nylon sacks under room temperature to JKUAT.

3.3 Methods

3.3.1 Sample preparation and grading

The tubers were first manually cleaned using distilled water to rid them of dirt and ensure no contamination with any organic matter and minerals. The tubers were dried using clean paper towels. Thirty tubers of each variety were picked for evaluation of physical characteristics following systematic random sampling whereby the total number of tubers was divided by 30 after to get a value "K". Every "Kth" tuber was picked from a nylon sack, after which the sack was shaken to mix the tubers before the next sampling interval. The tubers were categorized into three classes (following recommendations from the industry) based on the maximum dimension (Length) such that tubers with lengths ranging between 100-150 mm were categorized as grade one, those with lengths between 55 to 99 mm were labeled as grade two and tubers with lengths less than 55 mm as grade three. Two grades of Shangi and Unica were obtained **(Figure 3.2)** and only one grade of Dutch Robjin was obtained.

Tubers for storability assessment were apportioned in approximately 3kg (approximately 25 tubers) lots for the respective storage chambers. For proximate composition determination, tubers were peeled and cut into small pieces. Tubers for determination of simple sugars and vitamins were peeled, blended and analyzed.

Figure 3.2: Tuber grades of Shangi and Unica differentiated based on their length

3.3.2 Evaluation of physical characteristics

For Shangi and Unica varieties, comparative evaluation was done for both grades one and two. Dutch robjin was compared only to grade two tubers of Shangi and Unica since only grade two was obtained for Dutch robjin. Thirty representative tubers of similar size were randomly selected from each variety, then evaluated for each physical parameter.

3.3.2.1 Tuber weight

This was determined as described by Zheng *et al*. (2016). Each individual tuber, from the thirty-representative selected, was weighed using an electronic scale (KERN Pls 1200-3A) and the average for each variety and grade obtained.

3.3.2.2 Tuber size and shape (geometric properties)

Tuber size determination was carried out as described by Bubeníčková *et al*., (2011). Size in terms of linear dimensions was determined by measuring the length (largest diameter of the maximum projected area), width (minimum diameter of the maximum projected area) and thickness (diameter of the minimum projected area) as shown in **Figure 3.3** using a Vernier caliper (Mituyoyo-Japan) with an accuracy of 0.01mm.

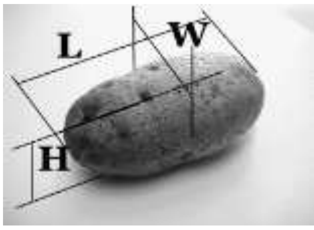

Figure 3.3: The geometric dimensions of a potato tuber (L= Length, W= width, H= Thickness)

Tuber shape was determined by calculating the shape index (I) of the measured tubers following the formula described by Gamea *et al*. (2009).

$$I = \frac{L}{\sqrt{DT}}$$

Where I= shape index, D = tuber width, L =Tuber length, T = tuber thickness. Data obtained was used to classify the tubers as spherical when I was ≤1.5 and I ≥1.5 for oval shape.

3.3.2.3 Eye depth and number

Eye-depth was determined using a Vernier caliper and recorded shallow (0-0.2mm), medium (0.3-0.5mm) or deep (>0.6mm). The number of eyes was determined by counting the total number of eyes of the 30 tubers per variety

3.3.2.4 Tuber skin and flesh color

Determination of color was conducted following the method described by Yang *et al*. (2016). Skin and flesh colors were measured using a hand-held colormeter (Model CR-200, Osaka, Japan) at three different regions per tuber. The L*, a* and b* values were determined directly from the colour meter while calculations were done for hue (H) angle and Chroma value(C*) as follows:

$$H = \tan^{-1}(b^*/a^*)$$

$$C* = (a^{*2} + b^{*2})^{1/2}$$

3.3.2.5 Specific gravity

Specific gravity was determined according to the method described by Abedi *et al*. (2019) where the mass of tuber in air and mass of water displaced by the tuber where measured.

$$\text{Specific gravity} = \frac{\text{Mass of tuber}}{\text{Mass of water displaced}}$$

3.3.3 Determination of nutritional properties

For nutrient composition, all three varieties (Shangi, Unica, and Dutch Robjin) were considered. Five representative tubers from each variety were randomly selected without considering the grade for proximate composition analysis. They were hand-peeled and chopped into small pieces for analysis. Tubers for determination of vitamins and reducing sugars were blended into a homogenous puree then analyzed.

3.3.3.1 Proximate content determination

Moisture content determination

Moisture content was determined according to AOAC, (1995) method. Moisture dishes were weighed then triplicate samples of 5g were weighed into the dishes and oven dried at 105°C to constant weight. The samples were then cooled in a desiccator and final weight recorded. Moisture content was reported as the loss in weight.

$$\% \text{ Moisture content} = \frac{\text{Weight of sample before drying} - \text{Weight of sample after drying}}{\text{Weight of sample before drying}} \times 100$$

Ash content determination

Ash content was determined using AOAC, (1995) methods. Crucibles were preconditioned in the oven, cooled in a desiccator and weighed. Five grams of samples were weighed into the conditioned crucibles then charred using flame until all smoke was removed. The samples were then transferred into a muffle furnace and incinerated at 550°C until white ash was obtained. The remains were cooled in a desiccator and weighed. Ash content was expressed as percentage of the original sample weight on dry weight basis as follows:

$$\% \text{ crude ash} = \frac{\text{weight of ash}}{\text{weight of sample}} \times 100$$

Crude protein determination

Crude protein was determined using the semi-micro kjeldahl method 976.05 AOAC, (1995).

This included digestion of 1.5 g sample which was weighed into a digestion flask followed by addition of a catalyst mixture composed of 5 g of potassium sulphate (K_2SO_4), 0.5g copper sulphate ($CuSO_4$) and 15 ml of concentrated sulphuric acid (H_2SO_4). The mixture was digested in a fume hood until the color changes to blue, indicating completion of digestion. The contents were cooled and transferred into a 100 ml volumetric flask which was topped up to the mark using distilled water. A blank digestion composed of catalyst and acid was performed simultaneously.

Approximately 10 ml of the topped-up digest was added into a distilling flask and washed with about 2 ml of distilled water, followed by addition of 15 ml of 40% sodium hydroxide (NaOH) also washed with about 2 ml distilled water. Distillation was performed to obtain a distillate of about 60 ml in volume. Into the distillate, mixed indicator was added, followed by titration with 0.02N HCl until colour changes to orange. All determinations were performed in triplicate. The titres were recorded and protein content determined following the process below:

$$\%\ \text{Nitrogen} = (\text{Titre for sample} - \text{titre for blank}) \times \text{N} \times \text{f} \times 0.014 \times \frac{100}{\text{S}} \times \frac{100}{\text{V}}$$

N = Normality of standard hydrochloric acid (HCl) solution (0.02)

f = factor of standard HCl solution

V = Volume of diluted digest taken for distillation (ml)

S = weight of sample taken (g)

% Protein = Nitrogen × protein factor (6.25)

Determination of crude fat

Crude fat was determined using the Soxhlet method 920.85-32.1.13, AOAC, (1995). Extraction flasks were conditioned in the oven for 1 hour at 105°C then cooled in a desiccator to room temperature and weighed. Five grams of pre-dried samples were weighed into extraction thimbles and covered with defatted cotton wool. The thimbles were placed in thimble support holders and fixed into the extraction unit. Fat extraction was done using petroleum ether and extraction proceeded for 8 hours. The extraction solvent was removed through rotary evaporation then the extracted fat was put to dry in an air oven at 105°C for 30 min. The extraction flasks were cooled in a desiccator and the final weight of the flasks with the extracted fat taken. Fat content in percentage was calculated as follows:

$$\%\ \text{fat} = \frac{\text{weight of extracted fat (g)}}{\text{weight of sample (g)}} \times 100$$

Determination of crude fibre

Crude fibre was determined according to AOAC, (1995). Two grams of sample was weighed into a conical flask. Sulphuric acid (1.25% H_2SO_4) (200 ml) was poured into the flask and boiled for 30 minutes under reflux. The mixture was filtered under slight vacuum condition using Pyrex glass filter after which the residue was washed thoroughly with boiling water to wash away the acid. About 200ml of boiling 1.25% NaOH was added to the washed residue and the same process above repeated. The mixture was filtered using the Pyrex glass used in the procedure above. After washing the residue, 1% HCl was used to rinse the residue followed by another rinsing with boiling water to rinse away the acid from residue. The residue was then washed twice using alcohol and three times using ether. The residue was dried in a hot-air oven at 105°C using a porcelain crucible to a constant weight (W1) then incinerated in a muffle furnace at 550°C for about 3 hours. The crucibles and samples were then cooled in a desiccator and weighed (W2). Crude fibre was quantified as follows:

$$\%\ \text{Crude fibre} = \frac{\text{W1} - \text{W2}}{\text{W}} \times 100$$

W1= weight of sample digested with acid and alkali (residue after digestion)

W2= weight of sample digested with acid and alkali then incinerated (the ash)

W= weight of the original sample

Determination of carbohydrate

Carbohydrate content was determined by difference method according to Alam *et al*. (2016):

$$\% \text{ Carbohydrate} = 100 - (\% \text{ moisture content} + \% \text{ crude fibre} + \% \text{ ash content} + \% \text{ fat content} + \% \text{ protein})$$

3.3.3.2 Determination of specific micronutrients

Determination of iron, zinc, and calcium

Iron, zinc and calcium were determined using AOAC method (1995). The ash obtained in the procedure described in section 3.3.3.1.1.was dissolved in 15 ml 0.5N HNO_3 in a volumetric flask. The mixture was topped up to the 100 ml mark using 0.1N HNO_3. The contents were filtered using Whatman no.4 filter paper. Mineral determination was then conducted using Atomic Absorption Spectrophotometer (Shimadzu AA-6200, Tokyo, Japan). The individual mineral element compositions were calculated from the readings obtained for the sample solution and the blank. Calibration curves of absorbance against the known concentration of standard solutions for each element were plotted and used to determine the concentration of minerals in the samples. All determinations were done in triplicate and reported in mg/100g sample.

$$\text{Mineral content (mg/100g)} = \frac{\text{Reading value in ppm} \times \text{dilution factor}}{\text{Sample weight}} \times 100$$

Determination of B-vitamins

Determination of Vitamins B_1 (Thiamine), B_2 (Riboflavin), B_3 (Niacin), B_6 (Pyridoxine), and B_9 (Folic acid) was done according to the method described by Ekinci and Kadakal, (2005).

Five grams of samples were weighed into centrifuge tubes and homogenized using deionized water for 1 minute at medium speed. The samples were then centrifuged for 10 min at 14 × 103g. After centrifugation, the samples were extracted using solid-phase extraction (SPE) with Sep-Pak C18 (500mg) cartridges which enhance separation of water-soluble vitamins and remove most of the interfering components. The stationary phase of the catridges was activated by flushing it with 10 mL methanol and 10 mL water adjusted to pH 4.2. The samples were then filtered through 0.45 μm pore size filters, then 20µl injected into an Ultra-Flow Liquid Chromatography (UFLC) (Shimadzu Nexera, Japan) machine equipped with a UV-Visible diode -array detector (model SPD-M20A), liquid chromatography pump (LC-20AD) and column oven (CTO-10ASvp). The column (Ultisil XB-C18 5-Micron, 4.6x250 mm internal diameter) was operated at 40°C with a flow rate of 1ml/min to obtain chromatographic peaks. Vitamins were separated through a gradient elution of 20 minutes constituting mobile phase A (100 mM KH_2PO_4) and mobile phase B MeOH (0 min-0.5%, 1 min-10%, 5 min-15%, 7.5 min-25%, 11 min-32%, 12.8 min-0%, 20 min-0%). Concentrations of the B-vitamins was calculated using peak areas of the samples and standard curves of the corresponding standards.

Simple sugars determination before and during potato storage at different conditions

The storage experiment was set up according to the method described by Abong *et al*. (2015).

After harvesting and transporting the potatoes to JKUAT, the tubers were left to cure at room temperature in a dark room for seven days. Undamaged and apparently healthy tubers were selected for experimentation. They were washed using distilled water and dried using paper towels. In triplicates, approximately 3 kgs of potato tubers were placed in incubators of similar lighting under different regimes of temperature and relative humidity as shown in **Table 3.1.** The tubers were evaluated at one-week intervals for Shangi variety (because it deteriorated faster than the rest) and two-week intervals for Unica and Dutch Robjin up to thirteen weeks (91 days).

Table Error! No text of specified style in document.**.4: Different temperature and relative humidity storage regimes for varieties Shangi, Unica and Dutch robjin**

Temperature (°C)	**Relative humidity (RH) (%)**
7	75
10	75
10	RH of the ambient air
Room temperature (21.7±3°C)	RH of the ambient air

Determination of simple sugars was done using the method described by Abong' and Kabira, (2011). Five grams of fresh blended potato was weighed into pear-shaped flasks and 20ml ethanol was added and swirled to mix. The mixture was refluxed at 100 °C for 1 hour and the resulting slurry was filtered to obtain the filtrate. The solvent was evaporated to dryness at 80°C using a rotary evaporator. The dried sample was reconstituted with 2ml of distilled water and acetonitrile in the ratio of 1:1. The samples were then micro-filtered (0.45 µm pore size) to eliminate any debris before injecting 20µl into a Shimadzu Nexera Ultra-Flow Liquid Chromatography machine (UFLC, Japan) fitted with a SIL-20A HT prominence autosampler, refractive index detector-20A, and an LC-20AD pump. Chromatographic conditions included; an isocratic elution of water and acetonitrile (25:75) pumped through a normal phase Ultisil NH_2 column with a 6 x 250 mm internal diameter at a flow rate of 1.8 ml/min. The column oven (CTO-10ASvp) temperature was set at 40°C. Sugars were quantified by comparing against standard solutions of fructose, glucose, sucrose, and expressed as mg/100g fresh weight.

Simple sugars quantification during storage

Glucose, fructose and sucrose contents were analyzed as described in **section** Relative sugar concentration was calculated as follows:

$$RC = \frac{s1 - s2}{s1}$$

RC = Relative sugar concentration

S1= Initial sugar concentration (before storage)

S2= Subsequent sugar concentrations during storage

3.3.4 Determination of storability

The potato tubers placed in the storage set up described in **section 3.3.3.2.1.3.** Were used for the evaluation of storability. The parameters evaluated during storage included weight loss, sprouting, greening and rotting.

3.3.4.1 Weight loss

Weight loss was calculated as the change between the initial weight at the beginning of the experiment and at each analysis interval for the whole of the storage period. The change in weight was expressed as a percentage of the original weight.

3.3.4.2 Sprouting

Tubers were considered sprouted if they had at least one visible sprout of at least 3mm length. The number of sprouted tubers were counted and sprouting was calculated as a percentage of the number of sprouted tubers per sample batch.

3.3.4.3 Greening and rotting

Greening and Rotting incidences were visually evaluated by observing each tuber for any sign of greening or decay. The number of greened and rotten tubers per sample batch was recorded. Percent greening and rotting were recorded as percentage of the total number of tubers per sample batch.

3.4 Data analysis

Taking the varieties as the source of variation, the results for physical attributes evaluation and nutrient content analysis were subjected to one-way analysis of variance (ANOVA) using the STATA software version 2011. For the storability results, a two-way analysis of variance was conducted. Bonferroni's mean separation test was applied to determine the difference between the means with significance defined at $p \leq 0.05$.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Physical characteristics of three potato varieties grown in Kenya

The physical tuber characteristics are presented in **Table 4.1**. Depending on their length, the tubers were manually categorized into different classes based on industry recommendations. Shangi and Unica yielded grades 1 and 2 while only one category (grade 2) was obtained for Dutch Robjin, hence it was not considered for physical attributes evaluation.

Table Error! No text of specified style in document.**.5: Physical properties of two grades of two potato varieties cultivated in Kenya**

	Grade 1			Grade 2			
Parameter/ Variety	**Shangi**	**Unica**	P-value	**Shangi**	**Unica**	Dutch robjin	P-value
Weight (g)	313.30±22.31^{a}	299.70±27.29^{a}	0.0974	142.42±14.19^{a}	141.78±4.53^{a}	101.43±10.12^{b}	0.0001
Length (mm)	123.68±11.75^{a}	133.15±8.44^{a}	0.0535	89.46±6.33^{a}	89.41±7.96^{a}	74.18±7.06^{b}	<0.0001
Width (mm)	70.65±4.80^{a}	69.67±4.04^{a}	0.6250	55.87±3.91^{a}	53.76±3.98^{a}	55.00±4.16^{a}	0.5083
Thickness(mm)	52.89±5.27^{a}	50.91±4.21^{a}	0.3653	45.26±2.63^{ab}	43.72±3.08^{a}	47.78±2.11^{b}	0.0069
Shape index	2.03±0.21^{a}	2.27± 0.19^{b}	0.0182	1.79±0.21^{a}	1.85±0.15^{a}	1.44± 0.11^{b}	<0.0001
No. of Eyes	15.33±2.68^{b}	10.72±1.41^{a}	<0.0001	11.87±2.51^{a}	9.42±2.77^{b}	12.77±2.07^{a}	0.0006
Eye-depth	2.98±0.65^{b}	2.04±0.80^{a}	0.0043	2.09±0.54^{a}	1.69±0.35^{a}	3.96±0.98^{b}	0.0001
Specific gravity	1.12±0.02^{b}	1.08±0.01^{a}	<0.0001	1.11±0.03^{b}	1.08±0.01^{a}	1.10±0.05^{ab}	0.0009

Values are means ± standard deviation. Means with different superscript letters in the same row for each grade are significantly different at $p<0.05$. n=30

4.1.2 Tuber weight of three potato varieties grown in Kenya

Shangi and Unica varieties did not show a significant difference in tuber weight for grade one (P= 0.0974). The average weights for grade one tubers were 313.3±22.31g for Shangi and 299.7±27.29g for Unica. A significant difference (P= 0.0001) in weight between Dutch robjin and the other two varieties was observed for grade two tubers. The tubers recorded weights of 142.42±14.19g for Shangi, 141.78g for Unica and 101.43±10.12g for Dutch robjin. Potato tuber weight is an important factor to consider because it is one of the key indices for measuring the yield and potatoes are sold on the basis of weight in farms, supermarkets and some open-air markets. Average weights of Shangi and Unica for both grades in this study were consistent with the mean values for grade one (213.17-220.94 g) and two (132.00-147.08g) tubers reported by Abedi *et al*., (2019).

4.1.3 Geometric properties (length, width, thickness) of three potato varieties (grown in Kenya

Tuber length exhibited no significant difference (P= 0.0535) between Shangi and Unica for grade one tubers. Grade one tubers of Shangi and Unica had average lengths of 123.68±11.75 mm and 133.15±8.44 mm respectively. For grade two tubers, the length differed significantly (p<0.0001) between Dutch robjin and the other two varieties. Shangi and Unica had lengths of 89.46 ±6.33 mm and 89.41±7.96 mm respectively while Dutch robjin tubers had the lowest length of 74.18±7.06. In terms of tuber width, there was no significant difference (P= 0.6250, P= 0.5083) across the varieties and grades. Grade one tubers had widths of 70.65± 4.80 mm and 69.67± 4.04mm for Shangi and Unica respectively while grade two tubers recorded widths of 55.87±3.91 mm, 53.76±3.98 mm and 55.00±4.16 mm for Shangi, Unica and Dutch robjin respectively. A similar observation was made for thickness in grade one tubers wjereby Shangi showed a value of 52.89±5.27 mm while Unica had a thickness of 50.91±4.21 mm. For grade two tubers, however, a significant difference (P= 0.0069) was observed whereby Shangi had the highest thickness (45.26±2.63 mm) followed by Dutch robjin (47.78±2.11) and Unica (43.72±3.08 mm).

Length, width, and thickness are important traits in potato tubers as they determine the suitability of tubers for processing of products such as French fries and crisps. Long tubers are preferred for French fry processing while tubers with large widths are preferred for crisp processing. Tubers with a length 50 mm and above are ideal for French fry processing (Nain *et al*., 2019), and based on length alone, all varieties and grades in this study are suitable for French fries.

Tubers with widths ranging between 40 mm to 60 mm are recommended for crisp processing (Abong *et al*., 2010). Tuber width beyond 60 mm is unsuitable because such tubers yield fragile crisps that are prone to breakage during post processing handling such as packaging and transportation (Abong *et al*., 2010). In this regard, both Shangi and Unica varieties in grade one failed this criterion. For the grade two category, the varieties had mean widths of 55.87±mm (Shangi) and 53.76±3.98 mm (Unica) and 55.00±4.16 (Dutch robjin) and were therefore within the recommended width range for crisp processing.

4.1.4 Tuber shape of three potato varieties grown in Kenya

Tuber shape as per the shape index values demonstrated that Shangi and Unica varieties were oval while Dutch robjin was round. A significant difference (P=0.0182) in the shape index of the tubers under grade one was observed between Shangi and Unica. Unica had a higher shape index value of 2.27±0.19 than Shangi (2.03±0.21) for grade one potatoes. These values exceeded the 1.5 threshold and were thus classified as oval. For grade two tubers, Dutch robjin had a significantly lower ($p<0.0001$) shape index value (1.44± 0.11) than Unica and Shangi which had shape index values of 1.85±0.15 and 1.79±0.21 respectively. Therefore, grade two tubers of Unica and Shangi were also classified as in shape, while Dutch robjin scored o value <1.5 and was thus classified as round-shaped. Both varieties and grades of Shangi and Unica met the prerequisites for French fry processing since long and oval tubers are preferred. Dutch robjin on the other hand would be the most suitable variety of the three for crisp processing as it would meet the desired crisp shape and size with minimal losses. (Ekin, 2011; Wayumba *et al*., 2019).

4.1.5 Eye number and depth of three potato varieties grown in Kenya

Eye number and depth are largely varietal characteristics (Nain *et al*., 2019). The varieties under this study displayed a significant difference in the number of eyes for both grades one ($p<0.0001$) and two ($P= 0.0006$). Shangi tubers had a higher average number of eyes (15.33±2.68) compared to Unica's (10.72±1.41) in grade one. For grade two, Unica had the lowest number of eyes (9.42±2.77) while Dutch robjin had the highest (12.77±2.07). Shangi variety also had deeper eyes (2.98±0.65) than Unica (2.04±0.80) for tubers in grade one. A significant difference ($p<0.0001$) in the eye-depth of tubers in grade two was observed. Dutch robjin had a significantly higher eye depth (3.96±0.98) than Shangi (2.09±0.54) and Unica (1.69±0.35). Varieties with shallow eyes are the most suitable for processing as deep eyes result in high losses during peeling and trimming, thus reducing product yield. Eye depth is classified as shallow, medium, and deep (Abong *et al*., 2010). Based on this classification, all varieties under this study were found to have deep eye depths which might reduce the peeling and trimming efficiency during processing.

4.1.6 Specific gravity of three potato varieties grown in Kenya

There was a significant difference in the specific gravity of tubers across the varieties and grades. Shangi had the highest specific gravity for both grades one (1.12±0.02) and two (1.11±0.03). For Unica, both grades recorded a specific gravity value of 1.08±0.01. Dutch robjin had a specific gravity of 1.10±0.05. These values were comparable to those observed by other researchers. Rahman *et al*. (2017) reported specific gravity values in the range of 1.057-1.123 in forty potato varieties cultivated in Bangladesh. Similarly, eighteen Peruvian potato varieties were reported to have a specific gravity range of 1.07-1.113 by Lara and Malaver, (2019) Specific gravity is considered one of the most practical index for potato quality as it is positively correlated with starch content, total solids, and dry matter (Ekin, 2011). High specific gravity is desired by processors of fried and dehydrated products as it enhances high product recovery rates, lower oil absorption, less energy consumption during processing, better flavor and texture, and generally high quality of fried products (Ooko, 2008). Tubers with low specific gravity on the other hand are suitable for canning because they are less likely to fall apart during processing (Gamea *et al*., 2009; Marwaha *et al*., 2005). All varieties and grades under this study had a specific gravity of at least 1.07 recommended for processing of crisps and French fries (Ekin, 2011).

4.1.7 Skin and flesh color of two potato varieties (Shangi and Unica) grown in Kenya

Color is a vital parameter as it is the main characteristic that influences consumer perception of a product (Spence, 2015). The varieties analyzed in this study differed significantly in terms of skin color **(Table 4.2).** Shangi was yellowish based on the high *b** values of 25.64±1.54 relative to Unica's 12.34±1.14 and Dutch robjin's 52.61±1.87*b** values. Unica and Dutch robjin had reddish skin as demonstrated by the higher values of *a** (14.05±1.91 and 7.85±0.60 respectively) compared to 1.23±0.25 for Shangi. Unica had twice as much redness (*a**) value as Dutch robjin. Shangi variety was further characterized by a higher hue angle (H*) of 87.17±2.84) which is located in the yellow region (90°h) of the CIE *L*a*b** color scale (Cabezas-Serrano *et al*., 2009), while Unica had a lower value (41.50±5.61) leaning towards the red region (0°h) of the color scale. Dutch robjin had a hue angle of 67.33±1.51, falling in between the red and yellow region. Red and purple skin-colored potatoes have been reported to possess high levels of phenolic and anthocyanin compounds which have high antioxidant activity (Emragi and Jayanty, 2021; Subía, 2013; Yang *et al*., 2015). In this regard, Unica and Dutch robjin would be more preferred by many consumers especially the health -conscious ones.

Table Error! No text of specified style in document.**.6: Skin and flesh color profiles of three Kenyan potato varieties**

Variety	Skin colour				
	(L*) Lightness	**(a*) Redness**	**(b*) Yellowness**	**(C*) Chroma**	**(H*) Hue angle**
Shangi	60.94±1.74[b]	1.23±0.25[a]	25.64±1.54[b]	25.70±1.52[b]	87.17±2.84[b]
Unica	48.87±1.95[a]	14.05±1.91[b]	12.34±1.14[a]	18.79±1.24[a]	41.50±5.61[a]
Dutch robjin	52.61±1.87[b]	7.85±0.60[b]	18.79±0.89[b]	20.37±0.93[b]	67.33±1.51[b]
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
		Flesh colour			
	(L*) Lightness	**(a*) Redness**	**(b*) Yellowness**	**(C*) Chroma**	**(H*) Hue angle**
Shangi	67.28±4.24[a]	-4.81±0.72[a]	21.14±4.03[a]	21.68±4.08[a]	102.89±0.71[b]
Unica	66.08±2.78[a]	-4.74±0.63[a]	23.99±1.69[b]	24.47±1.67[b]	101.22±1.59[a]
Dutch Robjin	69.99±3.52[b]	-4.76±0.59 [a]	24.85±1.81[b]	24.85±1.77[b]	101.08±1.10[a]
P-value	0.0320	0.9571	0.0137	0.0430	0.0010

Values are means ± standard deviation. Values with different superscript letters in the same column are significantly different at $p<0.05$ n=30

With respect to flesh color, there was no significant difference in the lightness (P= 0.42) and redness (P =0.81) scores of the three varieties. The *b** values were indicative that the three varieties were yellowish in color. However, there was a significant difference in the b* values between Shangi (21.14±4.03) and the other two varieties with Unica and Dutch robjin having higher scores of 23.99±1.69 and 24.85±1.81 respectively. Furthermore, Unica and Dutch robjin had lower hue angles of 101.22±0.71 and 101.08±1.10 respectively compared to that of Shangi (102.89±0.71). These values are situated in the second quadrant of the CIE *L*a*b** color scale whereby the lowest values fall within the yellow region (90°h) and the highest values are located on the on the green region (180°h) (Cabezas-Serrano *et al.*, 2009). Unica and Dutch robjin also had significantly higher chroma (C*) values than Shangi implying that their yellow color had a higher intensity than that of Shangi. Flesh color is important as it influences processors and consumers' variety selection. Tubers with yellow or cream-colored flesh yield slight golden color that is desirable in fried products and an attractive bright yellow color desired in boiled potatoes by consumers (de Oliveira *et al*., 2020; Kisakye *et al*., 2020; Ooko, 2008). Additionally, yellow fleshed potatoes have been reported to have high antioxidant content (carotenoids) compared to white fleshed potatoes (Beals, 2018; Tsao, 2009). The varieties under this study would, therefore, possibly yield products that would meet both processor and consumer preferences in terms of color.

4.2 Nutrient content of the potato varieties

4.2.1 Proximate composition of three potato varieties (Shangi, Unica and Dutch robjin) grown in Kenya

There was a significant difference (P= 0.0002) in the moisture content of the three varieties. Unica variety had the highest moisture content (81.01±0.33 g/100g) followed by Shangi (78.50±0.56 g/100g) and Dutch Robjin (75.55±0.94 g/100g) **(Table 4.3).** These values compare favorably with the results reported by other researchers of 72.48-81.54% in four potato varieties grown in Ireland (Tsikrika *et al*., 2019), 78.55-82.98% in three Japanese varieties (Sato *et al*., 2017) and 81.10-83.74% in four Korean varieties (Jin *et al*., 2016). Low moisture content is desired in potato tubers because water content is inversely proportional to the dry matter content. Low moisture content is linked to high dry matter content which is associated with better crispiness and texture of fried products. Low moisture content is also associated with less frying time to eliminate moisture from crisps and fries, less oil absorption during frying, lower risk of soggy products and discoloration during cooking, and higher productivity and profitability (Ekin, 2011; Högy and Fangmeier, 2009). A moisture content of ≤ 80% has been found favorable for processing. Based on the results of this study, Dutch Robjin and Shangi satisfied this criterion.

Table Error! No text of specified style in document.**.7: Proximate composition of three Kenyan potato varieties**

Parameter	**Variety**			
	Proximate content (g 100g^{-1} fresh weight)			
	Shangi	**Unica**	**Dutch Robjin**	**P value**
Moisture	78.50±0.56^{b}	81.01 ±0.33^{c}	75.55±0.94^{a}	0.0002
Protein	1.63±0.10^{a}	1.67±0.03^{a}	1.76± 0.09^{a}	0.2098
Carbohydrate	18.12±0.45^{b}	15.61±0.16^{a}	20.40±1.03^{c}	0.0003
Ash	0.89±0.05^{a}	0.88±0.01^{a}	1.10±0.03^{b}	0.0004
Crude fat	0.08±0.01^{a}	0.07±0.01^{a}	0.08±0.02^{a}	0.0950
Crude fibre	0.78±0.05^{ab}	0.77±0.15^{a}	1.11±0.15^{b}	0.0246

Values are means ± standard deviation. Means with different superscript letters in the same row are significantly different at p<0.05. (n=3)

Crude protein content ranged between 1.63±0.10 and 1.76±0.09 g/100g and did not differ significantly (P= 0.2098) across the varieties. This range compares well with that reported by Ngobese *et al*. (2017) and Niekerk, (2015) who reported values between 1.57-2.87g/100g and 0.88-1.69g/100g respectively in potato varieties cultivated in South Africa. Similarly, Fernandes *et al*. (2015) reported protein content between 1.6 and 1.8g/10g in Brazilian potato varieties. The protein content of potatoes analyzed in this study is lower than that of cereals such as maize which means that they would be best incorporated in a cereal diet to maximize the protein value of the diet. In terms of processing, the varieties under this study would qualify for processing products such as potato noodles which require high protein content of approximately 1.61g/100g and above (Zhang *et al*., 2017).

For carbohydrates, the results indicated a significant difference (P= 0.0003) across the three varieties with Dutch Robjin having the highest content (20.43±1.03mg/100g), followed by Shangi (18.15±0.45 mg/100g) then Unica (15.61±0.16mg/100g). The difference could be attributed to genotypic differences of the varieties. These values compare well with the findings of Tsikrika *et al*. (2019) who reported a range of 16.04-23.06g/100g in four potato varieties cultivated in Ireland. Similarly, Jin *et al*. (2016) found carbohydrate content ranging between 15.14 and 16.07g/100g in four Korean varieties. Carbohydrate is the principal macronutrient in potatoes with starch being predominant (Bonierbale *et al*., 2010). Starch content has a high positive linear correlation with dry matter and specific gravity and therefore has a direct influence on the quality of processed potato products such as crisps especially with regards to texture (Kita, 2002; Mohammed, 2016). High dry matter content increases product yield, reduces oil absorption during cooking and enhance the crispiness of fried potato products. It also enhances production of starch in starch processing industries. Therefore, varieties with high carbohydrate content are ideal for processing. On this basis, Dutch robjin would be the most suitable variety for processing followed by Shangi then Unica. On the other hand, varieties with high carbohydrates and therefore high starch content are likely to yield floury consistency when boiled or stewed, and may also undergo cell separation due to reduced cohesiveness (Mohammed, 2016). These characteristics may not be preferred by consumers such as diabetic patients as such varieties may lead to high glycemic index (Parada and Aguilera, 2009). The variety containing the lowest carbohydrate content, in this case Unica, would be the most suitable for such consumers.

There was no significant difference (P=0.0950) in crude fat content across the varieties. Shangi and Dutch Robjin had a similar fat content of 0.08±0.02 g/100g while Unica's fat content was 0.07±0.01 g/100g. These values were in agreement with the findings of Murniece *et al*. (2011) who reported fat content in the range of 0.03-0.19 g/100g in Latvian potatoes. Similarly, Liang *et al*. (2019) found that fat content ranged between 0.03-and 0.13g/100g in Chinese potato varieties. Although the low fat content in potatoes might not have a substantial nutritional effect, it enhances the sensory attributes of cooked potato tubers and promotes cellular integrity and resistance to bruising in tubers (Kalita and Jayanty, 2017).

Total ash content differed significantly (P= 0.0004) between Dutch Robjin and the other varieties. Dutch Robjin had significantly higher ash content (1.10±0.03 g/100g) followed by Shangi (0.89±0.05 g/100g) and Unica (0.88±0.01 g/100g). This variation was attributed to genotypic differences. This range was in agreement with the findings of Leonel *et al*. (2017) who reported a range between 0.81 and 1.38g/100g in Brazilian varieties. Similar ranges of (0.88 - 1.03g/100g) and 0.87-1.04 g/100g were reported by Sato *et al*. (2017) in four potato varieties grown in Japan and Jin *et al*., (2016) in Korean potato varieties respectively. These findings suggest that in terms of total ash, potatoes can substitute staple cereals such as maize and rice whose ash contents range approximately between 0.79-1.49 g/100g and 0.50-2.00 g/100g respectively (Abdulrahman and Omoniyi, 2016; Kataria, 2014; Oko and Ugwu, 2011; Sulaiman *et al*., 2020; Yankah *et al*., 2020)

Crude fibre content differed significantly (P= 0.0246) between Dutch Robjin and Unica. Crude fibre was highest in Dutch Robjin (1.11±0.15g/100g). Shangi had fibre content of 0.78±0.05g/100g while Unica had crude fibre content of 0.77±0.15g/100g. These values are consistent with the range reported by Leonel *et al*. (2017) of 0.4-0.8g/100g. Lower values of crude fibre (0.20-0.66 g/100g) and (0.56- 0.75 g/100g) have been reported by Garcia *et al*. (2015) and Murniece *et al*. (2011) respectively. This difference could be attributed to varietal differences and variations in geographical location, soil type and cultivation practices of the potatoes. These findings show that compared to other vegetables and root crops, potatoes are not a high-fibre food. However, they may provide a significant source of fiber for those who eat them regularly.

4.2.2 Mineral content of three Kenyan potato varieties

Iron content differed significantly (P= 0.0028) between Shangi and the other two varieties **(Table 4.4).** Shangi had the lowest iron content (0.63±0.02mg/100g) while Unica and Dutch Robjin had iron content of 0.81±0.07mg/100g and 0.87±0.05mg/100g respectively. This range was consistent with the values reported for thirteen Andean potato varieties by Wijesinha-Bettoni and Mouillé, (2019) of 0.94-3.94mg/100g. A higher range of iron content (1.24-2.52mg/100g) was reported by Fernandes *et al*. (2015) in two potato varieties cultivated in Brazil. The difference could be attributed to varietal differences and differences in soil characteristics and cultural practices during cultivation. While the iron content in potatoes is not particularly exceptional, its bioaccessibility exceeds that of many other iron-rich plants owing to extremely low levels or no antinutrients and chelators which inhibit iron absorption (Beals, 2018).

Table Error! No text of specified style in document.**.8: Mineral content of three Kenyan potato varieties**

Parameter	**Minerals in mg 100^{-1} fresh weight**			
	Shangi	**Unica**	**Dutch Robjin**	**P value**
Iron	0.63 ± 0.02^b	0.81 ± 0.07^a	0.87 ± 0.05^a	0.0028
Zinc	0.37 ± 0.05^a	0.41 ± 0.03^a	0.28 ± 0.01^b	0.0071
Calcium	5.44 ± 1.23^a	8.51 ± 1.30^a	7.63 ± 1.69^a	0.0903

Values are means ± standard deviation. Means with different superscript letters in the same row are significantly different at p<0.05. (n=3)

There was a significant variation in zinc content (P= 0.0071) between the varieties with values ranging between 0.28-0.41mg/100g. Unica had the highest concentration and Dutch Robjin the least. This difference was attributed to genotypic variations among the varieties. The range of zinc content in the varieties under this study were in agreement with the values of 0.34-0.62 mg/100g reported by Andre *et al*. (2007) in Andean potato varieties. Similarly, Fernandes *et al*. (2015) reported zinc content in the range of 0.20-0.37mg/100g. These concentrations of zinc are within the same range with the zinc contents of other common roots and tubers such as cassava (0.34g/100g), orange fleshed sweet potatoes (0.24-0.93g/100g) and yam (0.24g/100g). This indicates that potatoes can be utilized in place of other roots and tubers to provide a similar amount of zinc (Montagnac *et al*., 2009; Neela and Fanta, 2019; Safwan and Mohammed, 2016)

Calcium content did not differ significantly (P= 0.0903) across the varieties. Calcium content was in the range of range 5.44±1.23 - 8.51±11.30 g/100g. This range was comparable to the findings of Ngobese *et al*. (2017) who reported values between 5.2 and 10.2mg/100g in South African potato varieties. Jin *et al*. (2016) also reported calcium content ranging between 5.25 and 9.31mg/100g in Korean potatoes. A higher value of calcium (16.67mg/100g) has been reported by Elfaki and Abbsher, (2010) in Sudanese potato varieties. This variation could be attributed to differences in varieties and agronomic conditions during cultivation. Potatoes are generally not valuable sources of calcium but because of their lower phytic acid concentration, potatoes have relatively high calcium bioaccessibility (Raigond *et al*., 2020).

4.2.3 Vitamin B content

Thiamine content differed significantly ($p<0.0001$) between Dutch Robjin and the other two varieties **(Table 4.5).** Dutch Robjin had the highest content of thiamine (0.036±0.01 mg/100g) while Shangi and Unica had values of 0.026±0.01 mg/100g and 0.025±0.02 mg/100g respectively. These values compare well with the range reported by Jin *et al*. (2016) of 0.023-0.034mg/100g in Korean potatoes. Liang *et al*. (2019) reported a slightly higher range of 0.03-0.05mg/100g in fourteen Chinese potato varieties.

There was no significant difference in the content of riboflavin across the three varieties. All the varieties recorded an equal content of 0.023 mg/100g. This concentration was comparable with the range of 0.021- 0.059 mg/100g reported by Liang *et al*. (2019) in fourteen potato varieties cultivated in China. Medium sized tubers of 150 g of the varieties under this study would provide up to approximately 27% and 31% of the recommended daily allowance (RDA) of riboflavin for adult males and females respectively.

A significant difference in Vitamin B_3 (Niacin) concentration was observed among the varieties. Dutch Robjin had the highest concentration (0.93mg/100g) while Shangi and Unica had Niacin contents of 0.83mg/100g and 0.67mg/100g respectively. Lower concentration ranging between 0.015 and 0.280mg/100g has been reported by Jin *et al*., (2016) in four Korean potato varieties, probably due to varietal differences, location and growing cultural practices applied when growing the potatoes. Vitamin

B_3 is very important in potatoes as it has been demonstrated to be a potent inhibitor of acrylamide formation during potato processing (Zeng *et al*., 2009).

Table Error! No text of specified style in document.**.9: Vitamin B content of three Kenyan potato varieties**

Parameter	**Vitamins (fresh weight) per variety**			
	Shangi	**Unica**	**Dutch Robjin**	**P value**
Thiamine (B_1) mg/100g	0.026±0.01	0.025±0.02^{a}	0.036±0.01^{b}	<0.0001
Riboflavin (B_2) mg/100g	0.023±0.01	0.023±0.02^{a}	0.023±0.02^{a}	0.8987
Niacin (B_3) mg/100g	0.83±0.14^{a}	0.67±0.05^{a}	0.93±0.09^{b}	0.0439
Pyridoxine (B_6) mg/100g	0.55±0.06^{a}	0.36±0.05^{a}	1.92±0.02^{b}	< 0.0001
Folic Acid (µg/100g)	12.92±1.13	11.21±0.66^{a}	34.62±1.06^{b}	< 0.0001

Data are mean ±standard deviation. Different letters denote statistically significant differences ($P<0.05$) n=3

Vitamin B_6 (Pyridoxine) content differed significantly between Dutch Robjin and the other two varieties. Dutch Robjin displayed the highest concentration (1.92 mg/100g) while Shangi and Unica had pyridoxine contents of 0.55mg/100g and 0.36mg/100g respectively. Potatoes are a good source of vitamin B_6 which is involved in more body functions than any other single nutrient. It is a strong antioxidant and a versatile co-factor of numerous metabolic processes (Tambasco-Studart *et al*., 2005). The concentrations of vitamin B_6 obtained in this study were higher than the values reported by Bagri *et al*. (2018) of 0.052-0.102mg/100g. A 150g medium-size raw tuber of Dutch Robjin would possibly contribute up to 169% of the Recommended Dietary Allowance (RDA) for pyridoxine (1.3-1.7mg/day) for both male and female adults in Kenya (Ministry of Health, 2011).

Folate content varied significantly across the varieties ($p<0.05$) with Dutch Robjin recording the highest value (34.62 µg/100g) followed by Shangi (12.92 µg/100g) then Unica (11.21 µg/100g). These values are consistent with folate contents observed by other researchers who reported values of 12 µg/100g (Konings *et al.*, 2001) and 11-35 µg/100g (Goyer and Navarre, 2007). The values, however, differed with the findings of McKillop *et al*. (2002) who reported an elevated concentration of 125.1 µg/100g. These differences could be attributed to difference in growing regions, cultural practices and varietal differences.

4.2.4 Simple sugars of three Kenyan potato varieties and changes during storage of the potatoes

There was a significant difference in the content of Fructose (P=0.0001), glucose (P=0.0002), sucrose (P< 0.0001) and total reducing sugars (P=0.0083) across the three varieties **(Table 4.6).** Unica displayed the highest fructose content (59.14±2.88 mg/100g) followed by Dutch Robjin (52.08±1.52 mg/100g) then Shangi (37.97±1.81 mg/100g). Glucose content was highest in Shangi (59.78±2.07 mg/100g), followed by Dutch Robjin (55.06±0.29 mg/100g) then Unica (48.39±1.15 mg/100g). Sucrose concentration ranged between 62.39±2.05 and 115.30±1.84 mg/100g with Dutch Robjin recording the highest content and Unica the least. These values are within the range reported by Murniece *et al*. (2011) for fructose (10-130mg/100g), glucose (50-520mg/100g) and sucrose (60-1260mg/100g) in Latvian potatoes. Total reducing sugars content in the present study did not differ significantly between Unica and Dutch Robjin (107.53mg/100g and 107.14mg/100g respectively), while Shangi contained 97.75mg/100g reducing sugars. These values for reducing sugars compare well with those reported by Mareček *et al*. (2016) of 80-250mg/100g.

Table Error! No text of specified style in document.**.10: Simple sugars content of three Kenyan potato varieties (Fresh weight basis)**

Parameter	**Simple sugars (mg /100g)**			
	Shangi	**Unica**	**Dutch Robjin**	**P value**
Fructose	37.97±1.81^{c}	59.14±2.88^{a}	52.08±1.52^{b}	0.0001
Glucose	59.78±2.07^{a}	48.39±1.15^{c}	55.06±0.29^{b}	0.0002
Sucrose	93.14±2.81^{b}	62.39±2.05^{c}	115.30±1.84^{a}	< 0.0001
Total Reducing Sugars	97.75±2.53^{b}	107.53±3.84^{a}	107.14±1.44^{a}	0.0083

Values are means ± standard deviation of three replicates. Means with different letters in the same row are significantly different at p<0.05

Simple sugar content is very critical when selecting tubers for processing. During processing at high temperature such as frying and baking, reducing sugars react with free amino acids, mainly asparagine in a non-enzymatic Maillard reaction. This reaction leads to production of dark-pigmented fries and crisps with a bitter taste, which is undesirable (Campos and Ortiz, 2020). Maillard reaction also contributes to the formation of acrylamide (a neurotoxin and potential carcinogen) leading to food safety concerns over potato products such as French fries and crisps (Bhaskar *et al.*, 2010). Ideal reducing sugar content of up to 200mg/100g is recommended for tubers intended for processing (Mareček *et al.*, 2016). All three varieties under this study met this requirement.

4.2.5 Changes in simple sugars of Shangi Unica and Dutch robjin during storage under different conditions

In addition to physical tuber characteristics, the content of simple sugars (fructose, glucose, and sucrose) largely determines the processing quality of potato tubers during storage. In this study, an increase in the concentration of simple sugars in the stored tubers was observed. Simple sugars accumulated at different rates in the different storage conditions. Tubers stored under low temperature exhibited an increase in fructose, glucose, and sucrose concentrations over time, a process known as Cold Induced Sweetening (CIS) (Bhaskar *et al*., 2010).

4.2.5.1 Sucrose

Sucrose concentration of Shangi, Unica and Dutch Robjin increased in all storage conditions. The highest rate of accumulation was observed in tubers stored at 7°C75% RH followed by 10°C/ambient RH, 10°C/75% RH and the lowest rate was at room temperature and RH **(Figure 4.1**). There was no significant difference in the relative accumulation of sucrose among the varieties, in all storage conditions (P= 0.0475 (room conditions), P= 0.3477 (10°C/ambient RH), P= 0.2892 (10°C75% RH) and P= 0.6675 (7°C75% RH). However, the relative accumulation of sucrose was 4-10-fold lower that of fructose and glucose. This might be because sucrose is broken down to glucose and fructose enzymatically.

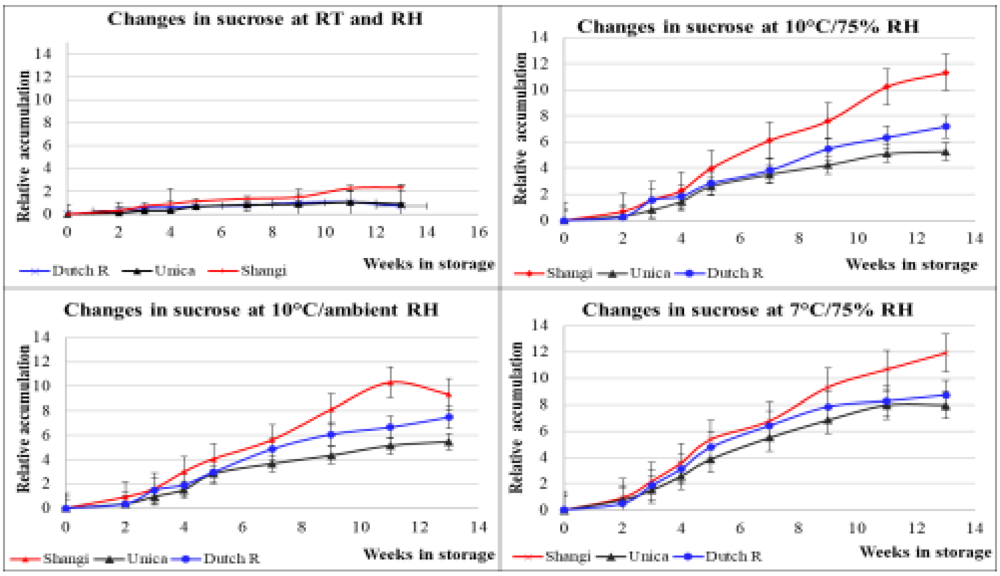

Figure 4.1: Relative change in sucrose concentration of three potato varieties stored under different storage conditions

Key: RT and RH- Room temperature (21.7±3°C) and Relative humidity, Ambient RH- Relative humidity of the ambient air

The low rate of sucrose accumulation in room conditions could be related to the high sprouting rate of tubers stored under this room temperature and RH. According to (Morales-Fernández et al., 2015), the transport of sucrose to the tuber buds is necessary to induce tuber sprouting and during this process the simple sugar content decreases until the sprouts reach approximately 1g dry matter.

During cold induced sweetening, the carbon fluxes connecting starch with sucrose are affected leading to an elevated rate of sucrose synthesis (Bhaskar *et al*., 2010). The enzymes involved in this process include sucrose phosphate phosphatase, UDP-glucose pyrophosphorylase, and sucrose phosphate synthase (Bhaskar *et al*., 2010). Due to an imbalance between the breakdown of starch and metabolism of sucrose, some sucrose enters into the cells' vacuoles. When sucrose reaches the vacuole, the enzyme vacuolar acid invertase (VINV) is up-regulated leading to the cleaving of sucrose into reducing sugars (fructose and glucose) (Bhaskar *et al*., 2010).

4.2.5.2 Fructose

Fructose content increased in all the varieties across all storage conditions with tubers stored at low temperatures displaying the highest concentrations. The rate of accumulation was least in tubers stored at room temperature and highest in tubers stored at 7°C as shown in **Figure 4.2.** There was a significant difference (P=0.0016) in the rate of fructose accumulation between Shangi and the other two varieties in tubers stored at room conditions. Significant differences (P= 0.0046) were observed in relative fructose accumulation across the three varieties stored at 7°C/75% RH, 10°C/75% RH and 10°C/ambient RH.

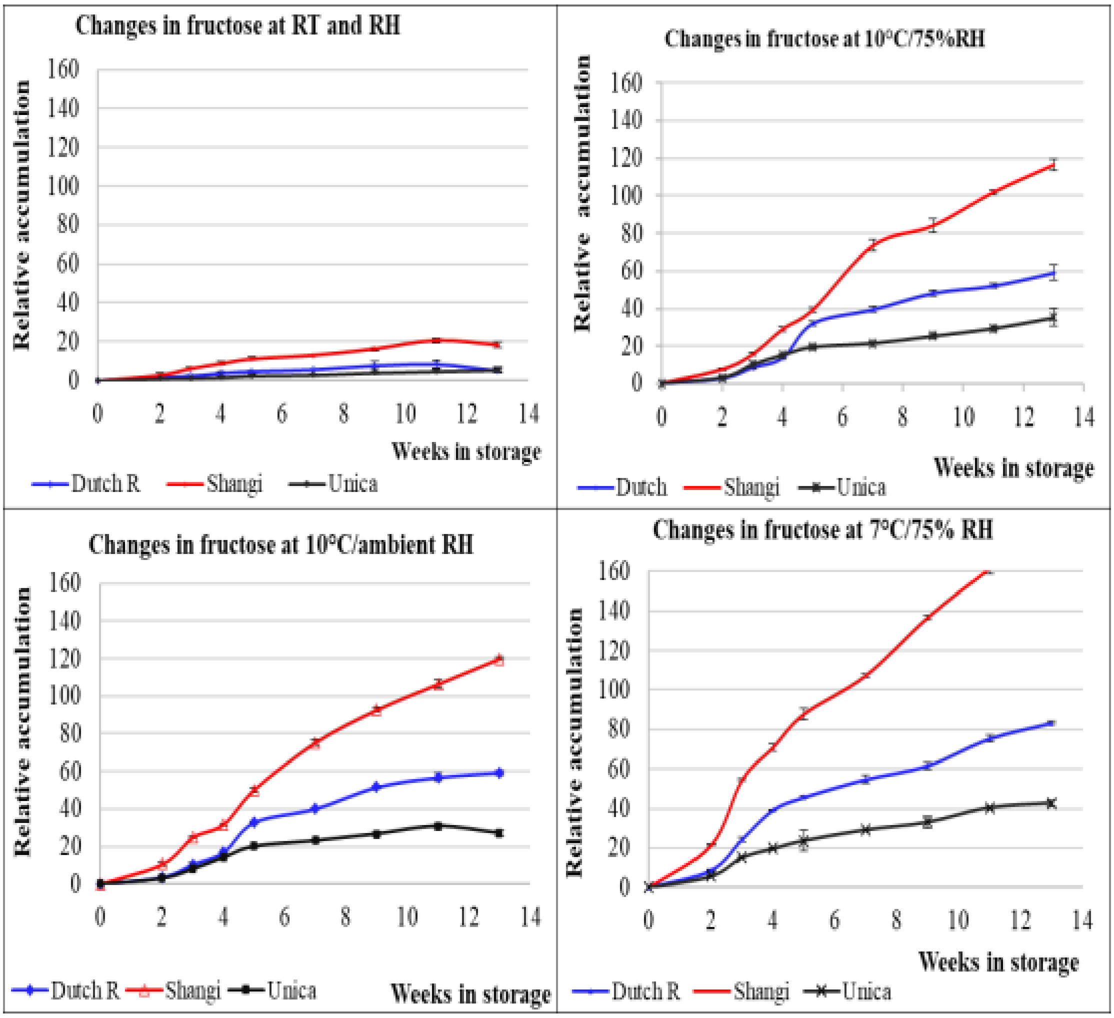

Figure 4.2: Rate of change in fructose concentration of three potato varieties stored under different storage conditions

Key: RT and RH- Room temperature (21.7±3°C) and relative humidity, Ambient RH- Relative humidity of ambient air

Shangi generally displayed the highest fructose accumulation rate followed by Dutch Robjin then Unica across all storage conditions. Interaction between variety and storage period did not, however, have a significant (P= 0.3533) effect on the fructose concentration of the three varieties during storage at room conditions. This might indicate that the storage condition had a similar impact on the three varieties stored at room temperature and RH. Increase in simple sugars at room conditions could be attributed to senescent sweetening. This is an irreversible natural process that takes place due to tuber aging, and it leads to cellular breakdown. The cellular breakdown leads to depolymerization of structural and non-structural carbohydrates by hydrolytic enzymes (Alamar et al., 2017).

A slightly higher rate of fructose accumulation was observed in tubers stored at 10°C/ RH of the ambient air than those at 10°C/75% RH implying that relative humidity in storage might influence sugar concentration. Fructose accumulation during cold storage was attributed to the conversion of starch into simple sugars. Storing potatoes at temperatures below 10°C causes a buildup of sucrose some of which is broken down to fructose by enzymes such as vacuolar acid invertase and sucrose synthase enzymes (Duarte-Delgado *et al*., 2016; Wiberley-Bradford *et al*., 2014). The differences in fructose accumulation could be attributed to genotypic variations of the tubers influencing the rate and ratio to which enzyme sucrose synthase converted sucrose to uridine diphosphate glucose (UDP-glucose) and fructose. On the other hand, the genotypic differences could have led to differential activities and affinities of hexokinases and fructokinases responsible for the irreversible phosphorylation of fructose for metabolic processes.

Since tuber sugar level is important in influencing the processing quality of tubers for frying, low sugar accumulation is an essential feature with significant commercial value. Fructose is a reducing sugar and reacts with free amino acids in potatoes during processing at high temperatures. This process leads to the development of undesirable brown colored and bitter-tasting potato products through a process called Maillard reaction (Kumar, 2011). Varieties with lower fructose accumulation rate would be preferred for processing.

4.2.5.3 Glucose

Like fructose, glucose concentration in tubers increased across all storage conditions with the highest rate being recorded in tubers stored at 7°C/75% RH followed by storage at 10°C/RH of ambient air, 10°C/75% RH, and room conditions in that order **(Figure 4.3).** Valencia Flórez *et al*. (2019) reported a similar observation in glucose accumulation whereby tubers stored at 4°C presented the highest accumulation rate followed by tubers stored at 18°C and 27°C. In this study, Shangi generally exhibited the highest rate of glucose buildup followed by Unica then Dutch Robjin in all storage treatments. There was no significant difference (P= 0.8604, P= 0.5248, P= 0.7068, P= 0939) among the varieties in the relative accumulation of glucose for all the storage conditions (Room conditions, 7°C/75% RH, 10°C/75% RH, and 10°C/RH of ambient air) respectively.

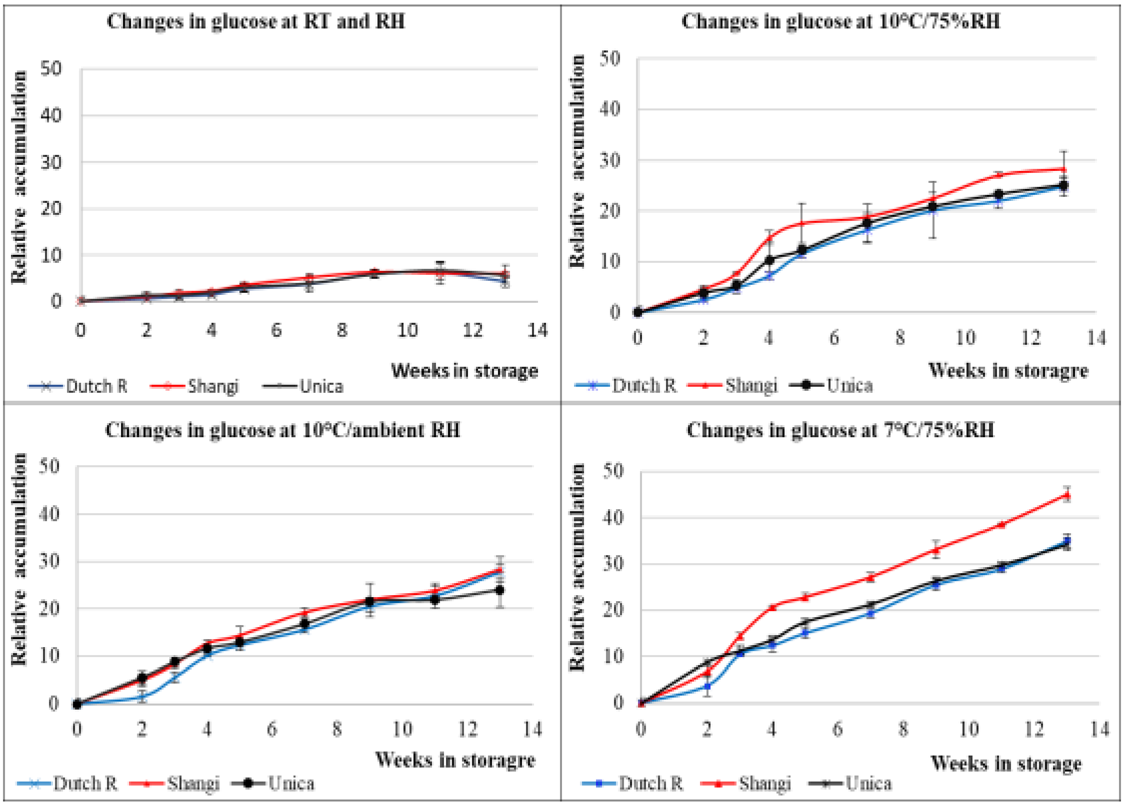

Figure 4.3: Relative change in glucose concentration of three potato varieties stored under different storage conditions

Key: RT and RH- Room temperature (21.7±3°C) and relative humidity, Ambient RH- Relative humidity of ambient air

Akin to fructose, glucose accumulation was caused by starch breakdown into simple sugars hydrolytically or phosphoroytically (Malone *et al*., 2006). It is suggested that CIS occurs due to restriction of hexose phosphates (products of starch degradation from the amyloplasts) from entering the glycolytic pathway. This restriction is attributed to the inactivation of glycolytic enzymes such as phosphofructokinase and fructose-6-phosphatase by low temperatures (Abbasi *et al*., 2016; Malone *et al*., 2006). The hexose phosphates and other starch metabolites are diverted into the sucrose synthesis pathway where they are converted to sucrose by enzyme sucrose phosphate synthase. Sucrose may be subsequently hydrolyzed to glucose and fructose (Wiberley-Bradford *et al*., 2014). According to (Malone *et al*., 2006), reducing temperature from 25°C to 4°C was observed to reduce the proportion of metabolized glucose entering the respiratory pathway leading to accumulation. Accumulation of glucose in low-temperature storage is another limitation for the use of cold storage as a means to delay sprouting and weight loss in potatoes.

4.2.5.4 Total reducing sugars as influenced by storage conditions and variety

Total reducing sugars in potatoes entails the sum of glucose and fructose concentration. The summary of changes in the total reducing sugars (glucose + fructose) is presented in **Table 4.7.** There were significant differences ($p<0.05$) in total reducing sugar content among the three varieties in all the storage conditions. The recommended total reducing sugar concentration limit for potato tubers intended for high heat processing is 250- 500mg/100g (Mareček *et al*., 2013). In this study, tubers of all three varieties stored at room temperature were still in good processing condition up to the 90th day (week 13) of storage with respect to total reducing sugar content.

Table Error! No text of specified style in document.**.11: Total reducing sugars (mg/100g) of three potato varieties stored under different conditions for 90 days**

Time in days	Storage condition	Shangi	Unica	Dutch Robjin	
0		7.61±0.32^{a}	17.04±0.59^{c}	12.94±1.05^{b}	0.0003
21	RT and RH	26.68±0.01^{a}	38.73±1.30^{c}	30.81±1.41^{b}	0.0001
	7°C/75%RH	167.78±2.55^{a}	198.13±2.10^{c}	190.82±2.08^{b}	<0.0001
	10°C/75%RH	66.53±1.63^{a}	190.84±1.96^{c}	79.47±0.93^{b}	<0.0001
	10°C/Ambient RH	83.87±2.83^{a}	202.72±1.09^{c}	99.60±2.37^{b}	<0.0001
35	RT and RH	43.24±1.81^{a}	64.91±0.62^{c}	54.42±0.35^{b}	<0.0001
	7°C/75%RH	272.18±3.50^{a}	274.90±2.64^{a}	442.43±2.23^{b}	<0.0001
	10°C/75%RH	144.71±1.49^{a}	254.31±1.47^{b}	323.19±1.78^{c}	<0.0001
	10°C/Ambient RH	171.66±1.24^{a}	266.17±1.29^{b}	341.73±1.85c	<0.0001
49	RT and RH	58.41±1.07^{a}	75.07±1.42^{c}	67.49±1.41^{b}	<0.0001
	7°C/75%RH	298.82±3.05^{a}	331.76±1.58^{b}	487.21±4.54^{c}	<0.0001
	10°C/75%RH	193.06±3.11^{a}	341.07±0.95^{b}	414.08±1.67^{c}	<0.0001
	10°C/Ambient RH	203.89±3.75^{a}	360.65±3.01^{b}	410.60±2.03^{c}	<0.0001
63	RT and RH	72.52±2.22^{a}	105.47±0.41^{c}	95.78±2.16^{b}	<0.0001
	7°C/75%RH	389.59±1.29^{a}	408.44±1.46^{b}	456.54±3.11^{c}	<0.0001
	10°C/75%RH	231.67±0.69^{a}	384.77±2.07^{b}	377.81±2.44^{b}	<0.0001
	10°C/Ambient RH	274.81±1.65^{a}	395.31±0.60^{b}	392.62±2.00^{b}	<0.0001
77	RT and RH	73.11±1.62^{a}	117.57±2.29^{c}	99.77±0.532^{b}	<0.0001
	7°C/75%RH	454.48±2.43^{a}	450.18±1.26^{a}	529.03±2.16^{b}	<0.0001
	10°C/75%RH	281.43±1.84^{a}	427.83±2.34^{c}	408.71±2.13^{b}	<0.0001
	10°C/Ambient RH	301.25±2.35^{a}	437.02±2.19^{c}	409.53±2.51^{b}	<0.0001
90	RT and RH	71.12±1.52^{b}	64.07±1.43^{a}	72.46±1.00^{b}	0.0005
	7°C/75%RH	521.01±2.08^{b}	442.89±1.80^{a}	633.01±0.57^{c}	<0.0001
	10°C/75%RH	447.26±1.52^{b}	403.13±1.81^{a}	449.26±1.55^{b}	<0.0001
	10°C/Ambient RH	469.78±2.51^{b}	434.42±1.01^{a}	466.88±1.53^{b}	<0.0001

Values are means± standard deviation. Means with different superscript letters in the same row are significantly different (p<0.05) *(n=3)*.

Key: RT and RH- Room temperature (21.7±3°C) and Relative humidity, Ambient RH- Relative humidity of the ambient air

At 7°C/75% RH, crisp and French fry processing is possible up to day 77 of storage for Shangi tubers, day 91 for Unica tubers, and day 63 for Dutch Robjin. Tubers stored at 10°C/75% RH and 10°C/ambient RH are suitable for processing up to day 91 of storage for all the three varieties. Galani *et al*.,(2016) similarly reported a significant increase in total reducing sugar content of eleven potato varieties stored at 4°C with concentration ranging between 1790.33 and 2509.85mg/100g (fresh weight basis) at 105 days.

Overall, in this study, storage caused an increase in total reducing sugars by 3.8 to 9.3-fold at room temperature, 26.0 to 68.5-fold at 7°C/75% RH, 23.7 to 58.8- fold at 10°C/75% RH, and 25.5 to 61.7-fold at 10°C/ ambient RH. Tubers stored at room temperature experienced the least sugar accumulation and would be best for processing except for the fact that they had deteriorated in other aspects such as weight loss, rotting, sprouting, and greening (Figures 4.1- 4.5). It was also noted that although Shangi had the lowest reducing sugar content among the other varieties at the beginning of the storage experiments, it did not maintain the least sugar concentration over the storage period. This suggests that varieties with low reducing sugar content at harvest will not necessarily have low sugar content after storage compared to their counterparts which might have had higher reducing sugar content before storage.

4.3 Storability of three Kenyan potato varieties under different conditions

4.3.1 Tuber weight loss of three Kenyan potato varieties during storage

Tuber weight loss was highest in storage at room temperature and relative humidity, followed by 10°C ambient RH, 10°C/75% RH and 7°C 75% RH respectively. Shangi variety presented the highest loss across all varieties and treatments as shown in **Figure 4.4**.

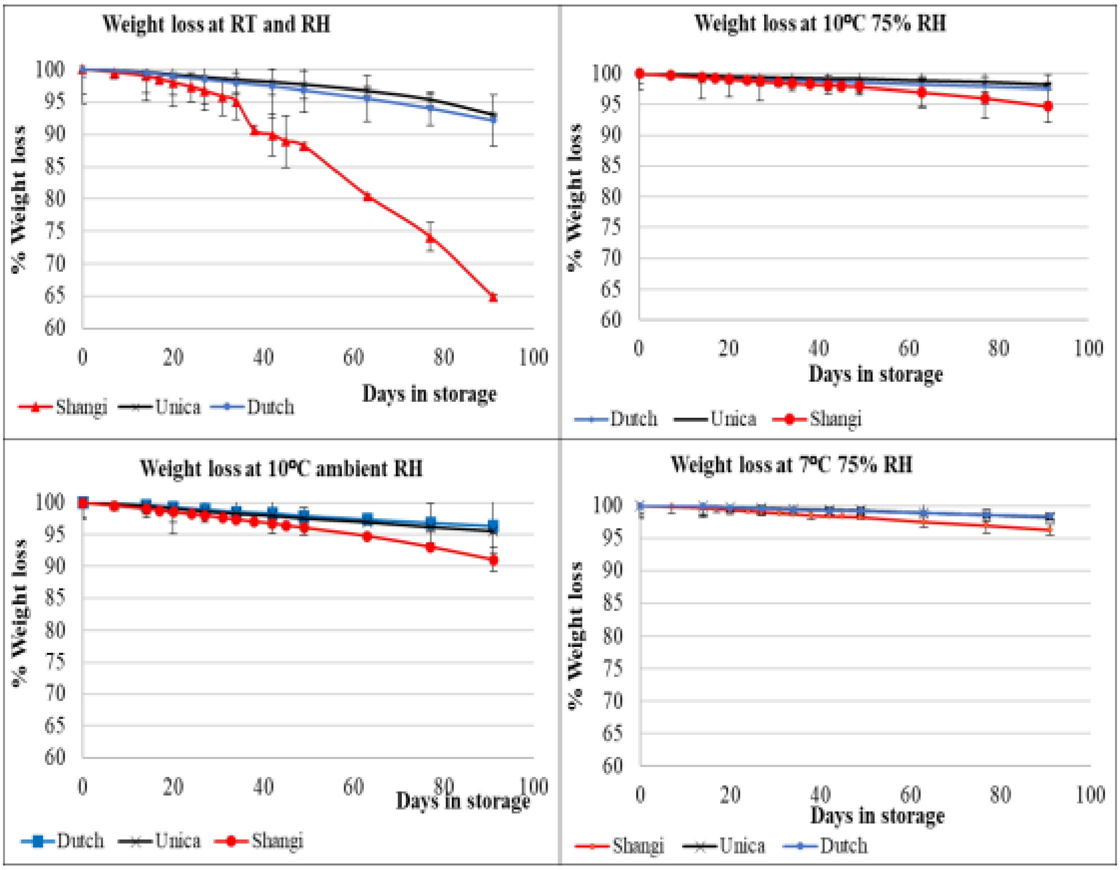

Figure 4.4: Weight loss rate in three potato varieties stored under different conditions

Key: RT and RH- Room temperature (21.7±3°C) and relative humidity, Ambient RH- Relative humidity of ambient air

At room temperature and RH, Shangi had a 35.13% total weight loss while Unica and Dutch Robjin had total weight losses of 6.9% and 7.8% respectively by the end of 3 months. Storage at 10°C/75% RH exhibited a lower rate in weight loss than room temperature with Shangi shoving weight loss of 5.2 % while Dutch Robjin and Unica both with 1.8 % weight loss. At 10°C ambient RH, weight loss was 9% in Shangi, 4.4% in Unica and 3.7% in Dutch Robjin. At 7°C 75% RH, only 3.7% weight loss was observed in Shangi, 1.8% in Unica and 1.6% in Dutch Robjin at the end of the experiment. There was a significant difference ($p<0.0001$) in the total weight loss of each variety in all the storage conditions. Shangi variety exhibited the highest and fastest loss of weight across all the storage conditions which indicates a short dormancy period. Tuber weight loss decreased with reduction in storage temperature, and storage at 7°C 75% RH best preserved the tuber weights. However, a cost-benefit analysis should be performed to check which storage condition has the best value for money.

Weight loss at 10°C/75% RH and 10°C/ ambient RH differed significantly ($p<0.0001$) suggesting that relative humidity has a substantial effect on tuber weight loss. High relative humidity has been found to reduce transpiration in fruits and vegetables thus reducing the incidence of shriveling, wilting, and weight loss (Aharoni *et al*., 2007). Evaporation and sprouting in tubers account for approximately 90% of the reduction of physiological weight while 3-10% loss is caused by respiration (Murigi, 2016). The high weight loss at room temperature and RH could be attributed to evaporative losses through the tubers' surfaces and sprouts. Sprout growth increases weight loss since sprouts increase the tuber surface area and the high permeability of sprout wall leads to greater water loss. It is estimated that sprout surface area equivalent to 1% the tuber surface area could double the potential evaporation rate (Ezekiel et al., 2007). In addition to evaporative and respiration losses, weight loss in Shangi tubers under room temperature and relative humidity storage was exacerbated by tuber rotting. Valencia Flórez *et al*., (2019) reported similar observations where weight loss in potato tubers was least in storage at 4°C, followed by storage at 18°C then storage at room temperature.

Variations in weight loss across varieties could be attributed to variations in varietal physiological traits and genotypic differences. Additionally, tubers with longer dormancy periods have been reported to maintain weight better in storage under non-cold storage conditions since sprouted tubers lose more weight than unsprouted ones. Other factors such as periderm thickness, quantity of lenticels on the tuber surface, and the number of cell layers in the periderm have also been reported to influence tuber weight loss (Mani *et al*., 2014).

4.3.2 Tuber sprouting of three Kenyan potato varieties during storage

Sprouting rate was highest in tubers stored at room temperature and relative humidity. Shangi variety exhibited the highest sprouting incidence across all varieties and storage treatments **(Figure 4.5).**

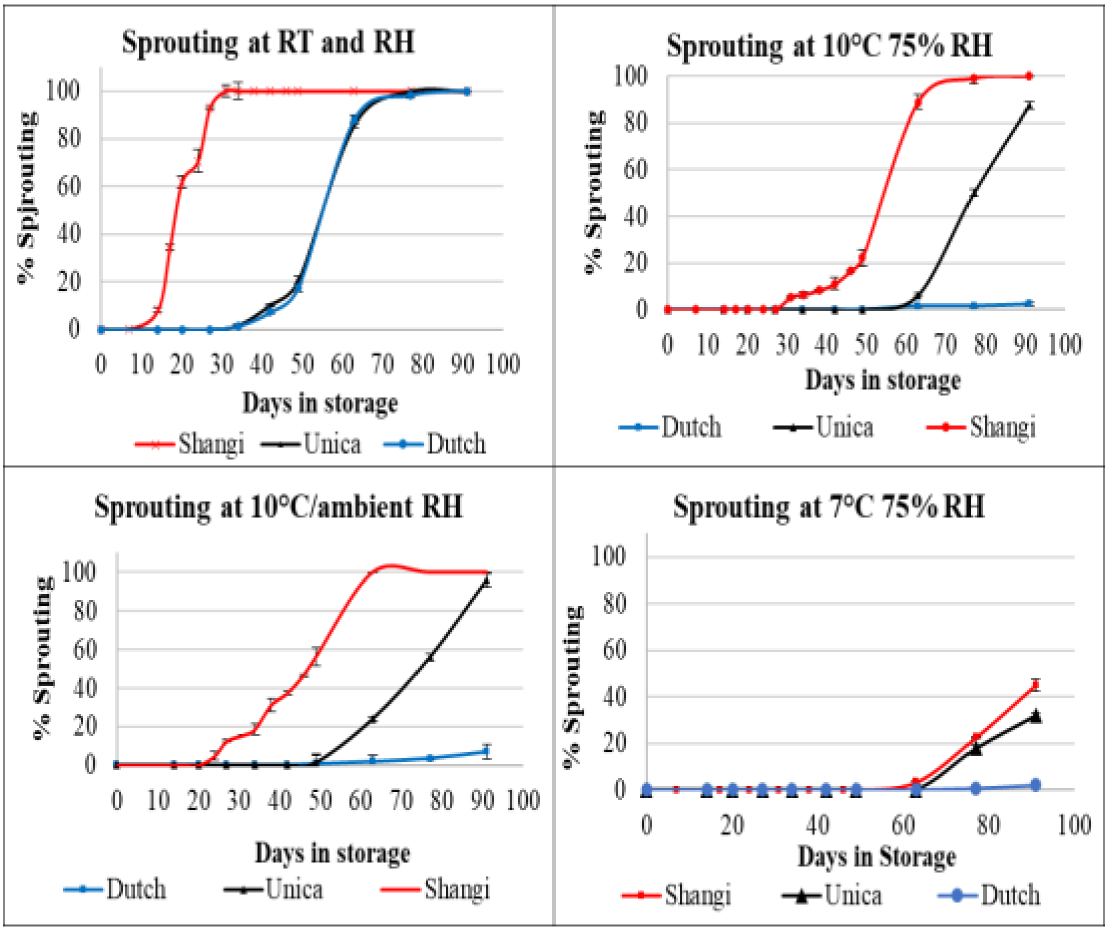

Figure 4.5: Sprouting rate in three potato varieties stored under different conditions

Key: RT and RH- Room temperature (21.7±3°C) and relative humidity, Ambient RH- Relative humidity of ambient air

At room temperature and RH, sprouting in Shangi began on day 14 of storage while Unica and Dutch Robjin both started sprouting on day 34. Shangi tubers exhibited 100% sprouting by day 30 while Unica and Dutch Robjin were 100% sprouted on days

77 and 91 respectively. A significant difference (p<0.0001) in sprouting rate was observed between Shangi variety and the rest from day14 to day 63 whereas Unica Dutch Robjin did not show a significant difference in the rate of sprouting at room temperature and RH throughout the storage period.

At 7°C 75% RH, tubers began sprouting on day 63 for Shangi, day 77 for Unica and day 91 for Dutch robjin varieties. Up until day 63, there was no significant difference (P= 0.2948) across the varieties in percentage sprouting, probably because the potatoes had not sprouted except for Shangi which exhibited 3.2% sprouting on day 63. A significant difference (P= 0.0001) across the varieties was observed from day 77 to the last day of storage when the sprouting rate was 45.2% for Shangi, 32.1% for Unica and 2% for Dutch robjin. Compared to storage at room temperature and RH, the rate of sprouting at 7°C 75% RH was less by 54.8% for Shangi, 67.9% for Unica and 98% for Dutch robjin.

At 10°C/75% RH, tubers started sprouting on day 31 for Shangi, day 63 for Unica and day 91 for Dutch Robjin. Only 2% of Dutch robjin had sprouted compared to 87.5% and 100% of Unica and Shangi respectively. There was a significant difference (P= 0.0002) in sprouting rate across the varieties beginning day 31 of storage when Shangi started sprouting. At 10°C/ambient RH, sprouting commenced on day 24 for Shangi and day 63 for both Unica and Dutch robjin. Dutch robjin displayed the least amount of sprouting by the last day of storage (7.1%) followed by Unica (96%) then Shangi (100%). From day 27, a significant difference (p<0.0001) in sprouting rate across the varieties was observed. Generally, Shangi variety sprouted the highest, while Dutch Robjin sprouted the least across all storage conditions.

Retaining tuber quality during storage in terms of appearance is vital to prevent economic loss. Not only does sprouting damage tuber appearance, diminishing marketability, it also leads to moisture loss in tubers, weight loss by elevating respiration, accelerates the breakdown of starch, increases glycoalkaloid levels, increases physiological aging, and decreases vitamin content (Pinhero *et al.*, 2009). **Figure 4.6** shows the physical appearance of the tubers used in the present study after 91 days of storage. Temperature significantly influences sprouting. Within the 3-20°C temperature range, potato dormancy is inversely proportional to temperature (Pinhero and Yada, 2016).

Room Temperature	**10°C 75% RH**	**10°C Ambient RH**	**7°C 75% RH**
Shangi			
			
Unica			
			
Dutch Robjin			
			

Figure 4.6: Physical appearance of the three potato varieties in different storage conditions on day 91

Dormancy breakage is associated with sprouting. This was observed in this study as tubers stored in room condition sprouted fastest followed by those stored at 10°C then tubers at 7°C. High relative humidity coupled with high temperature accelerates sprouting. Additionally, tubers that are damaged or diseased sprout earlier than others (Pinhero *et al.*, 2009). The difference in sprouting rate across the varieties could be attributed to varietal genotypic differences influencing dormancy length. Given the increasing awareness of health and environmental concerns related to the use of chemical sprout inhibitors, alternative non-chemical storage methods such as cold storage should be considered.

4.3.3 Tuber greening

Shangi variety exhibited the highest rate of greening followed by Dutch Robjin and then Unica in all storage conditions with an exception of 10°C ambient RH as shown in **Figure 4.7**. Greening incidence was highest at room temperature and RH for Shangi (24%) and Dutch Robjin (10.3%) and lowest at 7°C /75% RH (Shangi (16.1%) and Dutch robjin (2%). Unica on the other hand showed the highest greening rate (12%) at 10°C/ambient RH and the lowest (3.6%) at room temperature and RH storage. Compared to room temperature, the greening rate in tubers stored at 7°C/75% RH was lower by 7.9% in Shangi, 0.1% in Unica, and 8.3% in Dutch robjin. At 10°C /75% RH, the rate of tuber greening was less than that in room storage conditions by 4.7% in Shangi and 5.7% in Dutch robjin. This was however not the case for Unica which exhibited a higher greening rate compared to room conditions by 0.73%. For Shangi and Dutch robjin, there was no significant difference (P= 0.4401 and P= 0.3373 respectively) in the rate of greening between tubers stored at 10°C /75% RH and those at 10°C/ambient RH.

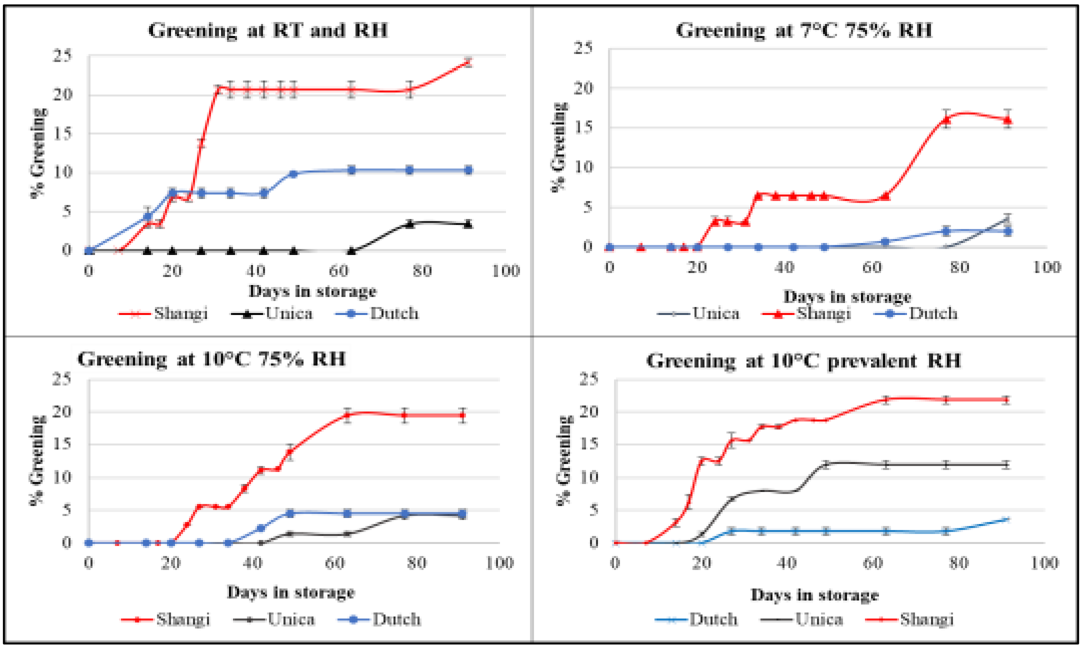

Figure 4.7: Greening incidence of three Kenyan potato varieties stored under different conditions

Key: RT and RH- Room temperature (21.7±3°C) and relative humidity, Ambient RH-Relative humidity of ambient air

Tanios *et al*., (2018) reported that the rate of potato greening lessens in cold storage and is higher at room temperature. Shangi and Dutch Robjin exhibited this trend while Unica had an opposite response. Variations in the greening behavior of the three cultivars across the different temperature treatments could be attributed to genotypic differences. Nyankanga, *et al*. (2018) also reported varietal differences in greening levels in potatoes stored using different packaging materials.

Greening diminishes tuber quality, marketability, and palatability. The green coloration occurs mainly due to exposure of tubers to light leading to chlorophyll accumulation in the amyloplasts (Chang, 2013). Although greening and glycoalkaloid formation occur simultaneously in response to light, they are formed through different biochemical processes (Bamberg *et al*., 2015; Chang, 2013). Chlorophyll accumulation is reliant on pre-harvest and post-harvest factors including temperature, wounding, light exposure, soil nitrogen, lighting conditions, and genotype

(Grunenfelder, 2005). Resistance to greening is suggested to be linked to tuber skin thickness and the presence of accessory pigments which influence the quality of light penetrating the periderm (Tanios *et al*., 2018).

4.3.4 Rotting incidence

Rotting was observed only in Shangi tubers stored at room temperature and ambient RH conditions. At the end of the experiment, 14% of Shangi tubers stored at room temperature and RH were rotten **(Figure 4.8)**.

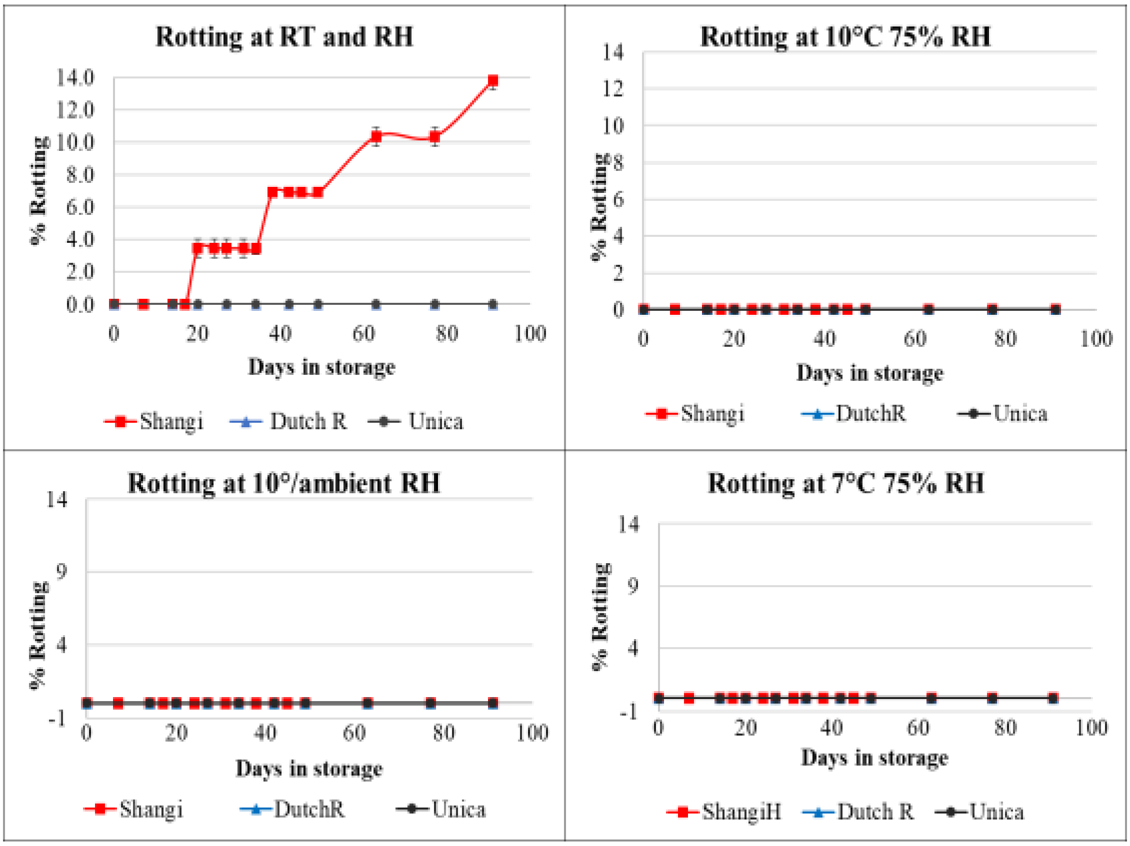

Figure 4.8: Rotting incidence in three Kenyan potato varieties stored under different conditions

Key: RT and RH- Room temperature (21.7±3°C) and relative humidity, Ambient RH- Relative humidity of ambient air

Tuber rotting not only renders potatoes unfit for consumption but also spreads the infection to the adjacent sound tubers in storage. Storage at 7°C/75% RH, 10°C/75% RH, and 10°C/ambient RH inhibited rotting in Shangi. Unica and Dutch robjin, in all storage conditions, did not rot demonstrating a significant varietal effect on tuber rotting during storage.

Some of the main causes of rotting in potatoes during storage include fungal diseases such as late blight and pink rot, and bacterial diseases like bacterial soft rot and blackleg (Pavlista, 2013). Soft rot and blackleg are the most common and destructive diseases in potatoes, leading to heavy losses in both seed and table potatoes due to rotting (Kamau *et al*., 2019; Pavlista, 2013). Soft rot and blackleg are caused by bacteria in the genera Pectobacterium spp and *Dickeya* commonly found in soils, weeds, crop debris, and on seed tubers. The bacteria can survive for long periods in plant debris such as potato tissue without causing disease and become active when the environmental conditions are favorable (Rosenzweig *et al*., 2016). Soft rot is characterized by water-soaked lesions on tubers that become soft, mushy, disintegrated, and discolored with time. The tissue around that region becomes black in color and/or creamy and slimy (*Pectobacterium carotovorum* spp. (*Pc*) and *Dickeya* spp.) creating a mushy mass of disorganized cells. The rotten Shangi tubers in this study exhibited such symptoms.

Factors influencing resistance to soft rot include tuber dry matter and sugar content, electrolyte composition, cell turgidity, oxygen levels during storage, water loss, membrane permeability, starch content and calcium content. These factors, however, interact in very complex ways depending on the genotypic characteristics of every variety (Chung *et al*., 2013). The high decay incidence in Shangi at room storage conditions compared to the other varieties may have been due to infection of the tubers by the *Pectobacterium* species prior to storage. The high rate of physical degradation including weight loss and sprouting of Shangi at room temperature could have altered the tuber physiology, affecting factors such as cell turgidity and membrane permeability, thus reducing Shangi’s resistance to the soft-rot and blackleg-causing bacteria. Rotting could also be attributed to the high surrounding temperature and relative humidity at room conditions, thus creating a favorable environment for the soft rot- causing bacteria to be active.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

From this study, it was established that Shangi, Unica and Dutch robjin differed in size and shape, specific gravity, eye-number and depth, and color. Therefore, based on their different physical attributes, these varieties, can be used for diverse applications depending on the grade. All three varieties are suitable for French fry processing, based on length, but Unica and Shangi would be most appropriate based on the tuber shape. All varieties (in grade two only) are suitable for crisp processing, but based on shape, Dutch robjin is the best. All varieties are also suitable for table use, but Unica would be the most suitable in terms of physical characteristics such as the low eye-number and depth which eases the peeling process, and its color attributes. Information on the tuber physical characteristics obtained in this study is valuable in predicting suitability of variety for intended use.

Nutrient contents of Shangi, Unica and Dutch robjin differed, with Duch robjin showing superior attributes with regards to carbohydrate content, crude ash, crude fibre, and the B-vitamins. The findings on the nutrient content of potatoes in this study highlight those potatoes can contribute significantly to human nutrition and food security.

Shangi, Unica and Dutch robjin differed in terms of simple sugars content, with Shangi showing the lowest content of reducing sugar prior to storage. All varieties had reducing sugar content within the recommended limit for processing. Sugar content in all the varieties increased with storage time and decreasing storage temperature. Shangi variety exhibited the highest degree of sugar accumulation. The highest rate and extent of sugar accumulation was observed in tubers stored at 7°C/75%RH.

With respect to storability, all varieties exhibited changes in the physical quality of tubers. Shangi variety had the highest rate and degree of change in physical quality. Potato storage at 7°C/75%RH best-preserved the tubers in terms of minimizing weight loss, sprouting, greening, and rotting. Storability of Shangi at this storage condition was extended by 2.5 months.

5.2 Recommendations and future work

All varieties under this study can be stored for at least three months in cold storage, but the change in sugar concentration is a problem. Further research is recommended on the effect of tuber reconditioning after cold storage in reducing the sugar content in these varieties prior to processing.

Enzyme activity leading to cold induced sweetening (CIS) in the varieties under this study should be investigated. Further studies are also recommended for the evaluation of glycoalkaloids and solanine accumulation in potato tubers during storage.

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