PHYSICO-CHEMICAL QUALITIES OF SELECTED POTATO (*Solanum tuberosum* L.) CULTIVARS AND THEIR SUITABILITY FOR PRODUCT DIVERSIFICATION IN RWANDA

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

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DECLARATION AND RECOMMENDATION

Declaration

I, Vedaste Ndungutse, certify that the work contained in this thesis has not been submitted for the award of any degree either at Egerton University or at any other higher learning institution. To the best of my knowledge and belief, this thesis contains no material which has been published or written by another person except where due reference is made.

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Recommendation

This thesis is the candidate's original work and has been prepared with our guidance and assistance; it has been submitted with our approval as the official University supervisors.

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DEDICATION

This thesis is dedicated to the memory of my parents Mr Jean Yaramba and Mrs. Générèse Alvera Nyirababirigi who believed in my education. This work is also dedicate to my brothers and sisters. Moreover, I would like to give special dedication to my wife Mrs. Stella Nyirabageni, my daughter Ishimwe Lucky Joyce and my son Nishimwe Mugisha Licious who endured pain of separation and did not get much attention and love from me during my studies.

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ABSTRACT

Potato (*Solanum tuberosum* L.) is bulky and perishable with up to 50% of losses in 3-5 months of storage. Losses can be reduced through processing into less bulky and more stable products. The aim of this study was to investigate morphological and biochemical factors which affect potato quality, effect of potato cultivars and fermentation on quality of French fries and crisps as well as starch characteristics. Cultivars used included vartieties like Gikungu, Kigega, Kinigi, Kirundo, Mabondo, and Sangema and clones such as CIP399075.22, CIP392617.54, CIP 393251.64 and CIP399062.115. Laboratory experiment was Completely Randomised Design (CRD) with three replications. The skin colours were red, white, yellow, pink or purple, while the flesh was yellow or white. Specific gravity was 1.075-1.099, dry matter (DM) 20.45-25.93%, starch 14.33-19.28% on Fresh Weight Basis (FWB). Reducing sugars were 0.10-0.20%, non-reducing sugars 0.16-0.35%, and total sugars 0.26-0.55% FWB. Kinigi, Kirundo, Mabondo, Sangema and CIP393251.64 were selected for processing suing discriminant analysis. Discriminant analysis did not distinguish these cultivars for crisps and French fries. Internal oil was higher than surface oil and lower for French fries than crisps. Total oil was 11.97-18.48% for French fries and 33.49-42.84% for crisps. Fermentation increased acidity 0.01-0.02%, reduced pH 7.30-4.31, acrylamide 629.6-267.73 µg/kg for French fries and 855.30-339.59 µg/kg for crisps. Potato flour had high water absorption capacity (WAC) 265.39-303.11%, oil absorption capacity (OAC) 99.21-123.14%, foaming capacity (FC) 6.27-18.05% and emulsification capacity (EC) 30.00-44.17%. Rapidly digestible starch was 0.82-2.00% for raw potatoes, 46.71-50.87% for French fries, 69.66-70.31% for crisps; slowly digestible starch was 5.89-14.40% for raw potatoes, 37.35-38.58% for French fries, and 23.50-27.21% for crisps; resistant starch was 83.61-93.30% for raw potatoes, 10.25-14.53% for French fries, 2.91-8.20% for crisps; glycemic index (GI) was 59.44-68.37% for French fries, 66.23-70.23% for crisps; glycemic load (GL) was 9.91-13.36% for French fries and 11.05-13.57% for crisps. High DM and low reducing sugars are indicators of good quality potato for fried and dehydtared products. Oil absorption reduced with increase of DM. Reduction of acrylamide increases safety of the products. High WAC of flour is an indicator for use in food as thickening agent and where bulk is needed and high OAC is good for flavour retention which inceases food palatability. GI and GL were medium for crisps and French fries and they can be used for control of metabolic disorders. Therefore, potato in this study can be used both as a source of nutrients and raw materials for processing of different potato products.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

AOAC: Association of Official Analytical Chemists
BV: Biological Value
CFU: Colony Forming Unit
CIP: Centre International de la Pomme de Terre (International Potato Center)
CVD: Cardio Vascular Disease
CRD: Completely Randomised Design
DM: Dry matter
DRI: Dietary Reference Intake
DWB: Dry Weight Basis
EC: Emulsification Capacity
ES: Emulsification Stability
FAO: Food and Agriculture Organization of the United Nations
FC: Foaming Capacity
FG: Free Glucose
FS: Foaming Stability
FWB: Fresh Weight Basis
GC-MS: Gas Chromatography Mass Spectrometry
GI: Glycemic Index
GL: Glycemic Load
HPLC: High Performance Liquid Chromatography
IO: Internal Oil
LAB: Lactic Acid Bacteria
MSD: Minimum Significant Difference
NICHE: The Netherlands Initiative for Capacity Development in Higher Education
NUFFIC: The Netherlands Organization for International Cooperation in High Education
OAC: Oil Absorption Capacity
PCA: Principal Component Analysis
PSO: Penetrated Surface Oil
RAB: Rwanda Agriculture Board
RAG: Rapidly Available Glucose

RCBD: Randomized Complete Block Design

RDA: Recommended Dietary Allowance

RDS: Rapidly Digestible starch

RS: Resistant Starch

SAG: Slowly Available Glucose

SCFA: Short Chain Fatty Acid

SDS: Slowly Digestible Starch

SG: Specific Gravity

SO: Surface Oil

STO: Structural Oil

TO: Total Oil

UR-CAVM: University of Rwanda, College of Agriculture, Animal Sciences and Veterinary Medicine

USAID: United States Agency for International Developmement

VRDS: Very Rapidly Digestible Starch

WHO: World Health Organization

WAC: Water Absorption Capacity

CHAPTER ONE

INTRODUCTION

1.1 Background information

Potato (*Solanum tuberosum* L.) is the world's fourth most important food crop, after maize, rice and wheat, with more than 380 million metric tons of production per year (Burke, 2016). It is a major food crop, grown in around 160 countries in the world (Donnelly and Kubow, 2011) and it is consumed by more than one billion people (Burke, 2016; CIP, 2018). It originated in the Andes in Peru, South America and it was first domesticated more than 7000 years ago (FAO, 2008).

This root crop was made known and spread by Spanish conquistador who came across it in Peru. It was in 1530's that Spanish found potato in Peru and the first evidence of growing potato in Europe was in 1565 in Spain (FAO, 2008). Initially, the crop was considered as poisonous where it was considered as food of disadvantaged people and it took three decades to spread in the whole Europe (FAO, 2008). In Ireland, the crop was adopted in 1780's; it suited its cool air and moist soil, it was considered as nutritious food for humans and from there it took the name of Irish potato (FAO, 2008). Thereafter, the species was spread in many parts of the world and it was introduced in Rwanda during the period of German colonization around 1900 (CIP, 2018).

Potato is superior to other vegetable crops due to high energy and protein content. On a scale of biological value (BV) compared to whole egg (BV100), the potato has a BV of 90-100 (Donnelly and Kubow, 2011). On the contrary, soybean has 84 and beans 73 and compared with the cereal proteins, potato protein has more lysine but less sulfur-containing amino acids such as methionine and cysteine (Donnelly and Kubow, 2011). Potatoes limited sulfur containing amino acids implies that they need to be complemented with other foods like cereals. The main component of potato is water ranging from 72 to 75% followed by carbohydrates from 16 to 20%, protein 2-2.5 %, dietary fibers of 1-1.8% and it has been found to be a good source of vitamin C which is an antioxidant (FAO, 2008). When complemented with beans it can provide a balanced diet.

This tuber crop is among the priority crops in Rwanda and its production has increased significantly since the beginning of the last decade despite losses which are encountered after harvesting. Potato production increased from 957,198 in 2000 to 1,789,404 metric tons in 2010 (Stone *et al.*, 2011; National Potato Council, 2016). In 2011 potato production was 2,171,000

metric tons and it increased to 2. 2 million metric tons in 2014 (National Potato Council, 2016). In Rwanda, potato is ranked the second source of calorie after cassava and its average consumption is 125 kg per person per year (FAO, 2008). Potato tubers are stored better at low temperature. However, at refrigeration temperature lower than 7^{o} C, they accumulate reducing sugars which are responsible for darkening when fried and acrylamide formation due to their interaction with amino acids like asparagine which is normally abundant in potato (Ciesarová *et al*., 2006). To avoid this accumulation of reducing sugars, it was suggested that potatoes should be stored at temperatures ranging from 7 to 10^{o} C (Eltawil *et al*., 2006). Potatoes encounter losses in different ways. Loss is also due to poor handling during loading and unloading which causes bruising followed by rotting. Due to inadequate infrastructure, losses of potatoes was estimated to be between 30 and 50% in 3-4 months of storage (USAID, 2010). This leads to unavailability of potatoes in off seasons and economic loss. To ensure availability of potatoes throughout the year and reduce storage cost it is better to process them into more stable products.

Processing is transformation of raw materials to end products which are more stable, palatable, attractive, less bulky and nutritious. In Rwanda, potato processing is still at its infancy. In 2010 about 0.7 metric tones/year were processed into chips at home level and 6.1 metric tones/year for retail (Tesfaye *et al.*, 2010). However, potato processing plants are emerging and the quantity of potato tubers which goes for processing is increasing. The quality of processed potato products depends on quality of raw materials. There are many varieties of potatoes grown in Rwanda. However, most processors rely only on one variety "Kinigi" which is being used for production of crisps and French fries. This is because suitability of potato varieties for processing in different products has not been studied. Processing of different potato products will increase potato products diversification and reduce postharvest losses of potatoes. Therefore, this study aimed at determining suitability of potato cultivars in processing of different potato products (French fries, crisps and potato flour) and changes occurring during processing which may be the leading factors affecting the quality of end products.

1.2 Statement of the problem

Storage of potato tubers is difficult because they are bulky and perishable. The bulkiness and perishable nature of the potatoes are major constraints to the marketing and availability of the crop especially in off-seasons and it is associated to food insecurity. Potato spoilage may be mechanical, biological and physiological. At room temperature, transpiration and respiration both contribute mutually to quantity and quality losses of potato. Storage of

potato in Rwanda is still rudimentary due to inadequate infrastructure and losses can go up to 50% during storage period. Despite this high loss, the production of potato has increased significantly since the beginning of the last decade. The production is likely to continue to increase in the coming years.In Rwanda, potatoes are consumed boiled, deep fat fried with/without skin (as whole or half potatoes) or as French fries. In order to reduce postharvest losses of potatoes and increase food diversification, it is better to process them into more stable products which are usually value-added products, more attractive, palatable, nutritious, and less bulky to permit continuous use. Currently, new potato processing industries are coming up in Rwanda in order to add value to potatoes. However, potato varieties grown in Rwanda have not been studied for their suitability for processing. Therefore, the purpose of this study is to investigate the suitability of potato cultivars grown in Rwanda for producing different processed potato products and quality of such products.

1.3 Objectives

1.3.1 General objective

The main objective of this study was to contribute to food security through identification of effects of potato (*Solanum tuberosum* L.) cultivars on quality attributes of processed potato products in Rwanda.

1.3.2 Specific objectives

The specific objectives of this study are:

i) To evaluate morphological and biochemical factors which affect quality of potatoes.
ii) To determine the effect of potato cultivars on quality of crisps and French fries
iii) To determine the effect of potato fermentation in brine solution on chemical and sensory quality of crisps and French fries.
iv) To determine effect of potato cultivars on functional properties of potato flour.
v) To characterize starch of different potato cultivars

1.4 Hypotheses

i) There are no significant differences in morphological and biochemical characteristics of different cultivars of potato tubers.
ii) There is no significant difference in crisps and French fries from different potato cultivars
iii) Fermentation of potatoes in brine solution has no significant effect on physico-chemical and sensory quality of crisps and French fries

iv) There is no significant difference in functional properties of flour from different potato cultivars.
v) There is no significant difference in starch characteristics from different potato cultivars.

1.5 Justification

Potatoes are widely grown in Rwanda and there is a need for processing in order to avoid up to 50% postharvest loss of the crop besides the need to diversify utilization of the crop. This is important to nutrition and food security as well as possible increase in domestic and foreign exchange earnings through sale of value added products. Different cultivars vary in their suitability for different processing methods. The Rwandan cultivars have not been researched on in this regard and neither have their physico-chemical initial qualities and changes occurring during processing. The study will guide big and small industries in making good choices of potato cultivars. There will also be information on the effects of processing techniques on quality of the final products.

1.6 Scope /limitations/assumptions

Potatoes were obtained from RAB Musanze and grown in University of Rwanda College of Agriculture, Animal Science and Veterinary Medicine (UR-CAVM) farm, Busogo campus located in Musanze district of Northern Province. They were grown in the same conditions in order to reduce variability which may be related to agricultural practices and it is assumed that climatic conditions were favorable for their growth. Six varieties which included Kirundo, Mabondo, Gikungu, Kigega, Kinigi and Sangema and four clones including CIP399075.22, CIP392617.54, CIP 393251.64 and CIP399062.115 were used.Thereafter, five best cultivars which had more promising processing characteristics were selected and used in processing. Quality of final processed potato products were assessed using both instrumental and sensory evaluation. Effect of season and location were not researched on in this study. Season and location my affect chemical composition and organoleptic characteristics of potato.

CHAPTER TWO
LITERATURE REVIEW

2.1 Role of potato in human diet

Potatoes are produced and consumed in both developed and developing countries. They are grown in more than 160 countries in the world (Donnelly and Kubow, 2011). They grow in all continents except Antarctica (Burke, 2016). Potatoes are non-cereal number one most important crop and rank the fourth after maize, rice and wheat (FAO, 2008). They produce more nutrients on less land where one hectare can produce two to four times than that produced by cereals (Burke, 2016). They utilize water seven times more efficiently than cereals (Burke, 2016). Potatoes are among priority across the world.

Potato is consumed by people from different back grounds. It is food to more than one billion people in the world (Burke, 2016;CIP, 2018). Most of potatoes produced in the world are used for direct consumption (50 to 60%), about 25% for animal feeds and 10% for seeds (Meyhuay, 2001). FAO (2008) reported that more than two thirds of potato produced is used for human consumption either in fresh or processed form. Asia consumes half of potato produced in the whole world due to its high population; it consumes 24 kg of potato per person per year (FAO, 2010). Average potato consumption is 31.3 kg per person per year in the world, 13.9 kg in Africa, 23,9 kg in Asia/Oceania, 87.8 kg in Europe, 20.7 kg in Latin America and 60.0 kg in North America and 125 kg in Rwanda (FAO, 2008). Rwanda ranks among the first six potato consumers in the world.

2.2 Postharvest loss of potato

Potato losses occurs throughout the value chain and it affects the economy. Potato losses are recorded to be higher in developing countries than developed ones. The loss is higher in developing countries like Dominican Republic up to 27%, Colombia up to 25% and low in developed countries like USA at 13% (Meyhuay, 2001). In Rwanda, loss of potatoes was estimated to be between 30 and 50% in 3-4 months of storage (USAID, 2010). Post-harvest losses of potato can be physiological or pathological (Singh and Kaur, 2009). Meyhuay (2001) reported the causes of losses to be rotting, weight loss, injury, greening and pest damage. Moreover, losses are related to factors like genetics, moisture stress, and agricultural practices (Vreugdenhil *et al.*, 2007; Singh and Kaur, 2009; Burke, 2016). Losses due to shrinkage was reported to be 15% in developed countries in 6 months of storage (Burke, 2016). Bruising and associated defects may causes losses ranging from 9 to 40% (Vreugdenhil *et al*., 2007).

Processing of potatoes into stable products can be one of the best options to reduce post-harvest losses especially in developing countries where storage facilities are inadequate and rudimentary.

2.3 Structure of potato

Potato is divided into the bud and stem ends with stem located at the stolon and the bud is richer in eyes than the stem as shown in Figure 1. Troncoso *et al*. (2009) divided potato structure into four parts, namely periderm, cortex, perimedullar zone and pith. Periderm is the outer layer which protect and covers the tuber. It is composed of three layers which are phellem made of rectangular cells oriented in radial rows, phellogen made of meristematic tissue which gives rise to phellem and phelloderm which is under phellogen. Cortex follows and it is located between periderm and vascular tissue and it is abundant in storage and phloem cells. It is followed by perimedullary tissue which is between vascular ring and pith and it forms the largest part of the potato. Thereafter there is pith which is in the center of the potato and it is angular with rays extending from the eyes of the potato. Pith is watery and cells in this zone are large with less starch content.

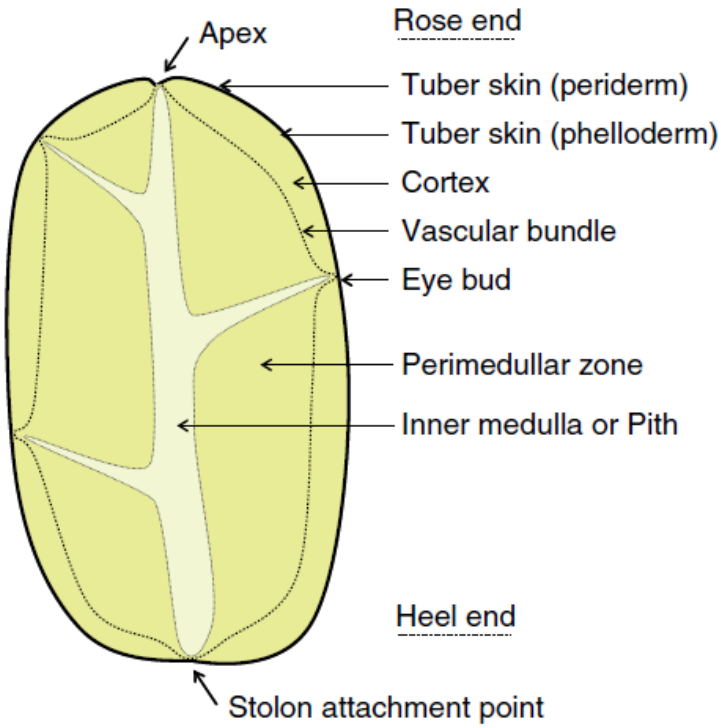


Figure 1. Anatomy of potato tuber

Source: Vreugdenhil *et al.* (2007)

2.4 Chemical composition of potato

Potato is made by macro and micro nutrients they all contributes to the nutritional quality. It is also made of phytonutrients which are present in small amount and they contribute to the protection of our bodies against different oxidative diseases.

2.4.1 Nutritional composition of potato

Potato tubers are food to many people of the world and their chemical composition can change from one cultivar to another as shown in figure 2. The main component of potato is water which is roughly 72-75% and starch of around 16-20% (FAO, 2008). Similarly, Singh and Kaur (2009) reported that around 20% of potato is dry matter and the remaining is water where starch accounts for around 70% of dry matter. Starch is the main source of energy. One hundred grams of boiled potato provides energy of 72-75 KCal which is half of rice (138 KCal) and pasta (159 KCal) and one third of bread (207-219 KCal) (Singh and Kaur, 2009). Four kilograms of potatoes are enough to cover calories and energy requirement per day for an adult (FAO, 2008). The low energy content of potato may be related to the low amount of fat it contains. Potato contributes to the body energy requirement.

2.4.2 Protein content of potato

Potato is good source of protein needed by the body. Potato protein ranges from 0.7 to 4.6% FWB (Singh and Kaur, 2009). The average of potato protein was reported to be 2.10 g/100g in fresh tubers (King and Slavin, 2013). Fresh potato of 100 g cooked with skin provides 1.7 to 2.1g of protein (Vreugdenhil *et al.*, 2007). The recommended daily intake of protein is 0.80 g/kg of body weight (Food and Nutrition Board, 2005). Based on FAO/WHO recommendation, 100 g of potato provides 8-13% and 6-7% of recommended daily intake of protein for children and adults respectively (Vreugdenhil *et al.*, 2007). Therefore, potato alone cannot supply enough protein for the body, and it needs to be complemented by other foods. However, potato contains high level of essential amino acids like lysine, threonine, and tryptophan (King and Slavin, 2013). They lack sulfur containing amino acids and they should be supplemented with food with sulfur containing amino acids like cereals to complement them.

2.4.3 Fiber content of potato

Fibers are types of carbohydrates comprising all plant materials that are not digested by digestive enzymes. Crude fibers are made of cell wall and intracellular components of potato tubers like cellulose, hemicellulose, pentosane and pectin, while dietary fiber is made of insoluble and soluble polysaccharides of cell wall along with lignin and resistant starch

(Vreugdenhil *et al*., 2007). Abong *et al*. (2009) reported crude fibers to range from 1.79 to 2.48% of fresh weight in eight potato varieties. Crude fibers were also reported to range from 0.17 to 3.48% FWB (Lister and Munro, 2000). On the other hand, the average of dietary fiber was reported to be 2.5% (Liu, 2013). A similar report revealed the amount of dietary fiber in potatoes to be 2.7 and 1.4% FWB with and without skin respectively (Visvanathan *et al.*, 2016). Crude fibers are like dietary fibers except that some fractions of soluble fibers are lost during the process in crude fibers. Potato dietary fiber is made of 55% insoluble materials which are mainly cellulose and 45% which are soluble and mainly made of pectin and gums (Pastuszewska *et al*., 2009). Fibers contribute to the bulk of feces, bind undesirable materials such as mutagens, carcinogens, and eases digestion by creating conducive environment for useful microflora in the intestine (Visvanathan *et al*., 2016). During fermentation, short chain fatty acids are formed and butyric acid is one of them and it is useful for defense against colon cancer due to its apoptosis which is programed death of cells (Lister and Munro, 2000). Moreover, dietary fibers have been reported to have numerous others benefits like regulating blood lipid levels, controlling blood glucose, and increasing satiety which is related to weight loss (Food and Nutrition Board, 2005). Recommended total fibers is 38 and 25 g per day for men and women of 19 to 50 years respectively (Food and Nutrition Board, 2005). Fibers are important in human body and potato consumption contributes to the fibers required by the body.

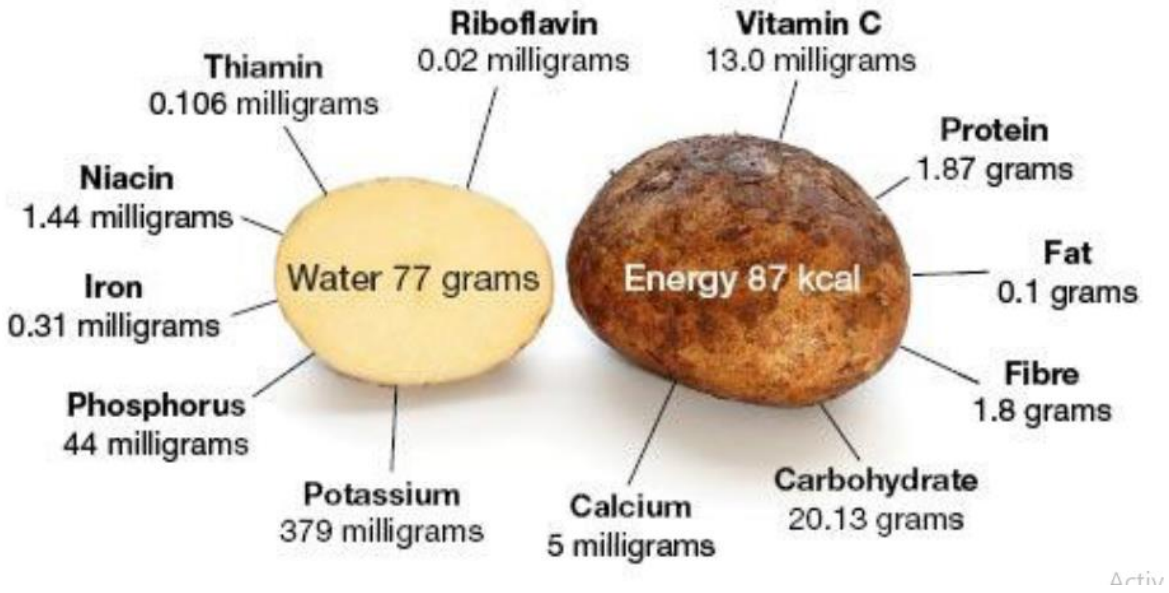


Figure 2. Nutrients content of potatoes based on 100 g of cooked unpeeled potatoes
Source: Stewart and Mcdougall (2012)

2.4.4 Lipid content of potato

Potato contain lipids at low concentration. Lipids in potatoes are very low at the level of less than 1% (Burke, 2016). Potato lipids were reported to range from 0.02 to 0.96% (Singh and Kaur, 2009). The average of potato lipid is 0.15 g/100g of fresh potatoes (King and Slavin, 2013). Despite the low nutritional density of potato lipid, it contributes to the palatability and increases cellular integrity by mitigating in tuber membrane permeability during storage (Singh and Kaur, 2009). Potato lipid is cholesterol free and around 75% of fatty acids of potato lipids are polyunsaturated linoleic and linolenic acids which contribute to the desirable flavour of cooked tubers (Ramadan and Oraby, 2016). Potato is low lipids food. However, depending on cooking methods, they are considered as high lipid due to oil used during frying. Therefore, their final lipid content is determined by the preparation methods.

2.4.5 Minerals content of potato

Potatoes contain different types of minerals in different concentrations. They are grouped in total ash which is around 1.1% in fresh potatoes (Donnelly and Kubow, 2011). Minerals are divided in macro and micro minerals. Macro elements are needed by the body in amount exceeding 100 mg per day and micro elements are required in less than 100 mg a day (Bhattacharya *et al*., 2016). Macro minerals comprise calcium, potassium, phosphorus, sodium, magnesium, sulfur and chloride, while micro elements are copper, iron, zinc, chromium, cobalt, iodine, molybdenum, and selenium (Singh and Kaur, 2009; Bhattacharya *et al*., 2016). Potassium predominates minerals in potatoes with higher concentration in the skin and it reduces towards inside of the tuber. It increases with maturity and it protects potato against bruising (Vreugdenhil *et al*., 2007). The second highest mineral in potato tuber is phosphorus, while zinc and iron are present in small amount (Vreugdenhil *et al*., 2007). Minerals content of potato is affected by genotype, soil type, soil pH, soil organic matter, fertilization, irrigation, weather and stage of development (Singh and Kaur, 2009). Iron was reported to be responsible for after cooking blackening due to its complex with chlorogenic acid which are oxidized on cooling to give a blue-grey discolouration (Vreugdenhil *et al.*, 2007). Potato was reported to provide 18% of RDA for potassium, 6% of iron (Fe), phosphorus (P) and mangasese (Mn) and 2% for calcium (Ca) and zinc (Zn) (Singh and Kaur, 2009). Similarly, it was reported that a fresh potato weighing 200 g can supply 26% of Copper (Cu), 17% to 18% of potassium (K), P, and Fe, 5% to 13% of Zn, magnesium (Mg) and Mn of Dietary Reference Intake (DRI) (White *et al.*, 2009). Minerals in potato are present in small amounts, but due to low antinutrients, they are well absorbed by the body.

2.5 Phytonutrients of potato tubers

Phytonutrients are chemicals compounds found in plant in small amount. They are produced by plants for their protection and at the same time they have been found to proctect consumers against different dieases related to oxidative stress.

2.5.1 Phenolic compounds in potato tubers

Potatoes are a good source of phenolic compounds. Polyphenols are secondary metabolites present in plants with health benefits. Potatoes contain a wide range of phenolic compounds in different concentrations. Some of them are free and others are in bound form. Total phenols in potatoes range from 5 to 30 mg/100g FWB (Lister and Munro, 2000). Other reports show that potato phenols can be as high as 123-441 mg/100g (Vreugdenhil *et al.*, 2007; Singh and Kaur, 2009). Phenolic content is influenced by genetic and environmental conditions (Lister and Munro, 2000; Ezekiel *et al*., 2013). Stress was reported to contribute to the increase in phenolic compounds (Hamouz *et al*., 2011). These compounds are produced by plants for defense against viruses, bacteria, fungi and insects (Liu, 2013; Akyol *et al.*, 2016). Phenolic compounds in tubers include polyphenols, monohydric phenols, coumarins, anthocyanins, flavones, tannins, and lignin (Lister and Munro, 2000; Liu, 2013). Potato is the third most important crop rich in phenols following apple and orange (Visvanathan *et al*., 2016). They are localized mainly between cortex and the skin (Ezekiel *et al*., 2013; Akyol *et al.*, 2016). Higher amount of phenols is present in coloured potatoes than in non-coloured ones. Red and purple skin coloured potatoes were reported to have twice phenolic acids than is found white skin coloured, while red and purple flesh coloured potatoes had three to four times phenolic acids than in white flesh coloured potatoes (Ezekiel *et al.*, 2013). The amount of phenols is reduced during cooking and processing (Ezekiel *et al*., 2013; Akyol *et al.*, 2016). Phenols were revealed to decrease risk of chronic disorders like cancer, heart diseases, and diabetes (Ezekiel *et al*., 2013; Liu, 2013). Phenols are present in various amount in potatoes and they protect the body against different types of oxidative diseases.

2.5.2 Anthocyanins in potato

Potatoes contain anthocyanins which are pigments in different colours. They are found in vacuoles and account for red, purple/black colours of potato skin and occasionally flesh (Lister and Munro, 2000). The coloration can fluctuate from modest coloration of vascular ring to the pigmentation of the entire tuber. Anthocyanin content was reported to range from 1.56 mg/100g to 89.95 mg/100g FWB (Lee *et al*., 2016). Similarly, the range of anthocyanin content was reported to vary from 1.5 to 48 mg/100g FWB (Brown *et al.*, 2008). Red and purple colored

potatoes contain more anthocyanins than yellow and white colored ones (Ezekiel *et al*., 2013). Similarly, potatoes with colored flesh have more antioxidant than skin only colored ones (Lister and Munro, 2000). Anthocyanins have antioxidant activity and it follows that red potatoes have more of antioxidants than non-colored ones and hence better at combating oxidative stress.

2.5.3 Carotenoids in potato

Carotenoids are plant pigments responsible for bright red, yellow and orange hues in many fruits and vegetables. More than 600 carotenoids with yellow, orange and red colours have been identified in fruits, vegetables, cereals and entire plants (Liu, 2013). The flesh of different varieties of potato tubers are generally coloured with yellow which is indicative of carotenoids which is a class of plastid pigment (Lister and Munro, 2000). The predominant carotenoids in potatoes are lutein, zeaxanthin, violaxanthin and neoxanthin with β-carotenoids in very small amount (Ezekiel *et al*., 2013). Zeaxanthin and lutein are responsible for orange and yellow colours respectively (Ezekiel *et al*., 2013). Total carotenoids are associated with yellow flesh colour and it is genotype dependent. Total carotenoids range from 0.5 to 2 mg/100g FWB (Singh and Kaur, 2009). Moreover, a wide range of carotenoid contents have been reported varying from 50 to 100 µg/100g for white fleshed potatoes, 100 to 350 µg/100g for yellow fleshed potatoes, 1000 µg and above for deep yellow or orange fleshed potatoes and the highest publication was 2600 µg/100g FWB (Brown *et al*., 2008). Carotenoids participate in defense against diverse disorders due to their ability to scavenge singlet oxygen generated during light induced lipid oxidation (Liu, 2013). Carotenoids contribute to the protection of the body against degenerative diseases emanating from oxidation.

2.5.4 Vitamin C in potato

Potatoes are a good source of vitamin C. Vitamin C is located mainly around the vascular system and less in the pith and skin (Lister and Munro, 2000). Potatoes contain 84-145 mg/100g of vitamin C on dry weight basis (Donnelly and Kubow, 2011). Similarly, it was reported to have amount of vitamin C ranging from 1 to 54 mg/100g on FWB with majority varying between 10 to 25 mg/100g FWB (Lister and Munro, 2000). A potato of 150 g consumed entirely supplies half of vitamin C required for adult (Burke, 2016). Vitamin C is vital for absorption of iron and for immune system of the body (Iqbal *et al*., 2004; Donnelly and Kubow, 2011; Burke, 2016). It is indispensable for hindrance of scurvy and an excellent antioxidant which helps in inhibition of oxidative stress (Iqbal *et al*., 2004;Visvanathan *et al*., 2016). It helps in formation of connective tissues, bone formation sustaining healthy gums and

it has substantial role in wound healing and protection against infection (Iqbal *et al*., 2004). Vitamin C is a strong antioxidant and protects the body against various oxidative stresses.

2.5.5 Glycoalkaloids in potato

Glycoalkaloids are secondary plant metabolites that are found in many human foods. The main glykoalkaloids found in food are α- solanine and α-chaconine which constitute up to 95% of glykoalkaloids present in potato (Singh and Kaur, 2009). Other glycoalkaloids which are present in low amounts include β-chaconine, γ-chaconine, β1-solanine, β2-solanine, and γ-solanine (Vreugdenhil *et al.,* 2007). They are produced for natural defense against animals, insects, fungi, bacteria and virus which might attack the plant (Burke, 2016). Average range of glycoalkaloids content in potato is 1-3 mg/100g FWB (Singh and Kaur, 2009). Total glycoalkaloids in most commercial potatoes range from 2 to 10 mg/100g of fresh potatoes (Vreugdenhil *et al*., 2007). The skin comprises 2-3% of the tubers and holds 30-80% of total glycoalkaloids (Vreugdenhil *et al*., 2007). They can be reduced during peeling. The conditions which favour glycoalkaloids accumulation in potatoes include immaturity, small tubers, exposure to sunlight directly after harvesting, short storage in light, damage and microbial infection (Burke, 2016). They are toxic at high concentration where they exert their toxicity effect on nervous system (Burke, 2016). Glycoalkaloids are heat stable. It was revealed that potato for consumption should not exceed 20 mg/100 g fresh weight of glycoalkaloids content (Kabira and Lemaga, 2003). Glycoalkaloids less than 150 mg/kg fresh weight was reported to improve flavour and it becomes bitter above 200 mg/ kg fresh weight, while it causes serious illness and possibly death above 280 mg/kg fresh weight (Nema *et al*., 2008). Negative consequences of consuming food with high glycoakaloids outweigh its benefit. Therefore, glycoalkaloids should be kept at low level in order not to compromise the quality of potatoes as well as health of consumers.

2.6 Processing quality of potato

Potatoes are processed into different products. Processing quality of potato depends on its morphology and chemical composition. Dehydrated and fried products are commonly potato products consumed around the world and many more potato products are emerging due to advancement into technology and innovation.

2.6.1 Morphological characteristics of potato

Potato quality is influenced by external parameters like skin colour, shape, size and eyes characteristics. Potatoes with many and deep eyes and uneven shapes increase peeling losses. Peeling losses also result from greened or damaged potatoes. Potatoes with irregular

shape, diseased or rotten, hollow hearted, sprouted, and greened are not of good quality because they increase peeling loss (Kabira and Lemaga, 2003; Lisiěska *et al.*, 2009). Damage due to mishandling, dumping or thrusting of potatoes induce changes in metabolism of potatoes thereby affecting their quality. Greening is caused by exposing potatoes to sun light thereby inducing formation of glycoalkaloids which are bitter, toxic if high in content and with unpleasing colour (Lisiěska *et al*., 2009). Processing quality of potatoes also depends on tuber size, shape, eye depth, number of eyes, blemishes and thickness of the skin (Lisiěska *et al*., 2009; Abong *et al*., 2010). Similarly, potato shape has an important implication during processing. Kabira and Lemaga (2003) suggested that potato for processing French fries should be long or long oval with 50 mm diameter or above, while the ones for crisps should be round oval between 40 to 60 mm diameters and that potatoes of above 60 mm are not preferred because they are susceptible to breaking during packaging. The recommended shape and size of potato was also confirmed by Genet (1992) where he reported that potatoes for French fries should be rectangular commonly known as " brick shaped" and the ones for crisps should be round ranging from 100 to 200 g as bigger sizes are prone to breakage during packaging. Round to oval potatoes are preferred for dehydrated products, oblong for French fries, round to oval for crisps and oval for canned potatoes (Marwaha *et al*., 2010). The appropriate size of potatoes for processing was also reported by other authors (Ekin, 2011;Ganga and Kulkarni, 2014) . Moreover, potatoes with white and yellow flesh are both preferred for crisps and French fries. White colour is mostly preferred for French fries and yellow for crisps (Genet, 1992). Potato skin and flesh colours are also important aspects that influence quality of potatoes. They include but not limited to white, cream, yellow, red, purple and pink and they contribute to customer attraction of fresh potatoes. Morphology of potatoes contributes to the external quality of potatoes and it is a good indicator of the potato quality.

2.6.2 Specific gravity of potato

Specific gravity is a quick indicator of potato quality. Potato specific gravity varies from one variety to another. Abebe *et al*.(2013) reported a wide range of specific gravity ranging from 1.050 to 1.119 from 25 varieties grown in three different areas. Specific gravity is categorized as high if it is above 1.086, intermediate between 1.077 and 1.086 and low if it is below 1.077 (Fitzpatrick *et al*., 1964). The specific gravity was reported to positively correlate with dry matter and starch by several authors (Ekin, 2011; Abebe *et al.*, 2013; Soboka *et al*., 2017). Feltran *et al.* (2004) confirmed positive correlation between specific gravity, dry matter, and yield in frying as well as negative correlation with reducing sugars and oil

absorption. It was revealed that increase of 0.005 in specific gravity is related to the increase by 1% of yield in chips (Genet, 1992; Vreugdenhil *et al*., 2007). The good quality of frying potato should be between 1.0701 to 1.0850 kg/l *(*Feltran *et al*., 2004). Low specific gravity is related to low quality and low yield. Similarly, roasting, baking and dehydrated products require potatoes with high specific gravity, while boiling and canning can use low specific gravity potatoes (Ekin, 2011). Specific gravity of potato should be taken into consideration while choosing potato for specific use.

2.6.3 Dry matter and starch content of potato

Dry matter and starch are interrelated in potato and play a major role in quality of potatoes for processing. Dry matter of potatoes ranges from13 to 37% with the average of 24% (Lister and Munro, 2000). It varies both within and between tubers and is higher in the outer part than in the core of the potato (Genet, 1992). Cacace *et al*. (1994) classified dry matter into three categories where potatoes with high dry matter have above 20%, intermediate are between 18 and 19.9% and low dry matter content are below 17.9 %. Excessive nitrogen fertilizer was linked to the reduction of dry matter and starch. The quality of potato reduces further during storage, while high phosphorus also reduces dry matter and starch content (Baniuniene and Zekaite, 2008). Dry matter is made of numerous compounds which are both soluble and insoluble in water. Starch content contributes up to 75% of the dry matter (Lister and Munro, 2000;Bandana *et al*.,2016). Starch content of potato on fresh mass ranges from 10 to 30% (Donnelly and Kubow, 2011). Dry matter increase with increase in starch content. Ganga and Kulkarni (2014) reported the starch content of potatoes ranging from 52.55 to 85.67% from ten varieties on dry weight basis. Potatoes with high dry matter are preferred for dehydrated products, stock feed and fried products (Lister and Munro, 2000). When the dry matter is to low the French fries or crisps will be too soggy and it requires a lot of heat to remove water and the yield will also be low. On the other hand, too high dry matter leads to hard products. Potatoes suitable for French fries have dry matter of 20 to 24% and up to 24% for crisps (Kabira and Lemaga, 2003). Crisps of low dry matter require more energy to remove water and more oil to replace it. Absorption of too much oil means low dry matter and the obtained crisps are soggy, oily with short shelf life and increase of production cost (Genet, 1992). High dry matter increases yield and less oil absorption during processing (Burke, 2016). High dry matter leads to products with unique texture, where crisps are crunchy, mealy and firm. Mealy texture is an indicator of high dry matter where tissues have dry appearance. They crumble during baking with physical disintegration and they are preferred for roasting,

mashing and frying, while wax-texture tubers show moist appearance with less disintegration during cooking and they are preferred for salads and creams (Feltran *et al.*, 2004). Variability in dry matter affects uniformity of processed products and quality.

2.6.4 Sugars of potato

The amount of sugars in potatoes varies among varieties and environmental conditions and they influence the quality of processed products. Total sugars vary from 0.05 to 8% with average of 0.5%, while reducing sugars vary from 0.0 to 0.5% with average of 0.3% on wet basis and above 2% of total sugars on dry basis (Lister and Munro, 2000). Sugars in potatoes are in form of monosaccharides (glucose and fructose) which are reducing sugars and disaccharide (sucrose) which is a non-reducing sugar. Potatoes with high amount of reducing sugars are not suitable for processing of dehydrated and fried potato products (Lister and Munro, 2000). Sugar content of less than 0.1% are preferred for chips of high quality, but it is difficult to achieve (Genet, 1992). On the other hand, it was reported that high reducing sugars lead to dark products, crisps should not be more than 0.2 to 0.3% and the ones for French fries should be up to 0.5% (Kabira and Lemaga, 2003). The amount of reducing sugars is related to factors like genotype, environmental conditions, cultural practices during growth, postharvest factors, and storage conditions (Kabira and Lemaga, 2003; Abong *et al*., 2009). Immature potatoes have a lot of sugars which reduce with maturity. Potentially good processing cultivars have sucrose of 1.91 mg/g and potentially poor have 4.53mg/g (Kumar *et al*., 2004). Storage at low temperature activates invertase which hydrolyzes sucrose into glucose and fructose in the process called "cold sweetening" and the ideal storage temperature of potatoes is 8-12^{o} C at relative humidity of 85 to 90% (Kumar *et al*., 2004;Kumar *et al.*, 2005). Moreover, at high temperature sugars dominated by sucrose also increase to the unacceptable level starting at 16^{o} C up to 28^{o} C in the process called senescence sweetening (Kumar *et al*., 2004). In the frying process, reducing sugars react with amino acids in the process of Maillard reaction. The reaction is favoured by high temperature and low moisture. High amount of reducing sugars is unacceptable as it leads to the formation of acrylamide which is a potential carcinogen (Zhu *et al*., 2010). This is associated with bitter and unfavorable brown colour of the products.

2.6.5 Free amino acids

Amino acids are building blocks of proteins. Amino acids in potatoes are present in two forms. They include protein forming amino acids and free amino acids. Free amino acids account for 40-60% of total amino acids (Vreugdenhil *et al.*, 2007). Free amino acids are affected by the same factors which affect protein content and they include variety, maturity

and fertilizer application (Vreugdenhil *et al*., 2007). Asparagine was reported as the highest free amino acid and the main co-reactant in acrylamide formation due to its interaction with reducing sugars. At harvest the major free amino acids are asparagine, glutamine, glutamic acid arginine and aspartic acid (Vreugdenhil *et al*., 2007). Nitrogen fertilizer increases glutamine content. It was reported that free amino acids vary from 73 to 137 mmol/kg DWB where asparagine contributes 14 to 29% (Burke, 2016). Free amino acids vary from one cultivar to another and they are main co-reactant in acrylamide formation when interacted with reducing sugars which reduces the quality of the product.

2.7 Processing of crisps and French fries

Potato is processed into crisps or French fries through deep frying in many countries. Crisps are very thinly sliced potatoes with around 1-1.5 mm thickness, which are deep fried at around 180^{o}C and they have moisture content of 1.3-1.5 %, while French fries are cut into thin slices of around 1 cm square in cross-section, they are fried to the golden colour at 180^{o}C with oil content of around 10% (Singh and Kaur, 2009). During frying some changes take place in fried products which include changes in physical, chemical and sensory characteristics where oil content, colour and texture are considered as the main parameters to define the quality of fried products (Arslan *et al.*, 2018). Frying oil contributes to the flavour of the products, the quality of fried potatoes is related to the amount of oil absorbed during frying (Arslan *et al*., 2018). During frying water soluble nutrients like ascorbic acid and potassium are maintained (Rojas-gonzalez *et al*., 2006). Oil used during frying contributes both nutritionally and as frying medium and it imparts flavour to the fried products. Frying process comprises four main steps. The first step consists of raising of the surface temperature of fried potatoes to reach the one of the frying medium which is oil, there is no vaporization of water and it lasts short time (Arslan *et al.*, 2018). The second consists of boiling of the water on the surface of fries or crisps followed by evaporation, and turbulent water increases by convection, crust formation starts to occur, shrinkage and pore formation and explosive evaporation is related to large pores (Arslan *et al.*, 2018). The third step is known as falling rate where the temperature in the core increases which leads to gradual reduction of water content and steam bubbles from the surface of the fried potatoes (Arslan *et al.*, 2018). The last step consists of disappearance of the bubbles from the surface (Arslan *et al*., 2018). Because of its large thickness, the core temperature for French fries is around 100^{o}C and for crisps the temperature rises a quite higher due to their thinly nature (Mellema, 2003). During frying there is loss of moisture and oil absorption simultaneously.

2.7.1 Oil absorption and moisture loss during frying

During frying oil is heated to temperature above boiling point of water which allows vaporization of water once fries or crisps are immersed into frying medium. French fries are fried to the moisture content of 38% and oil content of 15% (Aguilera and Gloria-Hernandez, 2000), while crisps are fried to the moisture content of 1.8 %, and oil content of 35% (Singh and Kaur, 2009). It was confirmed that one third of potato crisps is oil, while more than one third of French fries is water (Mellema, 2003). Oil absorption occurs both during frying and during cooling. Bouchon and Aguilera (2001) reported that during frying water and oil move in opposite directions. Oil content of fried products is divided into three categories including structural oil (STO) which is the oil absorbed during frying, penetrated surface oil (PSO) which is the oil suctioned into the food during cooling after removal from the fryer, and surface oil (SO) which is the oil that remains on the surface (Bouchon and Aguilera, 2001). It was reported that small amount of oil is absorbed during frying which may depend on frying rate and frying time *(*Bouchon *et al.*, 2003). However, most of oil is absorbed during cooling (Ziaiifar *et al*., 2008). Dana and Saguy (2006) reported that 70 to 80% of total oils are located on the surface and enter in the fried products through pores. This was confirmed by Saran and Chabra (2014) who reported that oil is located on the surface of French fries, while interior (core) is free from oil. Moreover, it was reported that 38% of total oil is absorbed during frying, while after cooling the situation is inverse where 65% of total oil is absorbed and 35% remains at the surface (Duran *et al.*, 2007). During frying there is water loss and oil uptake and they vary depending on the product.

2.7.2 Factors which favour oil uptake

The frying temperature and time have influence on oil absorption which is related to the type of product, its size and composition. Frying is done above boiling temperature of water and it is normally ranged from 120° C to 190° C (Saran and Chabra, 2014). Frying of thin products leads to increase in oil uptake as result of creation of many void spaces due to escape of water (Saran and Chabra, 2014). Thick slices absorb less oil because oil is restricted to the surface, it decreases with the increase of cross section (Mehta and Swinburn, 2001). The final oil and moisture content is 35 and 1.7% for chips and 15 and 38 for French fries respectively (Saran and Chabra, 2014). Frying at high temperatures (160–190° C) leads to quick heat transfer, and browning occurs in short time (Saran and Chabra, 2014). Recommended frying temperature is 180^{o} C in many countries, higher temperature results in excessive browning before cooking and low temperature stimulates more oil absorption where about 40% more oil is absorbed when temperature is reduced by 10% of recommended

temperature (Mehta and Swinburn, 2001). It was revealed that at temperature below 120^{o} C water removal is slow which increases frying time leading to the formation of spongy crust which favours oil entry (Saran and Chabra, 2014). Putting too much quantity of cold food into hot oil is not advisable due to quick reduction in temperature which takes longer cooking time and higher oil uptake. It is suggested that food to oil ratio should be 1/6 for better quality (Mehta and Swinburn, 2001). There are number of methods to reduce oil absorption which include coating with hydrophilic biopolymer (Mellema, 2003) and vacuum cooling (He *et al.*, 2013; Arslan *et al.*, 2018). On the other hand, high temperature favours formation of hard and compact crust which is resistant to oil absorption (Moyano and Berna, 2002). At very high frying temperature hard dark brown crust is formed which can also reduce acceptability of the product. Irregular surface affects oil absorption and absorbed oil is proportion to adhered surface oil, vigorous shaking directly after removal reduces oil absorption (Thanatuksorn *et al.*, 2005).

2.7.3 Acrylamide formation during frying

Acrylamide is a chemical compound formed as side product of Maillard reaction. It is a result of reaction between asparagine and reducing sugars which takes during baking, roasting, and frying at temperature above 120^{o} C (Pedreschi *et al.*, 2014). Acrylamide formation increases drastically at temperature above 175^{o} C and it is very high at 190^{o} C, it correlates with time and it reduces with reduction of temperature (Matthäus *et al.*,2004; Shojaee-Aliabadi *et al.*, 2013). Acrylamide increased by 60% from 170^{o} C to 190^{o} C (Shojaee-Aliabadi *et al.*, 2013). Acrylamide was reported to correlate positively with reducing sugars, but not with asparagine in crisps and French fries (Matthäus *et al.*, 2004; Zhu *et al.*, 2010; Shojaee-Aliabadi *et al.*, 2013). Storage at low temperature from 4 to 8 ^{o}C results in high reducing sugars which leads to higher acrylamide formation (Matthäus *et al.*, 2004). Acrylamide also increases with increase in surface area and reduction in thickness (Matthäus *et al.*, 2004). Acrylamide was reported as neurotoxic to human and as potential carcinogen (Pedreschi *et al.*, 2014). Increase in phenolic compounds correlated negatively with acrylamide formation (Zhu *et al.*, 2010). Blanching and washing reduced acrylamide by 65% (Matthäus *et al.*, 2004). It is recommended to reduce acrylamide to as low as possible due to its potention carcinogenicity.

2.8 Lactic acid fermentation

Fermentation, one of the oldest methods, has been used by people in different areas of the planet and it has been found to increase storage stability, palatability and availability of nutrients in fermented products (Steinkraus, 2002; Ray and Sivakumar, 2009). Fermented

foods are food substrates that are conquered by edible micro-organisms whose enzymes especially amylases, proteases and lipases hydrolyze the polysaccharides, proteins and lipids to non-toxic products with flavour, aromas and textures pleasant and attractive to the human consumers (Ray and Sivakumar, 2009). In case the product of enzyme activities have nasty odours or objectionable, unappealing flavours or poisonous products which can cause disease, the foods are designated as spoiled (Ray and Sivakumar, 2009). Lactic acid fermentation is done largely by lactic acid bacteria (LAB) which are a group of Gram -positive bacteria, anaerobic, non-spore forming, cocci or rods. Two types of lactic acid fermentation exists which include homo-fermentation and hetero-fermentation. Before fermentation occurs, there is split of glucose molecule into two molecules of pyruvate in the process of glycolysis (Das *et al*., 2016). In homo-fermentation, one molecule of glucose is transformed into two molecules of lactic acid (Das *et al*., 2016). For hetero-fermentation one molecule of glucose gives one molecule of lactic acid along with one molecule of ethanol and one molecule of carbon dioxide (Das *et al*., 2016). Lactic acid fermentation can be dry salted where fermentation is done on solid media or brine salted where food is submerged in a solution and in both cases the main byproduct of fermentation is lactic acid.

2.8.1 Fermentation conditions

Lactic acid fermentation is influenced by different conditions which include, water activity, pH, temperature, oxygen and nutrients. During fermentation there is decrease of pH which is an indicator that fermentation is taking place and it imparts the sourness to the products (Ray and Sivakumar, 2009). It was reported that LAB increased while other microbes reduced, reduction in other undesirable microbes like coliforms indicates their inhibition by LAB, this also indicates that they do not contribute in the acidification of fermented products (Kakou *et al*., 2010). pH contributes to the preservation and development of aroma and flavour of fermented products (Montet *et al*., 2014). Moreover, optimum temperature for fermentation is 20 to 30^{o} C and 50 to 55^{o} C for thermophiles, while those with cold temperature prefer 15 to 20^{o} C (Montet *et al.*, 2014). At high temperature the growth of homo-fermentation like *Lactobacillus plantarum* is favored resulting in low amount of acetic acid due to limited growth of hetero-fermentative LAB (Das *et al*., 2016). Yeast spoilage can occur with low concentration of carbon dioxide leading to poor shelf-life with dark colour and the ideal temperature for sauerkraut fermentation was reported to be 18^{o} C with range of 15 to 20^{o} C (Das *et al*., 2016). Lower temperature will constrain the start of fermentation and high temperature can cause an accelerated acid production resulting in undesirable flavour of the products (Das *et al*., 2016). Moreover, salt has the ability to change osmotic pressure. Different

microorganisms have their comfort zone for osmotic pressure. Modification of ordinary osmotic pressure affects growth and effectiveness of microorganisms. Low salt is more advantageous to the growth of hetero-fermentative like *Leuconostoc mesenteroides* which is more salt sensitive than others, while high salt concentration favours homo-fermentative but inhibit hetero-fermentative (Das *et al.*, 2016). Salt withdraws water from tissues which serves as substrates for LAB. It lowers water activity and inhibit the growth of non-salt tolerant microorganisms comprising pathogens (Das *et al.*, 2016). Salt together with acid inhibit growth of undesirable microorganisms and delay enzymatic softening. It was reported that insufficient salt leads to enzyme softening of sauerkraut which leads to products of undesirable flavour and salt concentration of 2 to 3% was suggested for fermentation of cabbage (Das *et al.*, 2016). Salt is needed for microbial growth and sensory property of the product. LAB required for fermentation are those with non-toxicity, stability, rapid acidification of the medium, resistance to bacteriocin and other processing conditions (Montet *et al*., 2014). LAB require nutrients and conducive environment for effective fermentation.

2.8. 2 Effect of fermentation on nutrients

Fermentation induces change in chemical composition of food. Reduction in nutrients was reported during fermentation of *fufu* flour using different starter culture. Protein content reduced from 1.65% to 1.14%, fat from 0.35% to 0.24%, fiber from 1.66% to 0.77%, ash from 1.31% to 0.54%, sugars varied from 5.21 to 4.41%, starch varied from 76.86 to 70.28%, while amylose increased from 19.80 to 21.30%, (Sobowale *et al*., 2007). Similarly, minerals were also affected by fermentation and with down trend except for Ca. Ca varied from 0.044 to 0.1%, Mg from 0.054 to 0.007%, K form 1.107 to 0.107%, Na from 0.0094% to 0.00 61%, Mn from 0.00038 to 0.002% , Fe from 0.002% to 0.0010%, Zn from 0.0009 to 0.000 438% and P from 0.06 to 0.01% (Sobowale *et al.*, 2007). Moreover, fermentation of sweet and bitter cassava showed reduction in nutrients composition. Total sugars were 2.2 mg/g for sweet cassava and 1.3mg/g for bitter cassava, after 24 hours they reduced to 1.43 mg/g for sweet and 1.16 for bitter and after 96 hours they reduced further varying from 0.75-0.8mg/g for both sweet and bitter cassava, reducing sugars varied from 1.23 to 0.91 in 24 hours for bitter cassava, and 1.3 to 1.4 mg/g for sweet cassava (Kakou *et al*., 2010). After 72 hours, 50% of reducing sugars in sweet cassava were degraded and for bitter cassava they were 20% (Kakou *et al*., 2010). However, it was reported that fermentation increases protein content and balance of amino acids, it also increases vitamin content like thiamine, riboflavin, niacin, and folic acids which have health benefits (Ray and Sivakumar, 2009). Reduction in some nutrients is related to their

utilization by LAB during fermentation. At the same time LAB can induce production of other useful compounds to the body.

2.8.3 Benefits of fermentation

Fermentation increases safety and availability of food. During fermentation there is production of compounds which inhibit growth of harmful microorganisms to grow in food. These compounds include lactic acid, alcohol, acetic acid and high salt used during fermentation (Steinkraus, 2002). These compounds also contribute to the pleasant flavour, aroma and texture of fermented food (Steinkraus, 2002; Ray and Sivakumar, 2009). At the same time fermented foods are enriched with vitamins, proteins, essential amino acids, and essential fatty acids (Steinkraus, 2002). There is also detoxification of fermented food and decrease in cooking time (Steinkraus, 2002). Kakou *et al.* (2010) reported reduction of cyanide in fermented cassava. Fermentation causes reduction of phytate which increases bioavailability of zinc, calcium, and iron content (Das *et al*., 2016). Lactic acid fermentation was reported to preserve ascorbic acid, glutathione and antioxidant activity during storage (Montet *et al*., 2014). Most of fermented roots and tubers are associated with lactic acid bacteria like *Lactobacillus, Leuconostoc, Streptococcus* and yeast like *Saccharomyces cerevisiae* which are considered as probiotics (Agrawal, 2005). Fermented food like *gari, fufu, lafun* are considered as functional foods as they are rich in dietary fibers, vitamins, essential amino acids and lactic acid (Ray and Sivakumar, 2009). Food rich in β-carotene, lutein and anthocyanin, vitamins, polyphenols, structural lipids and dietary fibers are designed as functional foods (Agrawal, 2005). These compounds have been reported for their health benefits like anti-aging, anti-cancer, protection against cataract, muscular degeneration and liver injury (Kaur and Kapoor, 2001). In addition to health benefits from probiotics, regular consumption of fermented lactic acid products enriched with pigments like anthocyanins, lutein and β-carotene is helpful for combating different diseases like night blindness, liver injury, aging and related ailment (Montet *et al.*, 2014). Fermentation with beneficial bacteria increases safety and nutritional quality of fermented products as well as numerous health benefits to the consumers.

2.9 Flour preparation

Flour is a powder obtained after milling cereals, roots or tubers. Apart from reducing moisture content of the products and milling them in small particles, chemical composition of the flour remains unchanged. Moisture content of flour less than 15% Adeleke and Odedeji (2010) or preferably less than 10% Onimawo and Akubor (2012) ensures storage stability. Cereals are milled after cleaning, washing and sorting, while legumes are soaked, dehulled,

dried and milled (Iwe *et al.*, 2016). Roots and tubers are sorted, washed, peeled, grated or sliced followed by drying and milling (Adeleke and Odedeji, 2010). However, in order to prevent browning reaction to occur, sliced potatoes are soaked in sodium bisulfate solution (0.5%) for around 10 minutes, drained and then dried at 45^{o} C for 48 hours in forced air oven (Cardoso *et al.*, 2015). Citric acid can also be added to prevent enzymatic reaction to occur. They may contribute to the change in pH. pH of wheat flour was reported to be 6.01 and 5.50 for sweet potato flour and addition of sweet potato flour in wheat flour reduced pH of wheat flour towards acidic pH (Adeleke and Odedeji, 2010). pH of flour influences its functional properties. Composite flour can be produced by blending flour from different origin like cereals, legumes, roots and tubers with or without wheat flour in order to enhance functional or nutritional properties. Functional property is related to the behaviour of ingredients during cooking or processing. It is also related to how they affect the final product like taste, appearance and feels.

2.9.1 Bulk density of flour

Bulk density is the density obtained without considering the influence of any compression. It is the the mass of a solid product which occupies a unit of volume including the voume of void spaces between particles making solid product. It varies from one type of flour to another. Bulk density obtained from composite flour of wheat, green gram, rice and potato ranged from 0.762 g/cm^3 to 0.820g/cm^3 (Chandra *et al*., 2015). Bulk density increased with increase of flour from rice, green gram and potato as well as with the decrease of wheat flour from composite flour, high bulk density is an indicator for suitability for use as thickener in food products (Chandra *et al*., 2015). Wheat flour was reported to have higher bulk density than sweet potato flour (Adeleke and Odedeji, 2010). Bulk density is associtated to geometry, particle size, and initial moisture content of flours (Adeleke and Odedeji, 2010; Chandra *et al*., 2015; Iwe *et al*., 2016). Bulk density increases with increase in starch content (Iwe *et al.*, 2016). Bulk density is used for prediction of required packaging material where higher bulk density requires denser packaging material (Iwe *et al*., 2016). On the other hand, low bulk density is advantageous for preparation of complementary food (Badifu *et al*., 2000; Omueti *et al*., 2009). Bulk density of food is important for both packaging and nutrition purposes.

2.9. 2 Water absorption capacity of flour

Water absorption capacity of flour is the amount of water absorbed by unit mass of flour. A study conducted on composite flour from green gram, rice and potato flour showed water absorption capacity ranging from 132 to 176% in blended flours (Chandra *et al.*, 2015).

Potato flour had the highest water absorption capacity of 752% (Chandra *et al*., 2015). Increase in water absorption after addition of potato flour in composite flour was associated to leaching of amylose, solubility and loss of starch crystallinity in potato flour (Chandra *et al.*, 2015). High WAC may be related to weakening of forces between amylose and amylopectin in starch granule resulting in weak association of starch granules and it is important when bulky is needed in the products like in bakery, flour with high WAC is preferred for bread making (Iwe *et al*., 2016). High amount of water absorption capacity is an indicator for food which can be used in products like sausage, dough, cheese and bakery products (Chandra *et al.*, 2015). The flour with high water absorption capacity has more hydrophilic compounds like polysaccharides. Protein has both hydrophilic and hydrophobic ends and it can interact with water in the food, where viscosity is required like in soup and gravies, flour with high WAC can be used (Chandra *et al*., 2015). Water absorption capacity varies from one type of flour to another and it is important in products where bulky is needed.

2.9.3 Oil absorption capacity of flour

Oil absorption capacity is the quantity of oil absorbed by unit mass of flour. Oil absorption capacity of composite flour from wheat, green gram, rice and potato flour ranged from 130 to 156% (Chandra *et al.*, 2015). It was reported that oil absorption of wheat flour increased with increase of other flours, the increase in oil absorption might have been caused by increase of hydrophobic groups from added flours (Chandra *et al.*, 2015). On the other hand, oil absorption capacity of composite wheat and sweet potato flour decreased with increase of sweet potato flour (Adeleke and Odedeji, 2010). Oil absorption was reported to be 0.46, 1.45 and 1.48 g/ml for rice, cowpea and African yam bean flours respectively (Iwe *et al.*, 2016). Proteins are the major compounds responsible for oil absorption due to their hydrophobic and hydrophilic nature (Adeleke and Odedeji, 2010; Chandra *et al*., 2015). Food with high oil absorption capacity are useful in flavour retention, improvement of palatability, and extension of shelf life of the products (Chandra *et al*., 2015). Furthermore, oil absorption in food improves mouthfeel and flavour retention which is important property in food formulation (Iwe *et al*., 2016). Oil absorption contributes to functional, nutritional and palatability of food.

2.9.4 Emulsification capacity and emulsification stability flour

Emulsification capacity of flour is the ability of its protein or its suspension to disperse oil in water, while emulsification stability is its ability to withstand drastic conditions like gravitational and processing forces. Emulsification of different flour blends ranged from 41.49 to 44.69% for emulsification capacity and from 38.38 to 48.65% for emulsification stability

(Chandra *et al.*, 2015). Emulsification capacity and emulsification stability increased with decrease of wheat flour up to 55% (Chandra *et al*., 2015). Sweet potato flour was reported to have emulsion capacity of 25.40% and 14.68% for wheat flour (Adeleke and Odedeji, 2010). Similarly, emulsification capacity was 42.50, 56.78 and 56.67% for rice, cowpea and African yam bean flours respectively and high emulsion was related to high protein content (Iwe *et al.*, 2016). Increase of emulsification capacity and emulsification stability are related to properties of protein to bind fat which imparts suitability in application in food like comminuted meat products, salad dressing, frozen desserts and mayonnaise (Adeleke and Odedeji, 2010; Chandra *et al.*, 2015).

2.9.5 Foaming capacity and foaming stability flour

Foam is colloidal of numerous gas bubbles enclosed in liquid or solid and it is a property of protein. In wheat, green gram, rice and potato composite flour, foaming capacity varied from 12.92 to 17.60%, while foaming stability ranged from 1.94 to 13.40% (Chandra *et al*., 2015). Foaming capacity and foaming stability increased with increase in blending ratio and the inverse relationship between foaming capacity and foaming stability was reported and it might have been caused by flour with high foaming capacity to form big bubbles surrounded by thinner and less flexible protein film which might have collapsed easily (Chandra *et al*., 2015). Wheat and sweet potato composite flours revealed high foaming capacity of 4.12% in wheat flour and 1.28% in sweet potato flour alone, more additional of sweet potato to wheat flour reduced foaming capacity (Adeleke and Odedeji, 2010). Rice flour had high foaming capacity of 10.40%, cowpea and AYB (African Yam Bean) had 18.17% (Iwe *et al*., 2016). Foaming capacity and stability contribute to the improvement of texture and appearance of the product, good foaming capacity and stability are desired in products like cookies, angel cakes, muffins and akra (Iwe *et al*., 2016). Foaming capacity and stability depend on source of flour and they have important functional contribution during processing.

2. 10 Potato starch characteristics and digestibility

Potato is characterized by its morphology, granular stach size and shape as well as chemicals content. Stach form different sources differ in size, shape and composition which all together contribute to its digestibility.

2.10. 1 Morphology of potato starch

Starch size and shape are the main characteristics of starch granules and they vary depending on their sources. Granular size was reported to range from 3-54 µm for cassava, 10-30 µm for maize, 1-100 µm for potato, 2-10 µm for rice and 2-38 µm for wheat (Tomasik,

2008). Roots and tubers revealed to have granular size of 1.05-40.15 µm for sweet potato, 1.05-36.08 µm for cassava and 1.62-68.58 µm for potato (Abegunde *et al*., 2012). It was up to 150 µm for potato and larger than other crops (Tomasik, 2008). Granular shapes differ depending on starch origin, it is polyhedral, and round for corn; cluster, angular and polygonal shape for rice; round, spherical, or polygonal in shape for wheat; round, spherical and truncate for tapioca and oval with flattened and ellipsoid granules for potatoes (Romano *et al.,* 2016). Abegunde *et al.*, (2012) reported the shape of potato starch to be round and oval, while the ones of sweet potatoes and cassava varied from polygonal, round, oval, cupoliform, and bell shapes. Starch of granular size above 25 µm are classified as large, 10-25 µm as medium, 5-10 µm as small, and less than 5 µm as very small (Lindeboom *et al*., 2004). It was revealed that membrane and physical characteristics of plastids are in control for contributing in a particular shape or morphology to granular starch during development (Lindeboom *et al*., 2004). Granular size, and particle size distribution are responsible for functional properties like swelling capacity, solubility and digestibility (Moorthy, 2002).

2. 10. 2 Phosphorus content of potato starch

Phosphorus is an integral part of potato starch and the form of phosphorus in potato starch is different from the one in cereals which also influence on functional properties. Phosphorus content of starch varies from one crop to another and it was found to be higher in potato comparing to other crops. It was reported to be 0.076% in potato, 0.007 to 0.012% in cassava, 0.020% in maize, 0.007% in rice and 0.045% in wheat (Tomasik, 2008). Similarly, phosphorus starch was reported to be 0.0995%, 0.021% and 0.018% for potato, sweet potato and cassava respectively (Abegunde *et al.*, 2012). Phosphorus content in three potato varieties ranged from 0.057 to 0.095% (Donner *et al.*, 2009). Organically grown potatoes had lower phosphorus than conventionally grown (Donner *et al.*, 2009). Phosphorus in starch is present in three main forms like phosphate monoesters, phospholipids and inorganic phosphate (Alcázar-alay and Meireles, 2015). Phosphorus in cereal starch is mainly phospholipid; while in roots and tubers is mono phosphate ester which is covalently bound to starch on C-6 bond (Alcázar-alay and Meireles, 2015). This has influence on functional properties of starch as phosphate in potato acts as polyelectrolyte. High phosphorus content could be responsible for high viscosity and it improves gel strength and high phosphorus starch could be used in food application requiring high gel strength (Abegunde *et al.*, 2012).

2.10. 3 Digestibility of potato starch

Starch digestion is done mainly by amylase enzymes. Amylose is hydrolyzed into maltose and maltotriose, while amylopectin is hydrolyzed into dextrins and oligomers formed by α-1,6 linkages, it is after arriving at the end of the intestine all of these polymers are hydrolyzed to glucose by enzymes which include α-glycosidase and oligo-α-1,6-glucosidase (Alcázar-alay and Meireles, 2015). α-Amylase degrades α-1, 4 glycosidic bonds randomly into dextrins which are further degraded into maltose by ß- Amylase which breakes down α-1,4 glycosidic bonds starting from non-reducing ends. Starch digestion is divided in different fractions based on its digestibility and in vitro digestibility is carried out at 37^{o} C to mimic human conditions (Amin *et al*., 2018). The Very Rapidly Digestible Starch (VRDS) is the amount of starch digested within one minute of onset of digestion, Rapidly Digestible Starch (RDS) is the amount of starch digested within 20 minutes of onset of digestion, and Slowly Digestible Starch (SDS) is the starch digested in the interval of 20 and 120 minutes of onset of digestion and any starch which is not digested within 120 minutes is considered as resistant starch (Amin *et al.,* 2018). Similarly, starch digestibility can be estimated based on glucose released by measuring Rapidly Available Glucose (RAG) and Slowly Available Glucose (SAG) to describe the likelihood of glucose released in the small intestine. RAG is the amount of glucose released within 20 minutes and SAG is glucose released between 20 and 120 minutes (Englyst *et al*., 2003). The logic for choosing 20 minutes for RDS is that most digestible starch like for white bread and homogenized starch are converted into glucose in the first 10 minutes in vitro, and only 5-10 % in the next 10 minutes, while 120 minutes were taken by imitating in vivo study using ileostomy subject where the time was enough for release of glucose (Zhang and Hamaker, 2009). The rate of starch digestibility depends on source of starch to be digested and pretreatment undergone before digestion.

Potatoes are digested at different rate depending on the mode of pretreatment. Digestibility of cooked potatoes revealed that RDS and SDS were below 5% of total starch in raw potatoes, cooking converted almost all starch digestible where above 95% were in RDS for freshly cooked potatoes, and cooling reduced RDS to around 45% of total starch and after freezing SDS was 35% and RS 4% (Mishra *et al*., 2008). RS fraction differ depending on varieties (Mishra *et al*., 2008). Effect of cooking on digestibility was also reported by Tian *et al*.(2018) using simulated stomach starch hydrolysis where 43.30, 41.93 and 31.72% of total starch were hydrolyzed after 5 minutes for boiled, stir-fried and fried potatoes and it increased to 82.21%, 68.19 and 53.45% after 120 minutes of hydrolysis for boiled, stir-fried and fried respectively. Cooling of cooked potatoes results in retrogradation which converts RDS to SDS

or back to RS. Reduction of RDS in favour of SDS and RS was also reported by Mishra *et al.* (2008). Processing reduces amount of resistant starch and the amount of resistant starch increases on cooling in the process of retrogradation.

2.10.4 Resistant starch in potato starch

Resistant starch is the total amount of starch which is not digested in the upper gastro-intestinal tract and passes into the colon where it is fermented by colonic bacteria. The contribution of glycemic by This starch does not contribute straight to blood glucose levels (Sajilata *et al.*, 2006; Zhang and Hamaker, 2009). According to Topping and Clifton (2001), resistant starch is divided in four groups which include RS1 which is physically inaccessible to digestive enzymes and it is protected by protein matrix or cell wall and it is mainly found in legumes, cereals and pasta. The second type RS2 is due to native, uncooked semi-crystalline starch granules protected from digestion by the structure of starch granules like in B or C polymorphs like in uncooked banana or uncooked potato. The third type RS3 is related to retrograded starch which is formed by cooling of heated food. The fourth category RS4 encompasses modified starch. Resistant starch contributes nutritionally to the health of consumers.

Resistant starch is beneficial to human due to its contribution to preventing occurrence of various types of diseases. Food with RS can slow or moderate the rate of starch digestion (Sajilata *et al*., 2006). The byproducts of indigestible carbohydrates are short chain fatty acids (SCFA), acetate, propionate, and butyrate. Acetate and butyrate are the main byproducts of fermentation where butyrate participates in regulation of cell proliferation and differentiation (Wong and Jenkins, 2007). Acetate has the ability to lower plasma free fat acids (Ferchaud-Roucher *et al*., 2005). Propionate was reported to reduce cholesterol synthesis (Wong and Jenkins, 2007). Butyric acid produced during fermentation of resistant starch was reported to have anti-carcinogenic effect (Lehmann and Robin, 2007). It was also revealed that resistant starch can increase satiety and reduce glycemic index (Nofrarías *et al*., 2008). Therefore, in order to increase health effect of processed products, it is better to preserve identity of resistant starch or use processing conditions which will enhance resistant starch in processed products. Nofrarías *et al.* (2008) reported that resistant starch were found in prevention of pathogens and diarrhea, protection of chronic diseases like reduction of colon cancer and in treatment of ulcerative colitis. RS can be considered as prebiotic and it was linked to the promotion of useful bacteria like bifidobacterium (Sajilata *et al*., 2006).

2.10.5 Factors affecting potato starch digestibility

Digestibility of starch is related to the interaction of different factors which include source, granular morphology, type of crystalline (A, B and C), lipid-amylose complexes and processing conditions (Sajilata *et al.*, 2006). Similarly, it was reported that digestibility rate and efficient of starch depends on granular size, the polymorphism, structure of amylopectin and amylose content, lipid content, enzyme activity and it was observed than small granular size are digested more rapidly than big size due to surface volume ratio (Tester *et al*., 2004; Noda *et al.*, 2008). Amylose content is negatively correlated to starch digestion. Amylose/amylopectin ratio in potato is 1:3 (Camire *et al*., 2009). This ratio indicates why potato starch is easily digestible as amylopectin is branched and easily gelatinized (Camire *et al*., 2009). Amylase digestion is prevented by esterified phosphate attached to glucosyl residue which yield phosphoryl-oligosaccharides (Noda *et al*., 2008). Starch of type A polymorphic like rice are digested easier than type B and C from potato. Type A allows occurrence of weak points in crystalline area for enzyme activity, while in type B these branching points are in amorphous region which leads to perfect crystalline structure this leads to type A being digested slowly while type B resists digestive enzymes (Zhang and Hamaker, 2009). Potato starch was reported to be less digestible comparing to sweet potato and cassava. This was attributed to their crystalline nature which is A for sweet potato and cassava and B for potato (Abegunde *et al*., 2012). Immature potatoes are digested more slowly due to high amylose content than mature potatoes. Starch in raw potato is resistant to digestive enzymes because it is encapsulated in starch granules. However, when cooked, starch swells and continuing cooking leads to rupture of cell wall which facilitates digestion and this increases digestive index of potatoes (Lehmann and Robin, 2007).

2.10.6 Glycemic index and glycemic load of potato starch

Glycemic index (GI) is a physiological approach to classify food based on their ability increase glycemia on the scale from 0 -100. It is known as incremental area under the blood glucose response curve produced by 50 g portion of available carbohydrate of a test food expressed as percentage of the response after a 50 g portion of glucose (reference food) taken by the same subject (Singh and Kaur, 2009). The reference food is used to correct variations between subjects. Rapidly digestible starch (RDS) or rapidly available glucose (RAG) are absorbed in the duodenum and proximal areas of the small intestine, it is attributed to the increase in blood glucose (Zhang and Hamaker, 2009). GI is classified in three categories based on the rate of starch absorption. GI above 70 is high, between 70 and 55 is intermediate and

below 55 is low (Eleazu, 2016). On the other hand, glycemic load (GL) also known as glycemic response is related to how much carbohydrates is in the food and how every gram in the food contributes to glycemia. Glycemic Load (GL) is obtained by multiplying glycemic Index (GI) with available carbohydrates divided by hundred and available carbohydrates is made of starch and sugars (Eleazu, 2016). Glycemic load is classified as low if less than 10, intermediate between 11 and 19, and high if above 20 (Eleazu, 2016). Regular consumption of RDS can lead to the production of free radical responsible of oxidative stress which is responsible for different diseases (Brownlee, 2005). However, some people like athletes are encouraged to eat food with high GI (Wee *et al*., 2014) but not very often (Stevenson *et al.*, 2009). Nevertheless, SDS or SAG is attributed to slow increase of postprandial blood glucose with the ability to maintain blood glucose to the desired level (Lehmann and Robin, 2007). Food with greater SDS than RDS are in category of intermediate or low GI (Englyst *et al*., 2003; Lehmann and Robin, 2007). Low glycemic index were found to play a role in reducing risks of CVD, diabetes, and certain cancers (Wong and Jenkins, 2007). GI index is an indicator of how food increases blood glucose after consumption and vary from one type of food to another and with preparation methods.

Glycemic index of food can be moderated during preparation. Reduction in GI was associate to pre-cooking, freezing and then reheating process which favours formation of SDS and RS (Garcia-Alonso and Goni, 2000). Another theory is that amylose-amylopectin formed during frying and or reheating is slowly digested by alpha-amylase (Garcia-Alono and Goni, 2000). Fat increases the time food stays in the stomach thereby slowing down the rate of starch digestion in intestine which reduces glycemic index (Eleazu, 2016). Cooking followed by cooling results in reduction of RDS, increase of SDS and RS and reduction in GI (Mishra *et al.*, 2008). Starch retrogradation was associated to reduction in digestibility. Moerover, it was reported that potatoes had glycemic index of 93 and dropped to 39 after complementing it with cheddar cheese (Henry *et al.*, 2006). Addition of organic acid reduces glycemic index, adding vinegar in boiled potatoes reduced GI by 31% from 168 to 96 based on bread reference (Singh and Kaur, 2009) . Glycemic index is related to increase of glucose in blood due to carbohydrate present in food. It was found that frequent consumption of food with high level of GI can increase risk of Diabetes mellitus, while low level can reduce the risk of diabetes and cardiovascular disease. Hyperglycemia is also associated to the consumption of simple sugars like glucose and maltose.

2.11 Gap in knowledge

Potato production in Rwanda has increased considerably since the beginning of the last decade. Potato processing industries are being introduced to cope with the high production. However, they rely only on one variety called Kinigi. This is because no study has been done on how different potato cultivars respond to the processing of different products. Morphological and biochemical parameters which determine potato quality have not been researched on potatoes grown in Rwanda nor chemical and sensory characteristics during processing. Unearthing morphological and chemical characteristics of potato cultivars grown in Rwanda as well as chemical changes will help on relating potato cultivars grown in Rwanda to quality of processed potato products. This will increase earnings for producers and help processing industries to make correct choice of potato cultivars for processing.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Study site

Potatoes were grown in Busogo farm of the University of Rwanda located in Musanze District, Northern Province of Rwanda. It is geographically located at 1° 33'26'' S and 29° 32'39''E. The site is characterized by Andosol due to volcanic soil. The average temperature is 16.2° C with average annual rainfall of 1420 mm (Climate-Data.Org, 2016). Laboratory analyses were carried out at the University of Rwanda, College of Agriculture, Animal Science and Veterinary Medicine (UR-CAVM) in Rwanda and Egerton University in Kenya.

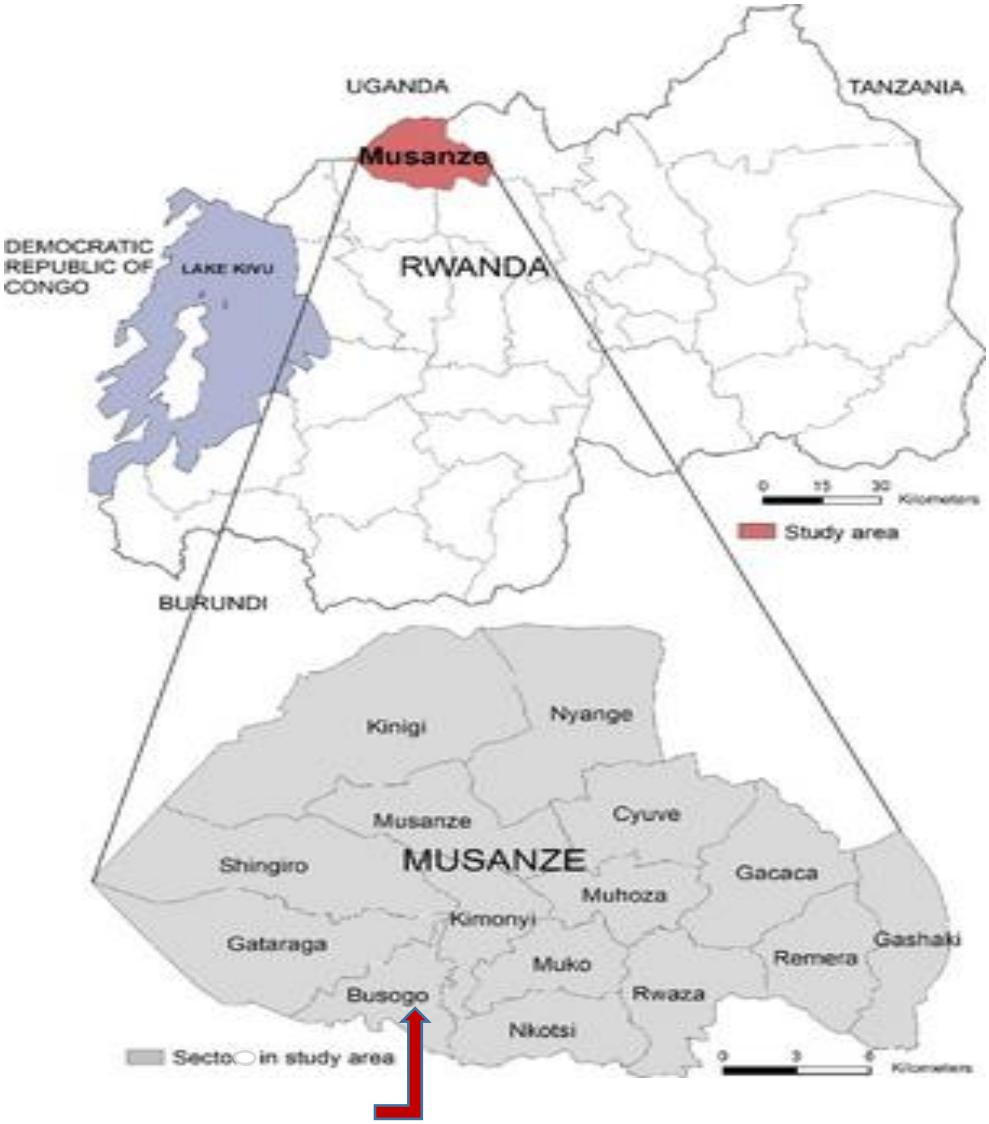


Figure 3. Map of Rwanda showing where potatoes were grown

Source: Akinyemi (2017).

3.2 Experimental design

Potatoes were grown in UR-CAVM Busogo farm. They were grown in Randomized Complete Block Design (RCBD). Planting materials were obtained from Rwanda Agriculture Board (RAB). Six varieties *viz.* Gikungu, Kigega, Kinigi, Kirundo, Mabondo,and Sangema and four clones *viz.* CIP399075.22, CIP392617.54, CIP393251.64 and CIP399062.115 were planted. Experimental unit of 3.2 x 1.8 m^2 was used. Adjacent plots were separated by guard rows of 0.8 m with spacing of 80 cm between the rows and 30 cm within the rows. They were grown under standard cultural conditions in the year of 2016/17. Fertilization rate was 300 kg of compound fertilizer NPK 17-17-17 per hectare. Laboratory experiment was laid out in Completly Randomized Design (CRD) in three replications and ten treatments representing cultivars known as factors in this experiment.

For the laboratory experiment the following linear model was used

$Y_{ij} = \mu + \alpha_i + \varepsilon_{ij}$…… (1)

where;

Y_{ij} = Overall observation

μ = Overall mean

α_i = Effect due to i^{th} cultivar (variety/clone)

ε_{ijk} = Random error

In the second, the third, the four and the fifth objectives, the best cultivars were selected based on their promising processing characteristics like high specific gravity, high starch content, high dry matter and low reducing sugars. The selected five cultivars included Kinigi, Kirundo, Mabondo, Sangema and CIP393251.64. For sensory analysis, 37 semi trained panelists were used and the experimental design was Randomized Complete Block Design (RCBD).

The following linear model was used for sensory evaluation:

$Y_{ijk} = \mu + \alpha_i + ß_j + \varepsilon_{ijk}$…… (2)

where;

Y_{ij}= Overall observation

μ= Overall mean

α_i= Effect due to i^{th} cultivar

$ß_j$= Effect due to j^{th} replicate (panelist)

ε_{ijk}= Random error

For fermented potatoes the following linear model was used

$Y_{ij} = \mu + \alpha_i + ß_j + (\alpha ß)_{ij} + \varepsilon_{ijk}$……..……..…… (3)

where;

Y_{ij}= Overall observation

μ= Overall mean

α_i= Effect due to i^{th} cultivar

$ß_j$= Effect due to j^{th} fermentation

$(\alpha ß)_{ij}$ = effect of interaction between i^{th} cultivar and j^{th} fermentation

ε_{ijk}= Random error

3.3 Raw sample preparation and analysis

Healthy potatoes of processing size of 40 mm diameter and above were selected for biochemical analysis. About one kilogram of fresh potatoes was selected randomly from the central rows of each plot. They were washed in portable water, grated into small pieces and sundried for one day. They were then ground into powder, kept in clean dry containers and refrigerated (4±2) ^{o}C for further analysis. Potato powder was thoroughly mixed and used for biochemical analysis and the results were converted in fresh weight basis using the method used by Reiling (2011).

3.3.1 Morphological quality of potato

Skin colour, flesh colour, eye depth, size and shape were analyzed using the method used by Abong *et al*.(2010). Ten tubers from each cultivar were picked at random and their skin colours were described as red, yellow, white, pink or purple. The potato was then cut into halves and the flesh was described as yellow or white. Tuber shapes were characterized as oblong, round or oval. Eyes were measured using a Vernier caliper (NSK Nippon Sokutei, Japan) and a ruler. They were classified as shallow (0.00-0.20 mm), medium (0.20- 0.50 mm) or deep (> 0.50 mm). For potato size, potatoes from ten hills of the central of the plot were used to measure tuber size after washing them in tap water. The size was classified into four categories based on their potential utilization and they included < 40 mm, 40-50 mm, 50-60 mm and > 60 mm diameters. Grading was done using grids made for that purpose, and tubers in each grade were weighed and percentage was calculated.

3.3.2 Specific gravity and dry matter

The method suggested by CIP (2006) was used for specific gravity and dry matter. For specific gravity, potatoes were washed, dried and around 5 kg were weighed in the air and in the tap water. Specific gravity was calculated as follows:

$$\text{Spefific gravity} = \frac{\text{Weight in air}}{\text{Weight in air} - \text{weight in water}} \quad \ldots\ldots (4)$$

For determination of dry matter, nine potatoes of processing size were sliced and thoroughly mixed. Thereafter about 10 g were weighed in a crucible with three replications and heated in forced air oven at 80^{o}C for 72 hours or until constant weight was obtained. The dry matter was calculated using the formula below

$$\text{Dry matter \%} = \frac{\text{Dry weight}}{\text{Fresh weight}} \text{ x100} \quad \ldots\ldots (5)$$

3.3.3 Determination of potato starch

The method of AOAC (2000) no 25.1.11 was used for determination of potato starch. About 3 g of samples were weighed into 250 ml volumetric flask. Amount of 200 ml of distilled water was added followed by 20 ml of concentrated HCl and 3 glass beads were added. The solution was refluxed until a clear solution was obtained. The solution was neutralized by adding 50% NaOH and 3 drops of phenolphthalein were used as indicator followed by filtration with Whatman no 541 with pore size of 20 -25 µm into a 250 volumetric flask and diluted to the mark with distilled water. For the analysis of sugars Fehling solution was used following the method of Lane-Eynon.

$$\text{Starch, g per 100g} = \text{\% Total sugar x 0.9} \quad \ldots\ldots (6)$$

3.3.4 Determination of reducing sugars, non-reducing sugars and total sugars

The Lane and Eynon titration method using Fehling's solution was used for determination of reducing sugars (RS) and total sugars (TS) (AOAC, 2000) no 925.35. Ten grams of sample were homogenized in 100 ml distilled water to dissolve all suspended particles and afterward filtered with Whatman no 541 pore size of 20-25 µm in a 250 ml volumetric flask. From filtrate, 10 ml of diluted HCl was added and boiled for 5 min. The obtained solution was allowed to cool at room temperature and neutralized with 10% NaOH using 3 drops of phenolphthalein as an indicator. It was there after made up to volume in a 250 ml volumetric flask with distilled water. The solution was titrated with Fehling's solution using 3 drops of methylene blue as an indicator and readings were recorded at the brick red end point and calculation used the formula below:

$$\text{Reducing sugars \%} = \frac{4.95 \text{ (factor)x } 250 \text{ (Dilution) } X\ 100}{\text{Weight of the sample x Titre x } 1000} \ldots\ldots\ldots (7)$$

$$\text{Total sugars \%} = \frac{4.95 \text{ (factor)x } 250 \text{ (Dilution)x } 2.5 \text{ X}100}{\text{Weight of the sample x Titre x } 1000} \ldots\ldots\ldots (8)$$

Non-reducing sugars were computed as the difference between total sugars and reducing sugars.

3.3.5 Determination of crude protein of potato

Analysis was done using the method described by AOAC (2000) no 960.52. All chemicals were analytical grade. Catalyst used was selenium (IV) dioxide. A solution made of 50% NaOH was prepared by dissolving 500 g of sodium hydroxide in distilled water and made up to one liter. The second solution consisted of 4% boric acid where 40 g of boric acid were dissolved in hot distilled water, cooled and made up to one liter and 3 ml of methyl red/bromocresol green solution were added and the colour was light green. The third solution was made of methyl red/bromocresol green indicator solution where 0.2 g of methyl red was diluted in 100 ml of 95% ethanol. Similarly, 1g of bromocresol green was diluted in 500 ml with 95% ethanol. Mixing ratio of indicator was one in five for f methyl red and bromocresol green respectively. The fourth solution consisted of 0.1 N hydrochloric acid standard solution where 8.3 ml from concentrated hydrochloric acid was pipetted into approximately 500 ml of distilled water in one liter volumetric flask soaked in ice cold water. The solution was cooled, diluted to the mark and allowed to stand three days before analysis. To standardize HCl, amount of 0.47g of sodium tetraborate decahydrate (borax) was weighed into 250 ml conical flask, dissolved in 250 ml of water and three drops of methyl red indicator solution were added. The solution was titrated with hydrochloric acid until the colour changed to pink at end point. Methyl red indicator solution was made of 1g of methyl red dissolved in 600 ml of alcohol and diluted with 400 ml of water.

$$\text{Normality} = \frac{\text{weight borax (g) X } 1000}{\text{mls HCl titrant X } 190.72} \ldots\ldots\ldots (9)$$

About 0.5 g of dried ground potato samples were put in a 100 ml digestion tube, 20 ml concentrate H_2SO_4 was added and then selenium was added as catalyst. It was put in digester till the white fumes appeared and the samples became clear and colourless. An Erlenmeyer flask of 250-500 ml containing 50 ml of 4% boric acid with indicator as receiver was placed on the distillation unit (R.Espinar,S.L, no 33230, SR: E1602257314, Barcelona, Spain). The tip of the condenser was extended below the surface of acid solution. To the digest 100 ml of

water and 70 ml of 50% NaOH were added and then distillation started. NaOH was in excess to neutralize all sulfuric acid and to ensure complete release of ammonia. Distillation was done until all ammonia was completely released or approximately above or equal to 150 ml of distillate was obtained. Thereafter the distillate was titrated with standardized 0.1N hydrochloric acid until the first appearance of pink colour. The volume of HCl used was recorded.

$$\text{N (g\%)} = \frac{(\text{ml 0.1N HCl} - \text{ml 0.1N blank}) \text{ X } 0.00\ 14 \text{ X N HCl X } 100}{\text{weight of the sample}} \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

$$\text{Crude protein (g per 100 g)} = \text{\% total nitrogen X } 6.25 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

3.3.6 Determination of crude lipid of potato

Crude lipids were determined using AOAC (2000) no 963.15. Dry clean round bottom flasks were put in oven set at 105^{o} C for 1 hour to dry. They were cooled in a desiccator and weighed. About 5.00 g of the sample was weighed and put it in a thimble. It was covered with cotton wool. The thimble and contents were put into the soxhlet extractor. The receiver flask was connected to the extractor and the extracting solvent (petroleum ether, B.P. 40-60° C) was added. The extractor was filled with solvent and allowed to drain to the flask and the extractor was filled with solvent again. The extractor was connected to the condenser and placed on the heating system (extraction mantle, model AV.SM-4, Serial number 338). Extraction took 8 hours, the thimble was removed and extracting solvent was recovered by evaporating and emptying the solvent in a beaker dried in oven at 105^{o}C for 30 minutes. The flask was cooled in desiccator and weighed.

$$\text{Crude Lipids(g\%)} = \frac{(\text{Weight of flask after extarction} - \text{weight of flask before extraction})\text{X}100}{\text{weight of the sample}} \ldots (12)$$

3.3.7 Determination of crude fiber of potato

The method used by AOAC (1995) no 962.09 was adopted. The reagents consisted of 1.25% sulfuric acid and 1.25% of sodium hydroxide. About 2.00 g of dried samples were weighed into a graduated glass beaker and 100 ml of hot water was added before adding 25 ml of 1.25% sulfuric acid. The volume was increased to 200 ml with hot water and the contents were boiled for 30 minutes. Timing started onset of boiling and the volume was kept at 200 ml by constantly adding hot water with gentle boiling. After 30 minutes, they were vacuum filtered using filter sticks packed with glass wool and washing was done three times with hot water. Thereafter, about 100 ml of hot water was added before adding 25 ml of 1.25% sodium

hydroxide and the volume was increased to 200 ml with hot water and kept constant during boiling by adding hot water. The filter sticks were allowed to remain in the solutions with residue and boiled for 30 minutes. After they were removed, filtered, and washed three times with hot water. Residues and glass wool were transferred into a 75 ml porcelain dish. The beaker with all residues were washed using hot water into the dish while filtering. Further washing was done with 5 ml ethyl alcohol to remove pigments like chlorophyll and carotene. The glass wool was pushed out into silica dish and wiped out any sample on it using glass wool soaked with ethyl alcohol. The dishes with contents were dried in an oven (type SO, FNr 862187, Schwabach, W-Germany) set at 105^{o} C overnight, cooled in desiccator and weighed accurately. They were placed in the furnace and allowed to ash at 600^{o} C for 4 hours. Thereafter, they were allowed to cool to about 100^{o} C and then continue cooling in a desiccator to room temperature and weighed.

$$\text{Crude Fibers (g\%)} = \frac{(\text{Weight of oven dried sample} - \text{weight of ashed sample})\ X\ 100}{\text{weight of fresh sample}} \quad (13)$$

3.3.8 Determination of ash content of potato

Crude ash was determined using AOAC (2000) no 923.03. Cleaned marked silica dishes were placed in the oven set at 105^{o} C for one hour. They were cooled in a desiccator and quickly weighed. About 2.00 g of sample were weighed and added into the dishes. The dishes containing samples were placed into the furnace (serial 10/88/1606, type GLM11/2, Birmingham, England) set at 600^{o} C and the temperature was allowed to rise gradually and ashing was done for 4 hours. The furnace was switched off and allowed to cool to about 100^{o} C before transferring into desiccators for cooling down to room temperature. The dishes were quickly weighed one by one immediately after removing from the desiccator as they are hydroscopic.

$$\text{Ash (g\%)} = \frac{\text{weight after ashing X 100}}{\text{weight of the sample}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots (14)$$

Total carbohydrates were calculate; % Carbohydrates = 100 - (% Moisture content + % Crude protein + Crude lipid + Crude ash).

3.3.9 Determination of gross energy content of potato

The gross energy of potatoes was determined using the method of (Amin *et al*., 2018) as follows:

$$\text{Energy(Kcal per 100g)} = [(\text{CL X 9}) + (\text{CP X 4}) + (\text{CHO X4})] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

Where CL is crude lipid (%), CP is crude protein (%) and CHO in carbohydrate %

3.3.10 Determination of mineral content of potato

Minerals were determined using AOAC (2000) no 50.1.14 method. One gram of sample was weighed accurately in a Teflon cup with screw cap. Amount of 5 ml conc. HNO_3 and 1ml conc.$HClO_4$ were added. It was allowed to stand closed overnight at room temperature to predigest the sample. Cups were placed in oven at 100^o C for 8 hours and cooled to room temperature in fume hood. The digests were transferred into a 100 ml volumetric flasks after filtration with Whatman filter paper No. 541 and to remove all digests deionized water was used. The dilution was done up to the mark. Calibration curve was made using standards of 0, 0.4, 0.8, 1.2, 1.6, 2.0 ppm. Specific lamps were used for every element and wavelength used were 422.7 nm for calcium, 285.2 nm for magnesium, 248.4 nm for iron, 213.9 nm for zinc. Atomic Absorption Spectrophotometer (Thermo Jarrell Ash Corporation model 6, Forge Parkway Franklin, USA) was used. Flame spectrophotometer (Corning Flame photometer model 410, Cambridge, United Kingdom) was used for determination of potassium and standard curve was plotted against concentrations of 0, 1, 2, 4, 6, 8, 10 ppm.

3.3.11 Determination of phosphorus content of potato

Phosphorus was analyzed using AOAC (2000) no.50.1.15 method. Ten ml of aliquot prepared previously for minerals were pipetted into 100 ml conical flask. To each flask 10 ml of 6N HNO_3 was added. Thereafter, 10 ml 0.25% ammonium monovanadate was added and 10 ml 5% ammonium molybdate. It was diluted to the mark, mixed and allowed to stand for 15 minutes. The absorbance was read at 400 nm in spectrophotometer (JENWAY 7315, Staffordshire, United Kingdom). Standard was prepared by dissolving 0.4390 g KH_2PO_4 in water (one liter) to obtain 10 mg phosphorus per 100 ml. Standard curve was plotted with 0, 0.2, 0.4, 0.6, 0.8, 1.0 and 1.2 ppm. Ammonium monovanadate 0.25% was prepared by dissolving 0.25 g of ammonium monovanadate in 2 ml conc. HNO_3 and diluted to 100 ml with deionized water. Ammonium molybdate 5% (w/v) was prepared by dissolving 5 g of ammonium molybdate with deionized water in 100 ml conical flask up to the mark.

3.3.12 Determination of total phenol of potato

The method used by Sun *et al.* (2015) was adopted for determination total phenols. About 1 g of potato flour was added to 20 ml of distilled water and shaken for 5 hours at 80 x g followed by centrifugation (HERMLE Labnet, model Z382K, Wehingen, Germany) at 400 x g for 5 minutes. Extract of 0.5 ml of potato powder was mixed with 2 N 0.5 ml of Folin-Ciocalteu reagent for 6 min. Thereafter, 1.5 ml 20% Na_2CO_3 was added and the volume was made to 10 ml with distilled water and incubation was done for 10 minutes at room temperature.

Absorbance was read at 765 nm with spectrophotometer (JENWAY 7315, Staffordshire, United Kingdom). Standard curve of 0, 0.2, 0.4, 0.6, 0.8 and 1 mg/100g gallic acid was plotted and total phenol was expressed as milligram of gallic acid equivalent per 100 gram of potato (mg GAE/100 g).

3.3.13 Determination of total anthocyanin of potato

The method described by Tokusoglu and Yildirim (2012) was used for determination of total anthocyanins. About 0.2 g of potato flour was extracted with 10 ml of 80% ethanol solution. Centrifugation (HERMLE Labnet, model Z382K, Wehingen, Germany) was done at 4000 x g for 5 minutes at 4^{o}C. Thereafter, 1ml of extract was diluted with 20 ml of water. From diluted aliquot, 0.5 ml was pipetted and homogenized with 4 ml of 10% formic acid (1:9v/v). The absorbance was read at 530 nm in spectrophotometer (JENWAY 7315, Staffordshire, United Kingdom). The amount of anthocyanin was obtained using the equation below and expressed as cyanidin-3-glucose equivalent.

Anthocyanin content (mg/100g of dry matter) = A × MW× DF × 100 / (ε × W) (as Cyanidin 3-glucoside, mg/l)

Where A = absorbance

MW = molecular weight of Cyanidin 3-glucoside ($C_{21}H_{21}ClO_{11}$, 449.2),

DF = dilution factor,

ε = molar absorptivity of Cyanidin 3-glucoside (26900),

W= weight of the sample

3.3.14 Determination of total carotenoid of potato

The method used by Robles-ramírez *et al*. (2016) was adopted. About 10 g of potato powder was used for extraction with 100 ml of 80% ethanol at room temperature overnight in orbital shaker at 80 x g. Thereafter, extracts were recovered by centrifuging (HERMLE Labnet, model Z382K, Wehingen, Germany), at 6182 x g for 15 minutes at 4^{o}C and the residues were re-extracted in the similar conditions and the two extracts were mixed. Sample extracts of 10 ml was added in assay tube wrapped with aluminum foil containing 10 ml of hexane. The tubes were put in an ice bath and shaken in an orbital shaker at 80 x g for 15 minutes. Thereafter, 3 ml of deionized water were added to every tube and mixed for 5 more minutes. The tubes were then allowed to stand at room temperature until phase separation occurred. The absorbance of hexane top layer (A) was read at 450 nm in spectrophotometer (JENWAY 7315, Staffordshire, United Kingdom). The total carotenoids (TC) concentration was calculated using the formula below: TC (mg/kg) = (A x V x 104) / (A1% x W); where A is the absorbance at 450 nm, V is

the hexane volume, A1% is the extinction coefficient for total carotenoids (2500), and W is the mass of the sample in the extract.

3.3.15 Determination of ascorbic acid content of potato

Ascorbic acid concentration was analyzed using spectrophotometric method described by Grudzińska *et al.* (2016). About 2 g of laboratory sample of potato tubers were extracted with a solution 40 ml of 0.4% oxalic acid and homogenized at 6750 x g for 3 minutes. The extract was filtered with filter paper and topped up to 100 ml with the same extracting solution. Thereafter, 5 ml of the extracts were allowed to react with 2 ml of 2, 6-dichloroindophenol (1.6%) for 2 minutes. The absorbance was measured at 500 nm using a spectrophotometer (JENWAY 7315, Staffordshire, United Kingdom). The blank consisted of oxalic acid and 2 ml of 2, 6-dichloroindophenol (1.6%). The ascorbic acid concentration was quantified using a standard curve of 0, 0.2, 0.5, 0.8 and 1 mg/ 100 ml of ascorbic acid. Ascorbic acid content was reported as milligrams per 100 grams.

3.3.16 Determination of free amino acids of potato

The method used by Khaleduzzaman *et al*. (2008) was adopted. Borate buffer 0.1 M (pH 9.2) was prepared by dissolving 1.2 g of boric acid in 100 ml of milli Q water, 0.8 g of sodium hydroxide in 100 ml milli Q water and the two solutions were mixed under stirring and adjusted to pH 9.2 with 5 M HCl. Performic acid was prepared by mixing 200 mg of phenol crystal, 1 ml of 30% hydrogen peroxide and 9 ml of formic acid, the mixture was allowed to stand for 30 minutes at room temperature before use. For preparation of 6 N HCl-phenol solution, 1 g of phenol crystal was weighed into 5 ml of deionized distilled water, while stirring slowly and 5 ml of conc. Hydrochloric acid was added and mixed. For preparation of OPA the amount of 100 mg of ortho-phthaldialdehyde (OPA) was mixed with 9 ml of ethanol, 1 ml of borate buffer and 100 µl mecaptoethanol were added. All the reagents were kept in refrigerator at 4^{o} C for further use.

About 0.4 g of potato flour was weighed into screw cup Pyrex tube, 2 ml of performic acid were added and allowed to stand at 4^{o} C for 16 hours, there after 0.84 g of sodium metabisulfite was added followed by 3 ml of 6 N HCl phenol solution, mixed and allowed to stand for 24 hours. One gram of barium hydroxide was added followed by 1ml of borate buffer added, mixed and filtered into 0.2µl syringe. Amount of 100 µl was pipetted out, mixed with 5 ml of distilled water, 1 ml of borate buffer and 100 µl of OPA and filtered into vial. From this mixture, 20 µl were loaded into HPLC. Instrument conditions were, column (Serial No DEACN45669, G1316A, 1260TCC) was reversed C-18 column (2.1 mm x 150 mm, 3.5 µm);

column temperature of 30^o C, gradient mode as shown in Table 1, flow rate of 1.3 ml/min, injection volume of 20 µl, run time of 60 minutes and post run time of 3 minutes. The detector used was FLD (Serial No, DEBV01707, G1321C, and 1260 FLD). External standard consisted of 2 mM of each amino acid and analsyis conditions were similar to that of the samples.

Table 1. Mobile phases and gradient elution conditions

Time (min)	Mobile phase A (%), 5% Acetonitrile 95% water	Mobile phase B (%) 80% ethanol +20% distilled water
1	100.00	0.00
10	95.00	5.00
20	85.00	15.00
40	80.00	20.00
50	70.00	30.00
55	60.00	40.00
56	60.00	40.00
60	100.00	0.00

Calculation of amino acids

$$\text{Response Factor} = \frac{\text{Peak Area}}{\text{Standard Amount}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

$$\text{Amount (sample)} = \frac{\text{Peak Area Sample}}{\text{Response Factor}} \text{ x M xD} \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (17)$$

Where,

M- Weight of the sample

D- Dilution factor

3.3.17 Determination of potato glycoalkaloids

The glycoalkaloid contents in potato tubers was determined by the method used by Zarzecka *et al*.(2013). About 10 g of potato powder was mixed with 150 ml of ethanol and extraction was done in a water bath at 90° C. Extracts were filtered and evaporated at 60° C using a rotary evaporator to reach the volume of 5 ml. Thereafter, 50 ml of 10% acetic acid were added followed by centrifuging (HERMLE Labnet, model Z382K, Wehingen, Germany). The liquid partion was poured into a flask, the sediment was poured to the supernatant (solution above the sediment) followed by addition of 4 ml of ammonia (NH_3) to adjust to pH = 10. The flask was thereafter heated in a water bath (70° C) for 20 min and allowed to cool at 4° C for 3 hours and centrifuged. The sediment was homogenized in 5 ml 7% phosphoric acid (H_3PO_4). Thereafter, 0.2 ml of the solution was mixed with 2 ml of 85% phosphoric acid with paraformaldehyde (30 mg/l) and mixed again. After 40 min, absorption from spectrophotometer (JENWAY 7315,

Staffordshire, United Kingdom) was read at the wavelength of 600 nm (solution colour changes to blue and then gets lighter). The quantity of total glycoalkaloids was obtaned using α-solanine standard curve. The results of the analyses were reported as mg/100g α-solanine equivalent of fresh weight.

3.4 Determination of the effect of potato cultivars on quality of crisps and French fries

The products which were processed are potato French fries andcrisps. For French fries, potatoes were cut into pieces of equal size of length 3-5 cm, width 1-2 cm, thickness 2-4 mm and washed for 2 minutes to remove adhering starch. Around 200 g of samples were fried into sun flower oil of 175± 5^{o} C until they were fully fried which took 8 minutes. They were then removed from the oil by placing on oil drainer. For crisps, peeled potatoes were sliced in 1.2-1.3 mm thick washed in running tap water for 2 minutes to remove adhering starch. Excess of water was removed by shaking. Around 200 g were fried in sun flower oil at 175 ± 5^{o} C for five minutes. Crisps were removed from the oil and shaken to remove adhering oil. The approximate capacity of fryer was 3 liters and the potato to oil ratio was 1:10 w/v in order to prevent temperature variation inside the fryer. Samples were placed in mesh basket bearing a cover in order to prevent any sample from floating on the surface of oil. Oil was replaced after 10 hours.

3.4.1 Determination of moisture content

The method suggested by CIP (2006) was used for moisture content determination. About 2 g were weighed in a crucible with three replications and heated in forced air oven at 80^{o} C for 72 hours or until constant weight was reached and cooled in desiccator. The moisture content was calculated using the formula below:

$$\text{Moisture content} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Fresh weight}} \text{ x}100 \quad \text{.....(18)}$$

3.4.2 Determination of surface and internal oil

The method described by Duran *et al*. (2007) was used for oil determination. The surface oil is the oil that remains on the surface without penetrating in microstructure of fried potatoes neither during frying nor during cooling. About 50 g of crisps or French fries were weighed, fried and immersed immediately after frying into 250 ml beaker containing 200 ml of extracting solvent (petroleum ether P.B 40-60^{o} C) at room temperature for 10 seconds. The petroleum ether was removed by heating at 80^{o} C and the difference in weight of empty beaker and beaker with oil was recorded as the amount of surface oil. Internal oil which is oil absorbed in microstructure of the fried potatoes during frying or cooling was measured using soxhlet

method for 8 hours after grinding samples free from surface oil. Total oil was the sum of surface and internal oil. For the determination of surface oil in cooled crisps and French fries, they were removed from the frying medium and allowed to cool for 4 minutes. Thereafter, surface oil and internal oil were analyzed as described above.

3.5 Determination of the effect of potato fermentation in brine solution on quality of processed potato products

The method used by Panda *et al.*(2007) was adopted. Peeled and washed potato of 140 g was submerged in a container of 500 ml containing 300 ml of 2% brine solution. It was allowed to undergo fermentation at room temperature for seven days using spontaneous fermentation. Once in two days, sampling of each sample of fermented potatoes was analyzed for pH and total titratable acidity. After completion of fermentation, potatoes were analyzed for reducing sugars, non-reducing sugars, total sugars, starch, protein, minerals, glycoalkaloids, anthocyanin, phenolic compounds and acrylamide formation as described in Section 3.3.

3.5.1 Determination of pH and titratable acidity

The method of Guetouache and Guessas (2015) was used for pH and titratable acidity which were measured once in two days during seven days of fermentation. For pH measurement, 5 g of fermented potatoes were ground and dissolved into 25 ml of distilled water and pH was measured using a pH meter initially calibrated with a buffer solutions at pH 4 and 7. For titratable acidity 25 ml of sample was transferred into a beaker and 5 drops of phenolphthalein 1% indicator was added and the sample was titrated with 0.1N NaOH until the end point or pink colour was obtained.

3.5. 2 Microbial analysis of fermented potato

The method of Aderiye and Ogunjobi (1998) was used. Amount of 5 g the fermented potatoes were mixed up in 45 ml peptone-physiological salt solution after sterilization and serial dilution up to to a concentration of 10^5 using pour-plate methods. Total aerobic mesophilic counts were done on plate count agar after 3 days of incubation at 30° C; lactic acid bacteria counts were done on De man Rogosa and Sharpe (MRS) agar containing 0.1% (w/v) of natanycin after 3 to 5 days of incubation at 30° C, while the enterobacteria (*Coliforms* and *E. coli*) counts after 24 hours at 37° C were done on MacConkey and violet red bile glucose agar (Oxoid, CM485). The counts of yeasts and moulds was determined using the method of Guetouache and Guessas (2015) potato dextrose agar (PDA), acidified with 10% tartaric acid to pH 3.5 by incubating at 30° C for 3-5 days.

3.5. 3 Determination of acrylamide formation in crisps and French fries

Acrylamide determination used Liquid Chromatography/Mass Spectrophotometer (LC-MS) as developed by Al-Taher (2012). Amount equivalent to 1 g of sample was measured into 50 ml centrifuge tube and 5 ml of hexane was added and vortexed. Thereafter, 10 ml of distilled water and 10 ml of acetonitrile were added followed by 0.5 g of NaCl and 4 g of $MgSO_4$ and manually shaken for one minute followed by centrifugation for 10 minutes at 2000 x g and the upper hexane layer was discarded. One ml of upper layer of acetonitrile was pipetted into a 2 ml micro centrifuge vial packed with 50 mg of Primary Second Amine (PSA) and 150 mg of $MgSO_4$ and vortexed for 30 seconds. It was thereafter centrifuged for 2 minutes at 4000 x g and 500 µl was pipetted into auto-sampler vial. For standard, acrylamide stock solution (1mg/1ml) was prepared by homogenizing 100 mg of acrylamide in 100 ml of acetonitrile and kept at 4^o C for further use. Preparation of internal standard (methacrylamide) stock solution (100, 000 µg/ml) consisted of pipetting 0.5 ml of the 1 mg/ml standard into 50 ml acetonitrile and kept at 4^o C. Daily preparation of all working solutions was done by using acetonitrile for serial dilution. Instrument conditions were, column was reversed C-18 column (2.1 mm x 150 mm, 3 µm); column temperature of 30^o C, isocratic mode (%B) of 2.5% methanol /97.5% of 0.1% formic acid, flow rate of 0.2 ml/min, injection volume of 10 µl, run time of 7 minutes and post run time of 3 minutes. Mass spectrophotometer was positive electrospray ionization mode with jet stream technology, capillary voltage of 4000 volts, nozzle voltage of 500 V, sheath gas temperature of 325^o C at 5l liters/minute, drying gas temperature of 350^o C at 11 liters/minutes. Acrylamide calibration curve was plotted as 0, 100, 200, 300, 400, 500, 600, 700, 800, 900, and 100 ng/ml against peak area.

3.5. 4 Sensory evaluation of potato crisps and French fries

The affective method used by Panda *et al.* (2007) was adopted. Sensory attributes (overall acceptability, taste, flavour, colour, crispness and dryness) were evaluated using a 9-point hedonic scale (where 1= dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely) by 37 panelists (21 males and 16 females aged from 22 to 33 years) were selected from students of the Department of Food Science and Technology of the University of Rwanda who are familiar with potato crisps and French fries. French fries and crisps were served at different days and staring time was at 10.00 am. The samples were served in white plate labeled with a 3-digit random numbers. Panelists were trained to be familiar with potato products and to have the same understanding on sensory attributes and terms used in

questionnaire. Questionnaires and water to rinse the mouth between each testing were provided. The panelists were requested to read throughout the questionnaires, and the meaning of attributes (overall acceptability, taste, flavour, colour, crispness and dryness) was clarified to avoid any misunderstanding. Panelists were not allowed to discuss their scores with one another during the evaluation session. A complete randomize block design was used for sample presentation sequences.

3.6 Determination of effect of potato cultivars on potato flour quality

Potato flour was prepared using peeled and sliced potatoes to facilitate drying operations. The sliced potatoes were washed and soaked in 0.5% citric acid for 2 minutes to prevent browning reaction. Thereafter, they were sundried until the moisture content was below 10%. They were then milled into flour which were used for further analysis. Flour from different cultivars of potato were used and parameters determined included bulk density, pH, water absorption capacity (WAC), oil absorption capacity (OAC), emulsifying capacity (EC), emulsification stability (ES), foaming capacity (FC) and foaming stability (FS).

3.6.1 Determination of bulk density of potato flour

Bulk density was determined following methods of Adeleke and Odedeji (2010). Ten grams of flour sample was weighed into a 50 ml measuring cylinder. The sample was packed by lightly tapping the cylinder 10 times on the bench top from a height of around 5 cm. The volume of the sample was recorded.

$$\text{Bulk density } (\frac{\text{g}}{\text{cm3}}) = \frac{\text{Weight of sample (g)}}{\text{Volume of sample after tapping (cm3)}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (19)$$

3.6.2 Potato flour pH determination

The pH was measured using a pH meter as described by Adeleke and Odedeji (2010). Ten grams of sample was measured and solubilize in 50 ml of distilled water while mixing. The obtained mixture was allowed to decant and the pH was measured using pH meter standardized with buffer solutions of pH 4.0 and 7.0.

3.6.3 Determination of water absorption capacity of potato flour

Water absorption capacity (WAC) was determined using the method described by Sosulski *et al*. (1976). One g of flour was weighed in 25 ml centrifuge tubes and 10 ml of distilled water was added. The tubes were vortexed for 2 minutes and allowed to stand at room temperature for 30 min. They were centrifuged at 2000 x g for 30 min. The clear supernatant was decanted and discarded. Drops of water adhered to the container were removed. Water absorption capacity was expressed as the amount of water bound by 100 g dried flour.

3.6.4 Determination of oil absorption capacity of potato flour

Oil absorption capacity (OAC) was determined using the method described by Sosulski *et al.* (1976). One gam of flour was mixed with 10 ml soybean oil for two minutes and allowed to stand at room temperature for 30 minutes. It was centrifuged at 2000 x g for 30 minutes. The volume of free oil was recorded and discaned. Fat absorption capacity was expressed as mls of oil bound by 100 g of dried flour.

3.6.5 Determination of emulsification capacity and emulsification stability

Emulsion activity was determined using the method described by Yasumatsu *et al.* (1972). One gram of flour was homogenized with 10 ml of distilled water and 10 ml of soya bean oil for 2 minutes. The mixture was centrifuged at 2000 x g for 5 minutes. The proportion of height of emulsion layer to the total height of the mixture was dtermined as emulsification activity. Emulsification stability was determined by heating the emulsion contained in centrifuge tubes at 80^{o} C for 30 minutes in water bath. It was cooled in running tap water and centrifuged at 2000 x g for 15 minutes. The emulsion stability was calculated as proportion of the height of emulsion layer to the total height mixture.

3.6.6 Determination of foaming capacity and foaming stability of potato flour

The foaming capacity (FC) and foaming stability (FS) were determined using the method described by Narayana and Narsinga (1982). One gram of the sample was mixed with 50 ml of distilled water at room temperature for 5 minutes to foam. The volume of foam 30 seconds after whipping was expressed as forming stability using the formula below:

$$\text{Foam capacity}\ (\%) = \frac{\text{Vol. after homogenization} - \text{vol. before homogenization}}{\text{Vol. before homogenization}} \text{X100} \ldots\ldots\ldots (20)$$

$$\text{Foam stability}(\%) = \frac{\text{Foam volume after time t}}{\text{Initial foam volume}} \text{X100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (21)$$

3. 7 Characterization of potato starch

Starch characteristics consisted of isolation of stach from raw potatoes which was used for starch granular shape and phosphorus content as well as digestibility of raw potato, fFrench fies and crisps as well as Glycemic index and Glycemic load of French fries, crisps

3.7.1 Potato starch starch isolation

Fresh potatoes of about one kilogram taken from the central of plot were washed with tap water grated in pan containing cold water. It was filtered in muslin clothe and allowed to decant. Upon decantation, starch precipitated and the supernatant was discarded. More cold water was added to wash the starch until clear white starch was obtained normally 3 times washing was done and decantation lasted 4 hours.

3.7. 2 Determination of potato starch granular size and shape

The granular shape of potato starch was analysed using light microscope by Mweta (2009). Two drops of distilled water were put on a clean slide, amount of starch rounding to 2 mg was mixed with water on slide until starch grains became firm and thinly spread on the slide. Starch granules on slides were photographed under light microscope (Nikon Eclipse TE2000-E).

3.7.3 Determination of potato starch digestibility

Raw potatoes, potato crisps and potato French fries were milled into flour before analysis. In vitro starch digestibility was determined using the method described by Ratnaningsih *et al.* (2017)**.** Porcine pancreatic α-enzyme 0.45 g (Megazyme International, Ireland) was homogenized in 4 ml of sterile distilled water followed by centrifugation at 1500×g for 12 min. The supernatant equivalent to 2.7 ml was pipetted into a glass beaker and 0.3 ml of amyloglucosidase with 3260 U/ml together with 0.2 ml of invertase with 355 U/ml were added to the solution. The fresh solution of enzyme was used each time for determination of starch digestibility. Amount of 100 mg of sample and 4 ml of 0.5 M sodium acetate buffer (pH 5.2) were added to each test tube. One ml of enzyme solution and 20 glass beads with 4 mm diameter were put to each tube and the tubes were kept in water bath at 37^{o} C while shaking at 80 x g. Aliquots of 0.1 ml were pipetted after 20 minutes and homogenized with 1 ml of 80% ethanol. The solution was kept again in a water bath at 37^{o} C while shaking at 80 x g and an aliquot of 1 ml was pipetted after 100 min and homogenized with 1 ml of 80% ethanol. Water bath was allowed to continue shaking during the sampling period. The aliquot pipetted after 20 minutes was for G_{20} (rapidly available glucose, RAG) and after 120 min for G_{120} (slowly available glucose, SAG) determination. Centrifugation was done for both G_{20} and G_{120} at 1500×g for 2 minutes to get a clear supernatant for quantification of glucose.

The remaining solution was take out of the shaking water bath, shaken strongly to break down all large particles and kept in water bath containing boiling water for 30 min. Theafter homogenization of test tubes was done and allowed to cool in ice-water for 15-20 min. It was followed by addition of 10 ml of 7 M KOH, homogenized and kept in a shaking water bath bearing ice-water for 30 minutes. An aliquot of 1 ml was pipetted, transferred to 10 ml of 0.5 M acetic acid and 0.2 ml of amyloglucosidase, kept at 70^{o} C for 30 min, followed by keeping it in the boiling water bath for 10 minutes, allowed to cool to room temperature, followed by dilution with 40 ml of distilled water and centrifuged at 1500×g for 5 minutes. An aliquot of 0.1 ml) was thereafter pipetted for Total Glucose (TG) measurement.

For analysis of Free Glucose (FG), amount of 400 mg of sample and 5 ml of 0.5 M sodium acetate buffer (pH 5.2) we homogenized into screw-cap test tubes, kept in a boiling water bath for half an hour and allowed to cool to room temperature. An aliquot of 1 ml was pipetted and mixed with 2 ml of 80% ethanol, followed by centrifugation at 1500×g for 5 minutes. Theafter 1ml of supernatant pipetted and mixed well with 5 ml of distilled water for the quantification of FG. The hydrolyzed glucose content was quantified using glucose oxidase-peroxidase reagent. Aliquots of 0.1 ml were pipetted, mixed with 3 ml of GOPOD reagent, kept at 40-50^{o}C for 20 minutes and allowed to cool at room temperature. Theafter, the absorbance was read at 510 nm. Starch categorised based on the speed of hydrolysis comprised rapidly digestible starch (RDS, digested within 20 min), slowly digestible starch (SDS, digested between 20 and 120 min) and resistant starch (RS, not digested after 120 min). Calculation of different categories of digestible starch is as follows:

$$RAG = G20 \quad (22)$$

$$SAG = G120 - G20 \quad (23)$$

$$RDS\% = (G20 - FG)\frac{0.9}{TS} X100 \quad (24)$$

$$SDS\% = (G120 - G20)\frac{0.9}{TS} X100 \quad (25)$$

$$TS\% = (TG - FG) X 0.9 \quad (26)$$

$$RS\% = TS - (RDS + SDS) \quad (27)$$

3.7.3 Glycemic index of potato starch

Determination of the GI of potato samples was conducted using the method of Ratnaningsih *et al.* (2017)**.** Amount of 50 mg of sample and 10 ml of HCl-KCl buffer (pH 1.5) were homogenized into conical tubes together with 0.2 ml of pepsin solution (1 g of pepsin, 0.7FIP U/mg in 10 ml of HCl-KCl buffer; pH 1.5) to each sample and kept at 40^{o}C for 1 hour in a shaking water bath. Tris-maleate buffer, pH 6.9 was added to reach 25 ml in each tube. Thereafter, 5 ml of pancreatic-amylase solution in tris-maleate buffer bearing 2.6 UI was added to each sample and kept at 37^{o}C in a shaking water bath. Amounnt of 0.1 ml was pipetted from each sample after every half an hour from 0-180 minutes and placed in a tube at 100^{o}C and were then kept in refrigerator until the end of the incubation time. Addition of sodium acetate buffer (1 ml, 0.4 M, pH 4.75) and 30 µl of amyloglucosidase was done to hydrolyze the digested starch into glucose after 45minutes at 60^{o}C in a shaking water bath. The hydrolyzed glucose content was quantified using the glucose oxidase-peroxidase reagent. Conversion of glucose into starch was done by multiplying 0.9 with the weight of the released glucose. The rate of starch digestion was reported as the percentage of total starch hydrolyzed at different times (0,

30, 60, 90,120 and 180 min). The total starch hydrolysis (%) of potato starches at different times were calculated as follows:

$$\text{Total starch hydrolysis } \% = \frac{\text{Released glucose weight x 0.9}}{\text{Total starch weight}} \text{ X100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ (28)}$$

Trapezoid method was used for calculation of GI using the method of (Chlup *et al.*, 2008). The reference food used was glucose. AUC is the area under curve.

$$\text{GI} = \frac{\text{Average AUC test food}}{\text{Average AUC of reference food}} \text{ X100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ (29)}$$

3.7.4 Glycemic load

The method described by Amin *et al*. (2018) was used. Glycemic load was estimated by multiplying glycemic index by the amount of available carbohydrates divided by 100 as shown in the equation below. The available carbohydrates comprises of starch and sugars.

$$\text{GL} = \frac{\text{Available carbohydrate X GI}}{100} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ (30)}$$

3.8 Statistical analyses

Data were subjected to analysis of variance (ANOVA) and means separated by the Tukey's test at 5% level of significance using Statistical Analysis System (SAS version 9.2) with General Linear Model (GLM) procedure (SAS institute Inc., 2008). Normality of the data was tested using capability procedure. Log transformation was carried out on biological data to normalize the data. Strength of the association between variables was analyzed using Pearson's correlation coefficient and orthogonal contrast was performed on varieties vs clones and simple linear regression was conducted to predict the starch content and dry matter based on specific gravity. Principal components analysis (PCA) was used to reduce the number of variables using varimax rotation. Discriminate analysis was used to separate the cultivars based on their specific gravity, starch content and dry matter.

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Morphological and biochemical factors which affect quality of potato

Morphology consists of shape and size, while processing quality is made by chemical components of potato. Quality of potato for processing depends on both morphology and chemical composition.

4.1.1 Morphological characteristics of potato

The results showing potato size are shown in Table 2, while Table 3 presents results related to potato colour, shape and eyes characteristics. The size of studied potato had the highest percentage of potato above 40 mm of diameter in almost all cultivars. The difference in potato size was statistically significant at ($P < 0.05$). Mabondo had the lowest percentage 85.67% and the highest was for CIP392617.54 at 93.33% of tubers above 40 mm. However, CIP399075.22 was exception where 90% of tubers had below 40 mm of diameter and 10% remaining ranged from 40 to 50 mm of diameter. Based on the classification of Kabira and Lemaga (2003) crisps processing requires potatoes of 40 to 60 mm and French fries above 50 mm. In this regards, all the potatoes studied had suitable size for crisps and French fries processing except CIP399075.22. Boiling and baking also require potatoes of 40 mm of diameter and above. However, the size of CIP399075.22 is convenient for canned potatoes which requires 20 to 35 mm (Marwaha *et al.*, 2010). Potato for starch production require above 25 mm (Lisiěska *et al*., 2009). Potato products require different size depending on their nature.

The colours of the skin were categorized as white, yellow, red, pink and purple. Similarly, most of flesh colours were yellow and white. The colour of potato has influence on consumer choice of fresh potatoes as some consumers prefer certain colours more than others. Potato colours were associated to phytochemicals (Ezekiel *et al*., 2013). For processing purpose, white and yellow flesh potatoes can both be used for French fries and crisps, while white is more preferred for French fries and yellow for crisps (Genet, 1992). However, red or purple flesh potatoes are not suitable for French fries, crisps and other products due to the colour of final products which may be objectionable to some consumers.

The shapes of potatoes were classified as round, oblong and oval. Due to the shape of end products, round ones are preferred for crisps and oval ones are preferred for French fries (Kabira and Lemaga, 2003). It was further reported that round to oval are preferred for dehydrated products, oblong for French fries, round to oval for chips and canned potatoes

(Marwaha *et al*., 2010). Potato shape has important consideration as it influences the shape of the final product.

Table 2. Distribution of potato diameter in millimeter for each variety or clone

	Cultivars	< 40mm (%)	40-50 mm (%)	50-60 mm (%)	> 60 mm (%)
Varieties	Gikungu	12.67 ± 1.20^{b}	12.67 ± 1.45^{abc}	46.33 ± 3.18^{ab}	28.33 ± 1.67^{bc}
	Kigega	13.33 ± 6.01^{b}	13.33 ± 1.67^{abc}	30.33 ± 2.91^{e}	43.00 ± 3.00^{a}
	Kinigi	8.33 ± 1.67^{b}	6.00 ± 1.00^{c}	47.33 ± 1.45^{ab}	38.33 ± 1.67^{ab}
	Kirundo	8.33 ± 3.33^{b}	12.00 ± 1.53^{abc}	33.00 ± 1.53^{de}	46.67 ± 3.33^{a}
	Mabondo	14.33 ± 0.67^{b}	12.00 ± 2.00^{abc}	53.67 ± 1.86^{a}	20.00 ± 2.89^{c}
	Sangema	11.00 ± 1.00^{b}	18.67 ± 1.86^{ab}	42.00 ± 1.53^{bcd}	28.33 ± 3.33^{bc}
Clones	CIP399075.22	90.00 ± 2.89^{a}	10.00 ± 2.89^{bc}	0.00 ± 00^{f}	0.00 ± 0.00^{d}
	CIP392617.54	6.67 ± 1.67 ^{b}	11.33 ± 1.33^{abc}	35.33 ± 2.60^{cde}	46.67 ± 1.67^{a}
	CIP393251.64	13.33 ± 1.67^{b}	19.33 ± 2.33^{a}	45.67 ± 2.33^{abc}	21.67 ± 1.67^{c}
	CIP 399062.115	8.33 ± 1.67^{b}	11.33 ± 1.33^{abc}	44.00 ± 2.08^{abc}	36.00 ± 2.08^{ab}
	Minimum	6.67	6.00	0.00	0.00
	Maximum	90.00	19.33	53.67	46.67
	CV	23.16	24.60	9.76	13.55
	MSD	12.634	9.121	10.79	12.254

MSD: Minimum significant deference; Means followed by the same letter in the column do not differ by Tukey's test at 5%.

Number of eyes and eye depth were also determined and they ranged from 6 for CIP399075.22, Kigega and Kinigi to 12 for Mabondo and the difference was statistically significant at ($P < 0.05$). Considering eye depth, the majority had shallow and medium eyes except Kinigi and CIP392617.54 which had deep eyes. Abong *et al*. (2010) classified eye depth as shallow (0.00-0.20 mm), medium (0.20- 0.50 mm) and deep (> 0.50 mm). High number of eyes and deep eyes influence peeling losses of potatoes. Losses are higher for potatoes with deep eyes like Kinigi and CIP392617.54 and less for potatoes with shallow eyes.

Table 3. Morphological characteristics of potato tubers

	Cultivars	Skin colour	Flesh colour	Shape	Number of eyes	Characteristic of eyes
Varieties	Gikungu	Red	Yellow	Oval	6.33 ± 0.33^{bc}	Shallow
	Kigega	Light yellow with pink eyes	White	Oblong	5.67 ± 1.20^{c}	Shallow
	Kinigi	Purple	Light yellow	Round	6.33 ± 0.33^{bc}	Deep
	Kirundo	White	White	Oblong	11.67 ± 0.33^{a}	Medium
	Mabondo	Pink	Light yellow	Oblong to Oval	12.00 ± 1.73^{a}	Medium
	Sangema	Light pink	Light yellow	Oblong	10.00 ± 0.58^{ab}	Shallow
Clones	CIP399075.22	Light yellow	Yellow	Oblong to Oval	5.67 ± 0.33^{c}	Shallow
	CIP392617.54	Pink and light yellow	White	Round	10.33 ± 0.88^{ab}	Deep
	CIP393251.64	Red with pink eyes	Light yellow	Round	9.67 ± 0.67^{abc}	Medium
	CIP 399062.115	Light yellow with pink eyes	Light yellow	Oblong	10.00 ± 0.58^{ab}	Medium

Means followed by the same letter in the column do not differ by Tukey's test at 5%.

4.1.2 Specific gravity, dry matter and starch content of potato

The results of specific gravity, starch content and dry matter are presented in Table 4. Specific gravity is an important parameter referred to during choosing potatoes for specific use. Potato cultivars tested in this study were statistically significantly different at ($P < 0.05$). The specific gravity ranged from 1.075 to 1.099. Kinigi was the highest, while Kigega and CIP392617.54 were the lowest. Orthogonal contrast showed a significant difference between varieties and clones. On average, varieties had higher specific gravity than clones.

Table 4. Specific gravity, starch and dry matter of potato

	Cultivars	Specific Gravity	Starch (% FWB)	Dry matter (% (FWB)
Varieties	Gikungu	1.080 ± 0.003^{cd}	15.23 ± 0.33^{de}	20.94 ± 0.69^{cd}
	Kigega	1.075 ± 0.001^{d}	14.72 ± 0.22^{e}	21.12 ± 0.38^{cd}
	Kinigi	1.099 ± 0.001^{a}	18.18 ± 0.18^{ab}	23.88 ± 0.10^{b}
	Kirundo	1.097 ± 0.002^{ab}	19.28 ± 0.11^{a}	25.93 ± 0.11^{a}
	Mabondo	1.088 ± 0.001^{abc}	17.01 ± 0.19^{bc}	23.67 ± 0.09^{b}
	Sangema	1.086 ± 0.004^{c}	16.38 ± 0.35^{bc}	22.93 ± 0.68^{b}
Clones	CIP399075.22	1.085 ± 0.002^{cd}	16.34 ± 0.15^{cd}	22.53 ± 0.06^{bc}
	CIP392617.54	1.075 ± 0.001^{d}	14.33 ± 0.24^{e}	20.45 ± 0.48^{d}
	CIP393251.64	1.088 ± 0.003^{abc}	16.49 ± 0.16^{cd}	23.33 ± 0.25^{b}
	CIP 399062.115	1.088 ± 0.001^{abc}	16.87 ± 0.21^{bc}	22.51 ± 0.41^{bc}
	Minimum	1.075	14.33	20.45
	Maximum	1.099	19.28	25.93
	CV	0.33	3.23	2.70
	MSD	0.0103	1.5592	1.7951

MSD: Minimum significant difference by Tukey at 5%; Means followed by the same letter in the column do not differ by Tukey's test at 5%.

These results agree with the ones reported by Mohammed (2016) and Abebe *et al.* (2013) which ranged from 1.061 to 1.095 on 17 varieties in three different locations of mid and low altitude and two cropping seasons and 1.050 to 1.119 in 25 varieties grown in three different locations respectively. Soboka *et al*. (2017) also reported the specific gravity of potatoes ranging from 1.086 to 1.107 on six varieties grown in two different locations. However, the results were higher than the ones of Ekin (2011) who reported specific gravity of 1.065 to 1.077 on eight varieties. Specific gravity was reported to be influenced by genetic and environmental factors (Abebe *et al*.,2013; Mohammed, 2016; Soboka *et al*., 2017). Fitzpatrick *et al*.(1964) classified specific gravity of potatoes in three categories where high if specific gravity is above 1.086, intermediate between 1.077 and 1.086 and low if less than 1.077. Based on this classification, kigega and CIP392617.54 fall in low specific gravity, Kinigi, Kirundo, Mabondo, CIP393251.64, CIP 399062.115 and Sangema had high specific gravity in that order, while CIP399075.22 and Gikungu exhibited intermediate specific gravity. The specific gravity

of potatoes is associated with their end use. Potatoes with high specific gravity are suitable for baking, frying, mashing and chipping; while low specific gravity are for boiling and canning (Ekin, 2011). Similarly, potatoes for dehydrated products, French fries, chips, should have 1.080 and above of specific gravity and less than 1.070 for canned potatoes (Marwaha *et al*., 2010). This aligns with the report of Abong *et al*. (2010) where potatoes for crisps should be above 1.080. Based on the study by Feltran *et al*. (2004) all the potatoes in this study would qualify for frying as they suggested that potatoes for frying should have specific gravity from 1.0701 to 1.0850. Moreover, it was reported that increase of each 0.005 in specific gravity corresponds to the increase in yield of fried products by 1% (Genet, 1992;Vreugdenhil *et al*., 2007). The cut off below which potatoes are unacceptable for processing are 1.077 for French fries and 1.079 for crisps, while the upper limit is 1.103 for French fries (Vreugdenhil *et al*., 2007). In this regard, Kigega and CIP392617.54 are the only potato cultivars which were not qualified for crisps, French fries and dehydrated products. Specific gravity of potatoes is an important parameter to consider while choosing potatoes for specific use and it is related to starch content and dry matter.

The dry matter of potatoes is perhaps the most important factor used to determine the quality of potatoes as the difference is made by water. Dry matter contents of studied cultivars were statistically significantly different at ($P < 0.05$). It ranged from 20.45% for CIP392617.54 to 25.93% for Kirundo. Orthogonal contrast showed a significant difference between dry matter of varieties and clones. On average varieties had more dry matter than clones. The results agree with the dry matter reported by Habtamu *et al*. (2016) where it ranged from 20.73 to 30.66% for 18 cultivars grown in three different regions. They also agree with the report of Elfnesh *et al*. (2011) for dry matter of 20.33 to 27.33% in five varieties from three distinct areas. Similarly, Soboka *et al.* (2017) reported dry matter ranging from 19.41 to 26.61% on six varieties in two different locations. Cacace *et al*.(1994) classified dry matter of potatoes into three categories where potatoes with high dry matter have above 20%, intermediate are between 18 and 19.9% and low dry matter content are below 17.9 %. According to this classification, all the potatoes studied qualify to be high in dry matter. Ekin (2011) revealed that potatoes with dry matter above 22% are suitable for crisps and French fries. Similarly, Kabira and Lemaga (2003) reported that potatoes with dry matter of 20 to 24% are suitable for French fries, while those up to 24% are ideal for crisps. Furthermore, potatoes for dehydrated products, French fries and crisps should have 20% and above, while the ones for canning should have less than 18% of dry matter (Marwaha *et al*., 2010). It was further reported that the lower limit is 19.5 for French

fries and 20% for crisps and upper limit is 25% for French fries (Vreugdenhil *et al*., 2007). High dry matter is not preferred for canned potatoes due to sloughing which is crumbling of the outer layer of potato (Marwaha *et al*., 2010). On the other hand, potatoes with high dry matter is related to less oil absorption, high yield, less energy consumption and crispy texture (Marwaha *et al*., 2010). Based on dry matter, all potatoes qualify for crisps, French fries processing and dehydrated products, while specific gravity excludes CIP392617.54, Kigega, Gikungu and CIP399075.22.

Starch is the highest component of dry matter and potatoes with high starch content have high dry matter. Potato starch in this study ranged from 14.33% for CIP392617.54 to 19.28% FW for Kirundo and the difference was statistically significant at ($P < 0.05$). Orthogonal contrast showed a significant difference between varieties and clones. On average, varieties had higher starch content than clones. Starch content of potato on fresh mass ranges from 10 to 30% (Donnelly and Kubow, 2011). The results agree with the study of Habtamu *et al*.(2016) who reported starch content ranging from 8.8 to 17.60% for 18 cultivars in three different locations. Furthermore, Soboka *et al*. (2017) reported starch content ranging from 14.61 to 19.19% on six varieties and two different locations. High starch content is favorable and it is associated with high yield and texture of the product due to high gelatinization during processing (Bandana *et al*., 2016). Starch content is categorized as highest if above 19% and is better for mashing, between 16 and 19% is high and better for roasting, intermediate is 13 to 15.9% and better for cooking or roasting and low if less than 12% and is used for boiling (Ekin, 2011). Based on this classification potatoes in this study fall in high and intermediate categories and are suitable for roasting and cooking. Moreover, potatoes with starch content of 15% and above are suitable for starch production, chips for 16-20%, French fries for 15-18% and dehydrated product for 15-19% (Lisiěska *et al.*, 2009). In this regard, Kigega and CIP392617.54 are the only cultivars which do not qualify for the above products. Majority of potato in this study are suitable for dehydrated products, frying, roasting and boiling. The quality and yield of the products increases with the increase of starch content.

Regression and correlation for specific gravity, starch content and dry matter were analysed. Results showing regression between specific gravity, starch content and dry matter are presented in Table 5. Regression analysis allows to express predicted variable (dependent variable or response) in function of independent variable (predictor). The relationship of specific gravity, starch content and dry matter was statistically significant at ($P < 0.05$) with coefficient of determination $R^2 = 0.92^{***}$ between specific gravity and starch, $R^2 = 0.79^{***}$

between specific gravity and dry matter and R^2 = 0.92*** between dry matter and starch. Moreover, there was a significant correlation between specific gravity and starch content (r = 0.92***), between specific gravity and dry mater (r = 0.98***) and between starch and dry matter (r = 0.96***). Relationship between specific gravity, starch content and dry matter was also reported by other authors (Von Scheele *et al.*, 1937; Tsegaw, 2011; Mohammed, 2016). This suggested that one variable can be expressed in function of the other. Higher coefficient of determination between starch and specific gravity and dry matter and starch suggests that they are better estimator than specific gravity and dry matter. Specific gravity is influenced by genetics, location and season (Elfnesh *et al.*, 2011; Hassanpanah *et al.*, 2011). Regression equations can be used to estimate starch content and dry matter of potatoes grown in Busogo. Specific gravity is a true indication of starch content and dry matter, it can be used by processors to estimate starch content and dry matter of potatoes.

Table 5. Regression analysis between specific gravity, starch and dry matter

Dependent variable (Y)	**Independent Variable (X)**	**R^2**	**Intercept (β_0)**	**Slope (β_1)**	**Regression equation $Y= \beta_0+\beta_1X$**
Starch	Specific gravity	0.92***	-181.04	181.87	Y = -181.04 +181.87X
Dry matter	Specific gravity	0.79***	-177.18	184.07	Y = -177.18+184.07X
Dry matter	Starch	0.92***	5.55	1.04	Y = 5.55 + 1.04X

R^2 = Coefficient of determination; *$P < 0.05$: Significant; ** $P < 0.01$: Highly significant; ***$P < 0.001$: Very highly significant.

Discriminate analysis was used to group potatoes based on the processing quality. Parameters used to group potatoes were starch content and dry matter. Kirundo, Kinigi, CIP399075.22 and CIP399062.115 were well separated from others, while Mabondo, Sangema and CIP393251.64 were close to each other and Kigega, Gikungu, and CIP392617.54 were also close to each other in another group. Based on pictorial presentation in Figure 4, the score on x axis and on y axis represent the position of each cultivar. In this regards, kirundo was the best, followed by Kinigi, CIP393251.64, Mabondo, Sangema, CIP399062.115, CIP399075.22, Gikungu, Kigega and CIP392617.54 in that order. Therefore, potato cultivars with high score are better for fried and dehydrated products, while those with low scores qualify for boiling, canning and salad making.

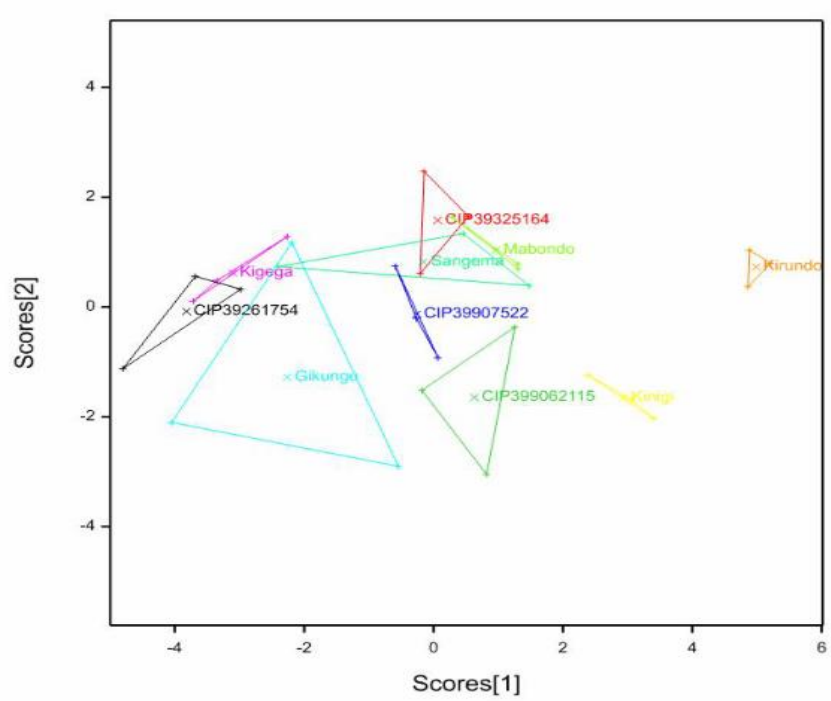


Figure 4. Discriminant analysis for processing quality of potatoes

4.1.3 Reducing sugars, non-reducing sugars and total sugars of potato

Sugar content of studied cultivars varied from one cultivar to another as presented in Table 6. Sugars are important for determination of the quality of potato products. They are classified as reducing sugars and non-reducing sugars. There was a statistically significant difference in sugars among the studied cultivars at ($P < 0.05$). Reducing sugars ranged from 0.10% for Kirundo to 0.20% for Mabondo, non-reducing sugars from 0.16% for Kirundo to 0.35% for Mabondo and total sugars from 0.26% for Kirundo to 0.55% for Mabondo FWB. Orthogonal contrast showed a significant difference between cultivars and clones in sugar content. On average, clones had higher reducing sugars, higher non-reducing sugars and higher total sugars than varieties.

The results agree with the ones of Bhattacharjee *et al.*(2014) who reported four varieties with reducing sugars of 0.23 to 0.32% which are higher than the ones in this study, non-reducing sugars of 0.19 to 0.32% and total sugars of 0.45 to 0.61%. On the other hand, Elfnesh *et al*. (2011) reported low reducing sugars ranging from 0.036 to 0.051g/100g FWB for five varieties from three distinct areas. The sugar content of potatoes is determined by the genotype and other factors like maturity of tubers, temperature during growth, mineral fertilization, irrigation, mechanical stresses and storage conditions (Kumar *et al.*, 2004). It was suggested that reducing sugars should be 0.25% for dehydrated products, 0.15% for French fries, less than 0.1% for crisps and 0.5% for canned potatoes (Marwaha *et al*., 2010). On the

other hand, reducing sugars for crisps should not be more than 0.2 to 0.3% and ones for French fries should be up to 0.5% (Kabira and Lemaga, 2003). Potatoes in this study were low in reducing sugars and they were all qualified for frying where Kirundo and Sangema were the best. However, due to high content of non-reducing sugars, these potatoes should be stored at 8-12^{o} C and relative humidity of 85- 90% as low temperature activates invertase enzymes to hydrolyze starch and non-reducing sugars into reducing sugars and temperature above 16^{o} C is not also conducive due to senescence sweetening (Kumar *et al*., 2004). During frying, reducing sugars react with amino acids in Maillard reaction. The colour of fried products is related to the reducing sugars being light in low reducing sugars and dark in high reducing sugars. Dark fried potato products are not preferred by consumers. The preferred colour for fried products is golden which is associated with relatively low amount of reducing sugars.

Table 6. Sugar content of potato in percentage of fresh weight

	Cultivars	**Reducing sugars**	**Non-reducing sugars**	**Total Sugars**
Varieties	Gikungu	0.12 ± 0.01^{cde}	0.19 ± 0.00^{de}	0.31 ± 0.01^{de}
	Kigega	0.13 ± 0.02^{bcd}	0.22 ± 0.00^{bcd}	0.35 ± 0.02^{bcd}
	Kinigi	0.14 ± 0.01^{bc}	0.23 ± 0.02^{bc}	0.37 ± 0.03^{bc}
	Kirundo	0.10 ± 0.01^{e}	0.16 ± 0.01^{e}	0.26 ± 0.02^{e}
	Mabondo	0.20 ± 0.01^{a}	0.35 ± 0.02^{a}	0.55 ± 0.04^{a}
	Sangema	0.10 ± 0.00^{de}	0.21 ± 0.01^{cd}	0.31 ± 0.01^{ef}
Clones	CIP399075.22	0.12 ± 0.00^{cde}	0.20 ± 0.00^{cde}	0.32 ± 0.01^{cd}
	CIP392617.54	0.14 ± 0.01^{bc}	0.24 ± 0.01^{bc}	0.38 ± 0.02^{b}
	CIP393251.64	0.15 ± 0.02^{b}	0.25 ± 0.01^{b}	0.40 ± 0.02^{b}
	CIP399062.115	0.13 ± 0.01^{bcd}	0.23 ± 0.01^{bcd}	0.36 ± 0.02^{bcd}
	Minimum	0.10	0.16	0.26
	Maximum	0.20	0.35	0.55
	CV	7.67	6.43	5.12
	MSD	0.0299	0.0432	0.0544

MSD: Minimum significant difference by Tukey at 5%; Means followed by the same letter in a column do not differ by Tukey's test at 5%.

4.1.4 Free amino acids in potato tubers

Results of free amino acids are presented in Table 7.

Table 7. Free amino acids of fresh potato tubers in µg/kg

	Cultivars	Aspartic acid	Arginine	Glutamic acid	Serine	Histidine
Varieties	Gikungu	142.43 14.60^{cd}	255.44 ± 8.63^{c}	260 ± 3.49^{cd}	273.02 ± 17.58^{a}	248.02 ± 15.76^{c}
	Kigega	85.87 ± 7.10^{e}	99.97 ± 5.77^{g}	310.65 ± 8.27^{c}	106.98 ± 1.91^{e}	332.95 ± 27.33^{b}
	Kinigi	231.61 ± 11.52^{b}	97.67 ± 6.17^{g}	176.31 ± 10.05^{ef}	136.99 ± 2.17^{de}	242.04 ± 8.61^{c}
	Kirundo	89.96 ± 9.22^{de}	332.93 ± 18.82^{b}	482.72 ± 14.65^{a}	175.59 ± 8^{bcd}	216.92 ± 12.47^{cd}
	Mabondo	286.40 ± 13.48^{a}	682.37 ± 16.65^{a}	434.68 ± 14.51^{a}	219.22 ± 16.73^{b}	137.64 ± 16.69^{e}
	Sangema	170.82 ± 5.08^{c}	73.84 ± 6.16^{g}	372.33 ± 5.36^{b}	273.09 ± 5.71^{a}	672.71 ± 5.52^{a}
Clones	CIP399075.22	173.70 ± 5.76^{c}	246.67 ± 8.82^{cd}	232.61 ± 23.33^{de}	172.97 ± 8.52^{bcd}	250.06 ± 1.38^{c}
	CIP392617.54	170.59 ± 1.78^{c}	163.33 ± 3.33^{ef}	142.35 ± 3.92^{f}	152.84 ± 1.48^{cde}	139.13 ± 1.51^{e}
	CIP393251.64	172.56 ± 6.33c	187.57 ± 8.62^{de}	130.19 ± 5.78^{f}	192.22 ± 10.68^{bc}	168.94 ± 10.68^{de}
	CIP399062.115	252.56 ± 21.71^{a}	125.00 ± 17.50^{fg}	145.45 ± 6.48^{f}	154.22 ± 13.83^{cde}	128.32 ± 4.72^{e}
	Minimum	85.87	73.84	130.19	106.98	137.64
	Maximum	286.40	682.37	482.72	273.09	672.71
	CV	10.45	9.13	7.49	9.63	9.22
	MSD	54.329	60.511	58.901	52.361	68.446

MSD: Minimum significant difference by Tukey at 5%; Means followed by the same letter in a column do not differ by Tukey's test at 5%.

The free amino acids of cultivars from this study were statistically significantly different at ($P < 0.05$). Aspartic acid ranged from 85.87 for Kigega to 286.40 µg/g for Mabondo, arginine ranged from 73.84 for Sangema to 682.37µg/g for Mabondo, glutamic acid ranged from 130.19 for CIP393251.64 to 482.72 µg/g Kirundo, Serine ranged from 106.98 for Kigega to 273.09 µg/g for Sangema, histidine ranged from 137.64 for Mabondo to 672.71 µg/g for Sangema. These results are in consistency with the ones of the study conducted in Japan with free amino acids varying during harvesting and storage. They varied from 571 µg/g Fw for earlier harvest to 1375 µg/g after storage at 18^{o}C for 4 weeks for Asparagine, from 103 for earlier harvesting to 216 µg/g after storage at 18^{o}C for 4 weeks for aspartic acid, from 268 for regular sharvesting time to 469 µg/g after storage at 18^{o}C for 4 weeks for glutamic acid and from 483 for earlier harvest to 740 µg/g after 2 weeks of storage for glutamine (Ohara-Takada *et al*., 2005). A study conducted in India on 5 varieties revealed total free amino acid of 90.72 mg/100g in Kufri chipson-1 variety and 150.32 mg/100g in Atlantic variety (Joseph *et al*., 2004). Free amino acids were reported to react with reducing sugars in Maillard reaction where asparagine, glutamate, glutamine, serine and alanine are the main co-reactants (Vreugdenhil *et al*., 2007). Free amino acids increase with nitrogen application and during storage (Vreugdenhil *et al*., 2007). Free amino acids vary from one cultivar to another and they influence processing quality due to their participation in Maillard reaction.

4.1.5 Total carbohydrates content of potato

Carbohydrates are the highest components of potato tubers after water and results for carbohydrates content are presented in Table 8. Potato carbohydrate contents of cultivars tested in this study were statistically significantly different at ($P < 0.05$). Orthogonal contrast showed that there was no significant difference in carbohydrates of varieties and clones. The study showed carbohydrates ranging from 16.90% to 22.33% FWB. Kirundo had the highest total carbohydrates, while CIP392617.54 had the lowest total carbohydrates. The results align with the ones of Abong *et al*. (2009) who reported carbohydrates ranging from 16.34 to 19.74% FWB. A study conducted on four potato varieties from four different areas in Japan showed carbohydrates of 14.25% to 19.16% FWB (Sato *et al*., 2017). Similarly, Donnelly and Kubow (2011) reported a wide range of carbohydrates from 10 to 30% FWB. Total carbohydrates in this study increased with increase in starch content. Carbohydrates in potatoes are mainly dominated by starch and other components are in small amount and they are the main source of energy. High amount of carbohydrates is associated with high dry matter which is a good indicator of potato for processing and a source of calorie for consumers. Carbohydrates should

Table 8. Major nutrients of potato in percentage of fresh weight

	Cultivars	Gross Energy	Crude ash	Crude lipids	Crude Protein	Crude fibers	Carbohydrates
Varieties	Gikungu	81.40 ± 7.58^{b}	0.84 ± 0.14^{bc}	0.20 ± 0.04^{bc}	1.82 ± 0.18^{c}	2.55 ± 0.21^{abcd}	18.09 ± 0.61^{bc}
	Kigega	81.96 ± 2.11^{b}	0.75 ± 0.09^{c}	0.09 ± 0.04^{e}	2.84 ± 0.13^{a}	2.37 ± 0.13^{cd}	17.74 ± 0.30^{bc}
	Kinigi	93.64 ± 3.14^{ab}	0.70 ± 0.08^{c}	0.18 ± 0.04^{c}	2.26 ± 0.03^{bc}	2.18 ± 0.15^{cd}	20.74 ± 0.38^{ab}
	Kirundo	101.24 ± 0.18^{a}	1.08 ± 0.11^{a}	0.18 ± 0.05^{c}	2.58 ± 0.11^{ab}	2.79 ± 0.17^{ab}	22.33 ± 0.13^{a}
	Mabondo	92.21 ± 1.15^{ab}	0.80 ± 0.09^{c}	0.15 ± 0.04^{d}	2.54 ± 0.13^{ab}	2.62 ± 0.12^{abc}	20.18 ± 0.21^{abc}
	Sangema	89.45 ± 3.62^{ab}	0.79 ± 0.10^{c}	0.17 ± 0.03^{c}	2.32 ± 0.11^{bc}	2.96 ± 0.07^{a}	$19.6\ 5\pm 0.42^{abc}$
Clones	CIP399075.22	87.08 ± 0.98^{ab}	1.03 ± 0.08^{ab}	0.21 ± 0.03^{ab}	2.57 ± 0.13^{ab}	2.06 ± 0.10^{d}	18.72 ± 0.22^{bc}
	CIP392617.54	79.54 ± 0.74^{b}	0.85 ± 0.09^{bc}	0.22 ± 0.05^{a}	2.48 ± 0.13^{ab}	2.19 ± 0.08^{cd}	16.90 ± 0.15^{c}
	CIP393251.64	89.98 ± 4.78^{ab}	0.84 ± 0.07^{bc}	0.20 ± 0.03^{bc}	2.62 ± 0.19^{ab}	2.54 ± 0.04^{abcd}	19.43 ± 0.44^{abc}
	CIP 399062.115	88.00 ± 1.76^{ab}	0.68 ± 0.07^{c}	0.14 ± 0.03^{d}	2.23 ± 0.15^{bc}	2.23 ± 0.15^{cd}	19.46 ± 0.30^{abc}
	Minimum	79.54	0.68	0.09	1.82	2.06	16.90
	Maximum	101.24	1.08	0.22	2.84	2.96	22.33
	CV	5.65	8.43	5.06	8.14	7.26	6.32
	MSD	14.624	0.2065	0.0258	0.5779	0.5207	3.5694

MSD: Minimum significant difference (Tukey at 5%), Means followed by the same letter in the column do not differ by Tukey's test at 5%, Gross energy is expressed in Kcal/100g.

supply 50% of total energy required for a well-balanced diet and they are important for prevention of weariness and hazardous fluid imbalance (Vreugdenhil *et al.*, 2007). Serving of 100 g of potato contributes 15.90 g equivalent to 12% Recommended Dietery Alloance (RDA) (Burke, 2016). Total carbohydrates of varieties and clones of this study did not differ. They had relatively high amount of carbohydrates which is a good indicator for processing and high calorie reservoir.

4.1.6 Crude protein content of potato

Potato protein is relatively in low amount with high biological value and results for potato protein are prented in Table 8. Protein content of cultivars in this study were statistically significantly different at ($P < 0.05$). Orthogonal contrast revealed than protein content of cultivars and clones did not differ significantly. This study showed crude protein content ranging from 1.82% to 2.84% FWB. Gikungu had the lowest protein content, while kigega had the highest amount of crude protein. The results agree with the study of Pal *et al.* (2008) where protein content ranged from 1.70 % to 2.44 % FWB in eleven potato varieties grown in India. A study conducted by Sato *et al.* (2017) showed lower protein content ranging from 1.37% to 1.92% FWB. Potato protein ranges from 0.69 to 4.63% (Lister and Munro, 2000). The average was reported to be 2% on wet basis and 8% on dry basis (Lister and Munro, 2000; Stone *et al*., 2011). Liu (2013) reported the average of potato protein to be 2.57%. Protein content depends on genetics, level of maturity and fertilizer application (Ahmed *et al.*, 2009). Nitrogen fertilizer increases protein content (Ahmed *et al.*, 2009). Protein requirement is 0.8 g/kg of body weight per day (Singh and Kaur, 2009). Consumption of 100 g of boiled potatoes supplies 8-13% and 6-7% of FAO-WHO recommended daily allowance for children and adults respectively (Vreugdenhil *et al*., 2007).Moreover, 100 g of potatoes contain around 1.89 g of protein with RDA of 3% (Burke, 2016).Protein content of varieties did not differ from the ones of clones. Potato is a reliable source of protein, both clones and varieties can be used interchangeably.

4.1.7 Crude ash content of potato

Ash encompasses different types of minerals which contribute both nutrition and metabolism. Results of ash content are shown in Table 8. Ash content of potato cultivars of this study were statistically significantly different at ($P < 0.05$). Orthogonal contrast showed that clones had significantly higher ash content than varieties on average. The ash content varied from 0.68 to 1.08% FWB being the lowest in CIP 399062.115 and the highest in Kirundo. The average mineral content in tubers was reported to be 1.1% FWB (Donnelly and Kubow, 2011). Total ash from eight Kenyan potato varieties was reported to be 0.94% on FWB,

while in fried ones, it was 1.01 to 1.14% (Abong *et al.*, 2009). Stone *et al.* (2011) reported total ash of four potato varieties from four different areas of Japan to range from 0.88 to 1.03%. The main contributors for the variation in ash content of potatoes is related to the genotype, soil characteristics, and fertilizer application (White *et al.*, 2009). Clones had higher ash content than varieties. Ash content is important to our bodies as it is a source of minerals which play an important role in metabolism and well-being.

4.1.8 Crude lipid content of potato

Potatoes contain very low amount of lipids as shown in Table 8. High amount of potato lipid is concentrated between the vascular ring and the peel and thin peeling is encouraged (Ramadan and Oraby, 2016). Lipid content of the studied potato cultivars were statistically significantly different at ($P < 0.05$). Orthogonal contrast showed a significant difference between varieties and clones. On average clones had higher lipid content than varieties. The present study revealed lipid content of 0.09 to 0.22%. The highest amount was for CIP392617.54, while the lowest was for Kigega. The results align with the ones reported by Lister and Munro (2000) where lipid content of potatoes ranged from 0.02 to 0.2 mg/100g FWB. However, they are lower than the ones reported by Burke (2016) stating lipid content of 1%. A study conducted on eight potato varieties grown in Kenya revealed lipid content higher than the findings of this study ranging from of 0.38 to 0.53% FWB (Abong *et al*., 2009). On the other hand, Sato *et al.* (2017) reported very low amount of lipid content of four potato varieties grown in three different areas of Japan ranging from 0.03 to 0.06%. Potato lipid is influenced by genotype, agricultural practices, storage, cooking and processing (Ramadan and Oraby, 2016). Lipid content in potato is very low and its contribution to the calorie is insignificant, but it imparts on flavour of potato products. Fresh potato of 100 g contains 0.10g of lipids contributing 0.50 % of RDA (Burke, 2016). Around 75% of fatty acids of potato lipids are polyunsaturated linoleic acids and they impart a desirable flavour in cooked tubers (Ramadan and Oraby, 2016). Fatty acid compounds like glycolipids, phospholipids, sterols, tocopherols and carotenoids have been reported as components of potato lipids and for their health benefits (Ramadan and Oraby, 2016). Clones had more lipids than varieties and they can both be considered in human diet. Potato lipids though present in small amount, they contribute to the protection of the body and increase of food palatability.

4.1.9 Crude fiber content of potato

Fibers are plant materials that remain after solvent extraction followed by digestion with dilute alkali and acid. Crude fibers of potato cultivars tested in this study were statistically

significantly different at ($P < 0.05$). Orthogonal contrast revealed a significant difference in fiber content between varieties and clones. Clones had lower crude fibers than varieties on average. They varied from 2.06 to 2.96 mg/100g FWB as presented in Table 8. Sangema had the highest fiber content and the lowest was for CIP399075.22.The results agree with the ones reported by Lister and Munro (2000) where crude fibers of potato ranged from 0.17 to 3.48%. Similarly, Liu (2013) reported dietary fiber of 2.5% and Visvanathan *et al.* (2016) reported dietary fiber of 2.7 and 1.4% FWB with and without skin respectively. Amount of fibers may be related to the genotype and agronomic factors. Dietary fibers are not uniformly distributed but they are higher in the skin than in the flesh and cooking affects them by solubilizing pectin and resistant starch (Vreugdenhil *et al.*, 2007). It is recommended to consume 14 g of fibers for every 1000 calories (Madhu *et al*., 2017). Fresh potato amounting to 100 g contains 2.5 g of dietary fiber contributing 7% of RDA (Burke, 2016). Moreover, Fibers have been reported for their high water and oil holding capacity during processing (Dhingra *et al*., 2012). Soluble fibers like hemicellulose and pectin are used as thickeners, stabilizers, emulsifiers and gelling agents during processing (Soral-śmietana *et al.*, 2003). Soluble fibers were reported to bind and exclude harmful compounds out of the body which helps to lower cholesterol and blood glucose, while insoluble fibers are for increasing fecal bulk and their speed in intestine (Pastuszewska *et al*., 2009). Fibers contribute to the bulk of feces, bind undesirable materials such as mutagenesis, carcinogen, and aids in digestion by creating a favorable environment for valuable microflora in the intestine (Visvanathan *et al*., 2016; Madhu *et al.*, 2017). Potato fibers revealed defense against different types of cancer by inducing apoptosis which is the annihilation of abnormal cells (Lister and Munro, 2000; Madhu *et al*., 2017). Numerous health benefits are associated to dietary fiber and they include but not limited to regulating blood lipid levels, controlling blood glucose, hemorrhoids, coronary heat diseases, and increasing satiety which is related to weight loss (Food and Nutrition Board, 2005; Madhu *et al.*, 2017).Varieties had high crude fibers than clones which also have acceptable range of crude fibers. Regular consumption of potatoes can be helpful for digestion and protection against different types of diseases due to their fiber content.

4.1.10 Gross energy content of potato

Gross energy content of potatoes of studied cultivars varied from one variety to another. Energy supplied by each food is related to the contribution of its nutrients. Gross energy of studied potatoes ranged from 79.54 for CIP392617.54 to 101.24 Kcal/100g FWB for Kirundo as shown in Table 8. There was a significant difference of energy content in different potatoes

at ($P < 0.05$). Orthogonal contrast showed a significant difference of gross energy content in studied varieties and clones. On average, varieties had more gross energy content than clones. The average of of gross energy of potatoes was reported to be 87 Kcal/100g (Singh and Kaur, 2009; Stewart and Mcdougall, 2012). Moreover, energy content of 70 kcal/100g for potato contributing 3.5% of RDA was reported by Burke (2016). Gross energy content of boiled potatoes is 72-75 Kcal/100g which is half of rice 138 Kcal, pasta 159 and nearly one third of bread 207 -219 Kcal/100g (Vreugdenhil *et al*., 2007). An average person requires between 2000 to 2500 kcal per day. Given than a boiled potato contains 72-75 kcal (Singh and Kaur, 2009), four kilograms of potatoes are enough to cover calories and energy requirement per day (FAO, 2008). Low energy content of potato may be related to its low fat content which has twice the energy value of carbohydrates. To meet energy requirements, a considerable amount of potatoes should be eaten. However, depending on cooking method, fried potatoes has high amount of gross energy emanating from cooking oil.

4.1.11 Minerals content of potato

Data showing minerals composition are presented in Table 9, while their correlations are shown in Table 10. Minerals are inorganic nutrients which are needed by human body in small amount. Human body needs less than 1 to 2500 mg a day (Soetan *et al.*, 2010). Potato minerals of cultivars in this study were statistically significantly different at ($P < 0.05$). Orthogonal contrast revealed that on the average there was no significant difference in calcium, magnesium and potassium content of varieties and clones. However, a significant difference was found for iron, zinc and phosphorus. On average varieties had higher iron and phosphorus than clones, while clones had higher zinc content than varieties. This study revealed the amount of calcium ranging from 4.41 mg/100g for Kigega to 10.21 mg/100g for Mabondo, magnesium from 13.40 mg/100g for CIP393251.64 to 23.99 mg/100g for Kirundo, iron from 0.53 mg/100g for Kigega to 1.06 mg/100g for Kinigi, zinc from 0.12 mg/100g for Gikungu to 0.37 mg/100g for Kinigi, potassium from 400.29 mg/100g for CIP399075.22 to 593.74 mg/100g Kirundo and phosphorus from 41.19 mg/100g for Sangema to 74.83 mg/100g FWB for Kirundo. The results agree with the study of Furrer *et al*. (2018) who reported mineral content of potatoes on average as 421 mg/100g for potassium, 57 mg/100g for phosphorus, 23 mg/100g for magnesium, 12 mg/100g for calcium, 0.78 mg/100g for iron, and 0.29mg/100g for Zinc. Moreover, the results align with the study of Pal *et al*. (2008) except for potassium and phosphorus and they reported 28.61 to 38.77 mg/100g for potassium, 6.36 to 10.50 mg/100g for calcium, 15.23 to 29.36 mg/100g for magnesium, 10.40 to 15.55 mg/100g for phosphorus, 0.35 to 1.49 mg/100g for iron, 0.51 to 0.88 mg/100g for zinc.

Table 9. Mineral content of fresh potato in mg/100g

	Cultivars	Calcium	Magnesium	Iron	Zinc	Potassium	Phosphorus
Varieties	Gikungu	5.59 ± 0.25^{bcd}	20.91 ± 0.35^{abc}	0.81 ± 0.09^{c}	0.12 ± 0.03^{g}	450.66 ± 1.81^{d}	63.11 ± 0.76^{ab}
	Kigega	4.41 ± 0.27^{e}	18.36 ± 0.33^{cd}	0.53 ± 0.08^{d}	0.20 ± 0.05^{e}	514.87 ± 1.53^{bc}	47.86 ± 0.51^{cd}
	Kinigi	6.35 ± 0.12b	19.45 ± 0.37b^{cd}	1.06 ± 0.08^{a}	0.37 ± 0.04^{a}	509.72 ± 1.45^{c}	52.92 ± 0.75^{bcd}
	Kirundo	5.09 ± 0.12^{cde}	23.99 ± 0.62^{a}	0.96 ± 0.09^{ab}	0.34 ± 0.05^{ab}	593.74 ± 1.56^{a}	74.83 ± 0.71^{a}
	Mabondo	10.21 ± 0.31^{a}	21.63 ± 0.34^{abc}	0.59 ± 0.07^{d}	0.27 ± 0.03^{d}	565.93 ± 1.55^{ab}	45.58 ± 0.55d
	Sangema	4.72 ± 0.09^{de}	21.70 ± 0.38^{abc}	0.96 ± 0.04^{ab}	0.15 ± 0.05^{fg}	417.63 ± 1.50^{d}	41.19 ± 0.54^{d}
Clones	CIP399075.22	6.24 ± 0.14^{b}	18.34 ± 0.39^{dc}	0.61 ± 0.03^{d}	0.30 ± 0.03^{cd}	400.29 ± 1.71^{d}	46.47 ± 0.66^{cd}
	CIP392617.54	5.92 ± 0.19^{bc}	16.49 ± 0.39^{de}	0.83 ± 0.09^{bc}	0.19 ± 0.03e	439.50 ± 1.76^{d}	46.45 ± 0.31^{cd}
	CIP393251.64	6.45 ± 0.17^{b}	13.40 ± 0.26^{e}	0.62 ± 0.04^{d}	0.18 ± 0.04^{ef}	409.70 ± 1.45^{d}	45.94 ± 0.86^{cd}
	CIP 399062.115	4.80 ± 0.13^{cde}	22.96 ± 0.51^{ab}	0.87 ± 0.09^{bc}	0.32 ± 0.04^{bc}	578.79 ± 1.83^{a}	58.52 ± 0.91^{bc}
	Minimum	4.41	13.40	0.53	0.12	400.29	41.19
	Maximum	10.21	23.99	1.06	0.37	593.74	74.83
	CV	6.37	6.98	5.86	4.80	3.85	8.35
	MSD	1.1148	4.0305	0.1345	0.0342	55.029	12.787

MSD: Minimum significant difference (Tukey at 5%), Means followed by the same letter in a column do not differ by Tukey's test at 5%.

Minerals are not distributed equally in all parts of the tuber. Calcium, potassium, magnesium, iron, manganese, zinc and copper are more concentrated in the skin than in the flesh (Singh and Kaur, 2009). Potato skin holds 17% of total zinc, 34% of calcium and 55% of iron and concentration of phosphorus, copper and calcium decreases from the periphery towards the center of potato tuber (Subramanian *et al*., 2011). Fresh potato of 100 g contains 10 mg of calcium, 0.73 mg of iron, 22 mg of magnesium, 0.141 mg of manganese, 61 mg of phosphorus and 0.33 mg of zinc (Burke, 2016). Potassium intervenes in prevention of bruising, it is higher in skin and cell layers nearing the skin than other parts of the tuber and it increases with maturity (Vreugdenhil *et al.*, 2007). Iron was also reported to be responsible for after cooking blackening due to its interaction with chlorogenic acid (Vreugdenhil *et al.*, 2007). A research done in Canada showed that one serving contributes 30 to 48% and 6 to 82% of recommended daily intake (RDI) of macro and micro minerals respectively (Donnelly and Kubow, 2011). Moreover, consumption of 100 g of fresh potato contributes 1% of calcium, 9% of iron, 5.5% of magnesium, 6% of manganese, 9% for phosphorus and 3% for zinc. Singh and Kaur (2009) reported that 100 g of potato contains 12% of RDA for Potassium. Potato minerals were widely distributed in varieties and clones and they play an important role in human diet.

There was a significant correlation among minerals in the studied cultivars. Correlation between Mg and Fe, Mg and K, Mg and P, Fe and P, Zn and K as well as K and P. Correlation of minerals in potatoes was also reported by other authors (Leriche *et al.*, 2009; Subramanian *et al*., 2011). Potassium and phosphorus were present in the highest amount followed by magnesium, while iron and zinc were in smallest amount. Mineral content depends on genotype, minerals present in soil and fertilizer application (White *et al.*, 2009). Minerals should be present in the soil to facilitate plant uptake which in return are absorbed by people during their consumption.

Table 10. Pearson correlation coefficients (r) for minerals of potato tubers

	Calcium	**Magnesium**	**Iron**	**Zinc**	**Potassium**
Magnesium	-0.77 ^{NS}				
Iron	-0.30^{NS}	0.41*			
Zinc	0.16^{NS}	0.35^{NS}	0.30^{NS}		
Potassium	0.15^{NS}	0.60***	0.19^{NS}	0.59***	
Phosphorus	-0.26^{NS}	0. 51**	0. 37*	0.34^{NS}	0.51**

NS: Not significant; *P < 0.05: Significant; ** P < 0.01: Highly significant; ***P < 0.001: Very highly significant.

4.1. 12 Total phenol content of potato

Phenols are bioactive compounds present in potato and they are in various amount in different types. Totaol phenols of stadied cultivars are presented in Table 11. Potato phenolic compounds are located between the cortex and skin where peels and the skin comprise around ten times more phenolic compounds than the flesh (Lister and Munro, 2000). Total phenols of potato cultivars in this study were statistically significantly different at ($P < 0.05$). Orthogonal contrast showed a statistically significant difference between varieties and clones. On average varieties had higher total phenols than clones. Total phenols ranged from 17.80 to 21.52 mg/100g GAE. The highest total phenol was found in Gikungu and the lowest in Kirundo. These results align with phenolic compounds ranging from 5 to 30 mg/100g (Lister and Munro, 2000). The results also agree with the ones in the study conducted by Pal *et al*. (2008) where phenolic content ranged from 16.16 to 31.63 mg/100g. Total phenols were reported to range from 34.475 to 64.230 mg/100g GAE for organically grown potatoes and from 26.854 to 52.172/100g GAE FW for conventionally grown potatoes (Murniece *et al.*, 2014). Lee *et al.* (2016) reported 168.44 to 423.92 mg/100g GAE in dried samples in white and coloured potatoes. Phenolic compounds may be affected by cultivars and environmental conditions. In addition to the variety characteristics, increase in phenolic content of potato was related to abiotic stress where chlorogenic acids increased with water stress and organically grown potatoes reported more chlorogenic acid than conventionally grown (Hamouz *et al.*, 2011). Phenolic content was reported to be high in potatoes with purple skin and purple flesh, followed by red skin and red flesh and yellow skin with yellow flesh followed (Reddivari *et al*., 2007). There was no red nor purple flesh potatoes in this study. Flesh of studied potatoes were either yellow or white. Potatoes with purple and red skin fall in the same category where their total phenolic contents were not statistically different at ($P < 0.05$) and they were higher than those with yellow and white skin which also fall in the same category.

Potatoes with white skin and white flesh had the lowest phenolic compounds. Low total phenolic compounds in the studied potatoes may be linked to the varieties which do not have flesh colour like purple or red. Varieties had more total phenols than clones. However, red and purple potatoes had more phenolic compounds than white or yellow potatoes. Therefore, phenolic compounds are linked to certain colours. Phenolic compounds are important for human due to their role in protection against oxidative diseases. Beneficial effect of phenolic compounds were reported to include bacteria and virus growth inhibition, antiglycemic, inhibition and destruction of cancer cells, anti-inflammatory and vasodilatory properties (Singh and Kaur, 2009; Akyol *et al*., 2016). Phenols were higher in varieties than in clones where

Table 11. Phytonutrients of fresh potato in mg/100g

	Cultivars	Total Phenols	Total Anthocyanins	Total Carotenoids	Vitamin C	Total Glycoalkaloids
Varieties	Gikungu	21.52 ± 0.22^{a}	1.46 ± 0.06^{a}	0.13 ± 0.03^{bc}	9.21 ± 0.27^{d}	3.53 ± 0.14^{c}
	Kigega	18.40 ± 0.44^{b}	0.74 ± 0.10^{c}	0.05 ± 0.03^{e}	8.66 ± 0.57^{d}	5.15 ± 0.24^{a}
	Kinigi	20.07 ± 0.34^{ab}	1.31 ± 0.12^{ab}	0.07 ± 0.00^{de}	15.33 ± 0.41^{b}	3.86 ± 0.18^{bc}
	Kirundo	17.80 ± 0.42^{b}	0.43 ± 0.07^{d}	0.07 ± 0.03^{de}	8.24 ± 0.51^{d}	4.44 ± 0.14^{abc}
	Mabondo	19.48 ± 0.32^{ab}	1.12 ± 0.13^{b}	0.08 ± 0.03^{de}	9.57 ± 0.53^{cd}	3.85 ± 0.18^{bc}
	Sangema	19.43 ± 0.10^{ab}	1.10 ± 0.05^{b}	0.11 ± 0.03^{c}	5.31 ± 0.33^{d}	4.60 ± 0.13^{ab}
Clones	CIP399075.22	19.99 ± 0.17^{ab}	0.24 ± 0.08^{d}	0.19 ± 0.04^{a}	26.60 ± 0.48^{a}	4.99 ± 0.14^{a}
	CIP392617.54	17.88 ± 0.33^{b}	0.77 ± 0.11^{c}	0.09 ± 0.03^{d}	15.58 ± 0.40^{b}	3.92 ± 0.21^{bc}
	CIP393251.64	21.11 ± 0.40^{a}	1.21 ± 0.102^{b}	0.07 ± 0.03^{de}	7.58 ± 0.29^{d}	5.35 ± 0.23^{a}
	CIP 399062.115	18.54 ± 0.33^{b}	0.38 ± 0.03^{d}	0.14 ± 0.03^{b}	14.70 ± 0.32^{bc}	4.62 ± 0.21^{ab}
	Minimum	17.80	0.24	0.05	5.31	3.53
	Maximum	21.52	1.46	0.19	26.60	5.35
	CV	4.46	9.89	6.27	15.19	7.32
	MSD	2.5334	0.253	0.021	5.3719	0.9501

MSD: Minimum significant difference (Tukey at 5%), Means followed by the same letter in a column do not differ by Tukey's test at 5%.

coloured potatoes had higher than non-coloured ones. Consumption of food containing phenolic compounds can help in protection against ailments related to oxidative stress.

4.1.13 Total Anthocyanin content of potato

Anthocyanins are plant pigments which are responsible for colours. Total anthocyanins in potato cultivars of this study were statistically significantly different at ($P < 0.05$) as shown in Table 11. Orthogonal contrast showed a significant difference between anthocyanins in varieties and in the clones. On average, varieties had higher anthocyanins than the clones. Total anthocyanin content ranged from 0.24 to 1.46 mg/100g cyanidin 3-glucoside equivalent. CIP399075.22 had the lowest amount of anthocyanins while Gikungu had the highest. Anthocyanin content of potatoes was reported to range from 61.5 to 573.5 mg/kg cyanidin3-glucoside equivalent FWB being higher in dark coloured potatoes (Hamouz *et al.,* 2011). A similar study revealed anthocyanins ranging from 6.9 to 35.0 mg/100g FWB in red fleshed potatoes and 5.5 to 17.1 mg/100g in purple fleshed potatoes FWB (Brown *et al*., 2003). Anthocyanins for white coloured potatoes were found to be 1.56 mg/100g and for coloured potatoes 89.95 mg/100 g of dried samples (Lee *et al*., 2016). Similarly, anthocyanins in potato samples reported by Brown *et al.* (2008) ranged from 1.5 to 48 mg/100g FWB. It was further reported that potatoes with red skin and white flesh have less than 1.5 mg/100g FW of anthocyanin content (Brown, 2008). Anthocyanin of potatoes in this study was low and this might have been caused by cultivars which do not have a visible colouration in the flesh where all potatoes had yellow or white flesh colours. Potatoes with red and purple skin had higher anthocyanins than those with yellow or white colours. Apart from variety genotype, anthocyanin content increases due to abiotic stress (Hamouz *et al*., 2011). Anthocyanins were reported to have antioxidant properties and potatoes with coloured flesh have more antioxidant than those only skin coloured (Lister and Munro, 2000; Brown, 2008). Coloured potatoes were reported to have high anthocyanin content and high antioxidant properties (Lee *et al*., 2016). Antioxidant in purple potatoes was 5.03 times higher than white and yellow coloured flesh potato, while it was 4.34 higher in red fleshed potatoes than in white or yellow coloured flesh potatoes (Hamouz *et al*., 2011). On average total anthocyanins were higher in varieties than in clones. Coloured potatoes had more anthocyanins than non-coloured ones. Anthocyanins in potatoes play a role of customer attraction and antioxidant properties.

4.1. 14 Total carotenoid content of potato

Carotenoids are plant pigments governing colours like red, yellow and orange in many fruits and vegetables. Total carotenoids of potato cultivars in this study were statistically

significantly different at ($P < 0.05$). Orthogonal contrast revealed that there was a statistically significantly difference between varieties and clones. On average, clones had higher total carotenoids than varieties. They varied from 0.05 to 0.19 mg/100g FWB. The highest amount of total carotenoids was for CIP399075.22, while the lowest was for Kigega. Potatoes with yellow flesh colour had higher total carotenoids than those with white colour. Carotenoids from organically grown potatoes was reported to range from 0.089 to 0.385 mg/100g FWB and 0.068 to 0.371 mg/100g FWB for conventionally grown potatoes Murniece *et al*. (2014) which align with the results of this study. On the other hand, Singh and Kaur (2009) reported 0.02 to 2 mg/100g FWB. Total carotenoids in potatoes is very low comparing to sweet potato which can have 0.1 to 7.5 mg/100g FWB and dark varieties can have up to 20 mg/100g (Lister and Munro, 2000). Brown *et al*.(2008) reported carotenoids ranging from 50 to 100 µg for white fleshed potatoes, 100 to 350 µg/100g for yellow fleshed potatoes, 1000 µg/100g and above for deep yellow or orange fleshed potatoes and the highest publication was 2600 µg/100g FWB. Carotenoids are involved in protection against different diseases due to their ability to scavenge singlet oxygen generated during light induced lipid oxidation (Ezekiel *et al*., 2013; Lee *et al*., 2016). The carotenoids in potatoes are identical to those in the human retina and are involved in nutritional therapies for macular degeneration and cataracts (Brown, 2008). Total carotenoids were higher in clones than varieties on average. Consumption of carotenoids rich potatoes helps to protect the body against diseases related to oxidative stress.

4.1.15 Vitamin C content in potato

Potatoes are a good source of vitamin C and results for vitamic C content are presented in Table 11. Vitamin C is located mainly around the vascular system and lower in the pith and skin (Lister and Munro, 2000). Vitamin C of potato cultivars in this study was statistically significantly different at ($P < 0.05$). Orthogonal contrast showed that there was a significant difference between vitamin C of clones and varieties. Clones had higher vitamin C than varieties. In this study, vitamin C varied from 5.31 to 26.60 mg/100g FWB. CIP399075.22 had the highest, while Sangema had the lowest of vitamin C content. The results in this study align with the ones reported by Lister and Munro (2000) which ranged from 1 to 54 mg/100g on FWB where majority were between 10 to 25 mg/100g. They also agree with the ones reported by Pal *et al.* (2008) which ranged from 10.74 to 19.32 mg/100g FWB. Amount of 100 g of fresh potato contains 11.4 mg of vitamic C supplying 20% of RDA (Burke, 2016). Vitamin C content may be influenced by genotype, maturity and agronomic factors. Length of storage and temperature were also reported to influence vitamin C losses (Singh and Kaur, 2009). Vitamin C is essential for avoidance of scurvy. It is also an excellent antioxidant and it helps

in prevention of oxidative stress (Lee *et al.*, 2016). Clones had higher vitamin C content than varieties on average and this might have been influenced by varieties used for breeding. Regular consumption of potatoes can help to meet requirements of vitamin C for the body thereby protecting it against different diseases which are associated to oxidation.

4.1.16 Total glycoalkaloid content of potato

Glycoalkaloids are toxic compounds which are produced by plants for their protection. The main ones are α-solanine and α-chaconine. Glycoalkaloids of potato cultivars in this study were statistically significantly different at ($P < 0.05$). Orthogonal contrast showed a significant difference in total glycoalkaloids content of potato varieties and clones. Glycoalkaloids varied from 3.53 mg/100g for Gikungu to 5.35 mg/100g α-Solanine equivalent for CIP393251.64 FWB. It is recommended that the upper level of potato glycoalkaloids should be 20 mg/100g FWB and most of potatoes range from 3 to 10 mg/100g (Lister and Munro, 2000). Glycoalkaloids content may be related to cultivars, agronomic factors and postharvest handling. Their production continue after harvesting and inappropriate storage can contribute to their increase (Lister and Munro, 2000). Glycoalkaloids are high in potatoes which are not mature, small tubers and tubers stored in open area or injured (Burke, 2016). It was advised that safety limit should be 150 mg/kg FWB (Burke, 2016). They are not destroyed by heat. However, the highest amount is eliminated when sprouts are detached, peeled and they leach in water as they are water soluble (Liu, 2013). Nevertheless, glycoalkaloids were also found to lower serum glucose, to have antibiotic effect, to hinder cancer cell growth, to lessen serum cholesterol levels, anti-inflammatory and anti-pyretic effects (Camire *et al.*, 2009). At low concentration they also contribute to the flavour of the potato. Potato glycoalkaloids contribute to the flavour and prevention of some diseases and are toxic at high concentration. Potatoes with high glycoalkaloids have abitter taste which is a warning to the consumers and they should not be eaten due to their high toxicity.

4.2. Effect of potato cultivars on quality of crisps and French fries

Potato processing in French fries and crisps showed reduction in moisture content in fried products in Table 12 and oil absorption for French fries in figure 5 and in figure 6 for crisps.

4.2.1 Moisture content of raw potato for crisps and French fries

Initial moisture content of French fries was slightly different from the one of crisps which might have been caused by washing of potatoes after peeling and slicing. Moisture content of raw French fries and crisps are presented in Table 12. Moisture content ranged from

74.9 to 76.89% for raw French fries, the lowest moisture content was for Mabondo and the highest moisture content was for Kinigi. For raw crisps the moisture content ranged from 73.47 to 76. 40%. The lowest moisture content was for Mabondo and the highest was for Sangema. In both cases the difference in moisture content was not statistically significant at ($P > 0.05$). The results agree with moisture content reported by Norell *et l.*(2016) which ranged from 75 to 85%. Similarly, four potato varieties grown in four regions of Japan were reported to have moisture content ranging from 78.09% to 82.98% (Sato *et al.*, 2017). Moisture content is influenced by variety, level of maturity, growing location, seasonal effects, fertilizer application and storage conditions (Norell *et al.*, 2016). Potatoes with low moisture content below 80% are suitable for frying and dehydrated products, while potatoes with high moisture content are suitable for canning (Marwaha *et al.*, 2010).

Table 12. Moisture loss in French fries and crisp in percentage

Cultivars	**French fries**		**Crisps**	
	Initial moisture content %	**Moisture of French fries %**	**Initial moisture content %**	**Moisture of crisps %**
Kinigi	76.89 ± 0.46[a]	41.33 ± 0.38[a]	74.66 ± 0.46[a]	1.78 ± 0.06[a]
Kirundo	76.03± 0.35[a]	32.23 ± 0.59[b]	74.00 ± 0.35[a]	1.73 ± 0.20[a]
Mabondo	74.49 ± 0.38[a]	37.25 ± 0.75[ab]	73.47 ± 0.23[a]	1.99 ± 0.11[a]
Sangema	76.46 ± 0.40[a]	41.58 ± 0.97[a]	76.24 ± 0.40[a]	1.87 ± 0.12[a]
CIP393251.64	75.51 ± 0.10[a]	36.80 ± 1.64[ab]	74.92 ± 0.10[a]	2.05 ± 0.09[a]
Minimum	74.49	32.23	73.47	1.73
Maximum	76.89	41.58	76.24	2.05
CV	2.41	6.73	1.75	11.02
MSD	5.1621	7.1792	3.695	0.5855

MSD: Minimum significant difference (Tukey at 5%), Means followed by the same letter in a column do not differ by Tukey's test at 5%.

Potatoes with low moisture content have high dry matter. It was further reported that the lower limit of dry matter content is 19.5% for French fries and 20% for crisps and upper limit is 25% for French fries (Vreugdenhil *et al.*, 2007). The initial moisture content is related to the rate at which water is removed from food during frying. Potatoes with low moisture content are related to less oil absorption, high yield, less energy consumption and crispy texture

(Marwaha *et al*., 2010). More oil is absorbed in the products where initial moisture content is higher than in products where initial water content is low which affects quality of the final products. Therefore, potatoes with low moisture content are preferred in fried potato products.

4.2.2 Moisture content of potato French fries and crisps

Final moisture content of fried potato products depends on both raw materials and nature of the product. The final moisture content of fried French fries ranged from 32.23 for Kirundo to 41.58% for Sangema. On the other hand, for crisps, moisture content ranged from 1.73 for Kirundo to 2.05% for CIP393251.64. The difference in moisture content was statistically significantly different at ($P < 0.05$) for French fries, while it was not statistically significantly different for crisps at ($P > 0.05$). The average moisture content of crisps was reported to be 1.8% and from 30 to 50% for French fries Singh and Kaur (2009) which aligns with the results of this study. Reduction of moisture content of crisps up to 2% was reported by other authors (Aguilera and Gloria-Hernandez, 2000; Bouchon *et al*., 2003; Pedreschi *et al*., 2008). Moreover, the average moisture content of French fries was reported to be around 38% (Aguilera and Gloria-Hernandez, 2000). A study conducted on six varieties of potatoes fried in French fries after blanching revealed moisture content ranging from 46 to 57% (Ngobese *et al*., 2017). Microwave frying had moisture content ranging from 35.47 to 41.24% (Aydınkaptan and Mazı, 2017). Moisture content of French fries was reported to range from 51.2 to 58.8% in four varieties after 4 minutes of frying at 150^{o}C and 2 minutes at 180^{o}C respectively (Mesías *et al*., 2017). Moisture content of pre dried French fries was 48.18% after 30 minutes of drying, 49.60% after 20 minutes of drying, 52.99% after 10 minutes of drying and 58.88% for non-dried French fries (Garmakhany *et al*., 2010). It was confirmed that thick products contain moisture content ranging from 30 to 50% and less than 5% for thin products (Ziaiifar *et al*., 2008). During frying, water in the crust evaporates and leaves the food. More water migrates from core to the crust and the crust must remain permeable to allow water evaporation which leaves from pores in the product. Food with high amount of moisture loss has high amount of oil uptake due to high number of pores formation (Vitrac *et al*., 2000). Frying removes almost all the water from crisps while in French fries significant amount of water remains. This is because of thickness of the products where for crisps with large surface area and thin water removal is very fast, while for French fries water from the surface is removed very fast while the one in the core goes very slowly and cooking of entire slice happens before much water is removed.

After putting French fries or crisps in hot oil, water starts boiling and it is released in form of bubbles this causes reduction in temperature of frying medium which again increases to reach the set temperature (Arslan *et al*., 2018). The amount of evaporated water is proportional to the temperature difference between the oil and the boiling point of water (Vitrac *et al.*, 2002). Due to high temperature, water is converted to steam and steam escapes through deformities, cracks, channels and open capillaries present in membrane and cellular structure (Arslan *et al.*, 2018). As frying time increases the number of bubbles decreases (Arslan *et al*., 2018). Moreover, as frying proceeds there is crust formation and its thickness reduces water removal thereby increasing vapor pressure below the crust which leads to formation of swollen pockets and the water vapor is released by busting due to stress caused by high pressure (Troncoso *et al*., 2009). This crust may be attributed to the slow removal of moisture from French fries comparing to crisps. Due to their thinness, crisps are considered like crusts of French fries (Troncoso *et al*., 2009). When dehydrated crust has fully developed, the crust temperature equilibrates with frying medium where there is gradual increase in core temperature to reach 100^{o} C, the heating of core is done by convection and due to large crust of French fries, the temperature of the core remains at 100^{o} C, while for crisps the temperature is moderately higher (Mellema, 2003; Gökmen *et al.*, 2006). The difference in moisture content of fried products can also vary from one cultivar to another due to initial moisture content, whether it is free or bound, cell microstructure and frying temperature. Potatoes with low moisture content which can easily be removed during frying are preferred for both French fries and crisps.

4.2.3 Oil absorption of French fries and crisps during frying

During frying, a portion of oil is absorbed in microstructure of potatoes, while another portion remains at the surface. Internal oil during frying ranged from 3.77% for Kirundo to 4.21% for Kinigi, while the surface oil was from 3.07% for Kirundo to 6.85% for CIP393251.64 in French fries. The internal oil was not statistically significantly different among cultivars at ($P > 0.05$), while the difference was statistically significant for surface oil at ($P < 0.05$). Total oil for French fries ranged from 6.84 % for Kirundo to 10.9% for CIP393251.64 and the difference was statistically significant at ($P < 0.05$). On the other hand, for crisps internal oil ranged from 4.95 % for Mabondo to 6.93% for Sangema, while surface oil was from 7.65 % for Kirundo to 9.63 % for CIP393251.64 and the difference was statistically significant for both internal and surface oil at ($P < 0.05$). Total oil for crisps during frying ranged from 12.7 % for Kirundo to 16.49 % for Sangema and the difference was

statistically significant at ($P < 0.05$). Oil content in fried products includes structural oil, penetrated surface oil and surface oil where penetrated surface oil was reported to occupy the highest proportion (Pedreschi *et al*., 2008). It was reported that during frying, internal oil increased from 4.5 to 7.6% of total oil (He *et al*., 2013).

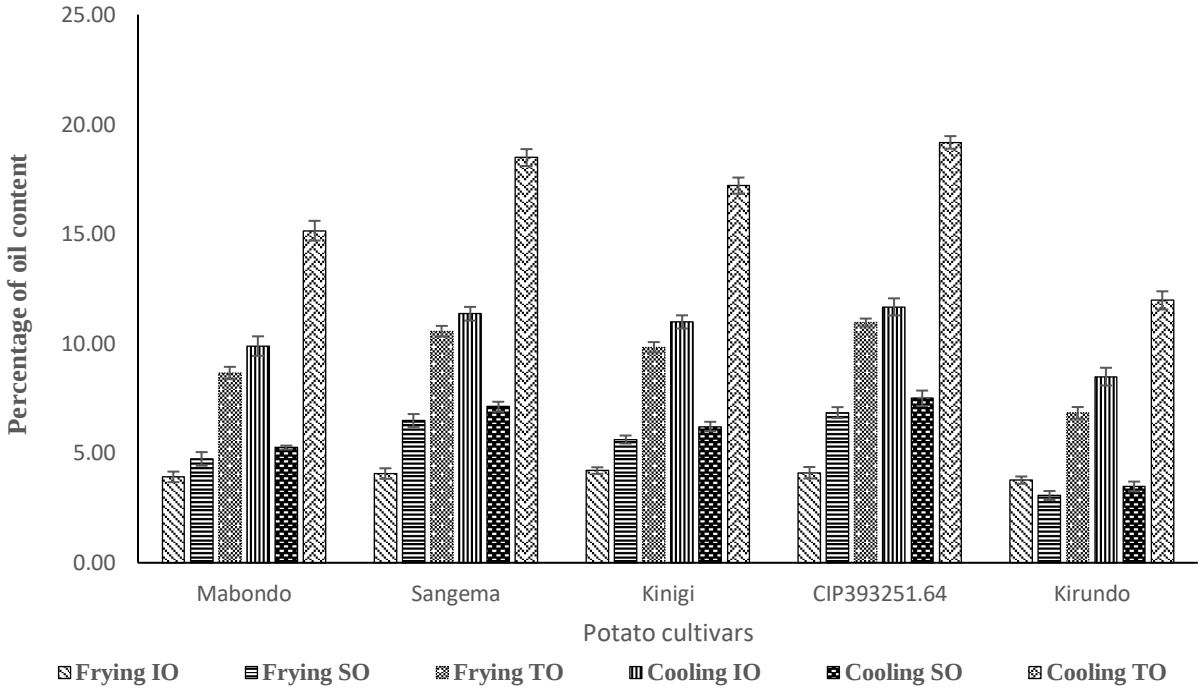


Figure 5. Oil content of French fries

IO: Internal oil, SO: Surface oil, TO: Total oil, error bars represent standard error of the means

Frying potato chips at 120^{o}C, 150^{o}C and 180^{o}C revealed penetrated oil ranging from 7 to 18% for non-blanched and 5 to 17% for blanched of total oil which indicates that small amount of oil penetrates during frying (Pedreschi *et al*., 2008). Oil absorbed by French fries from four varieties fried for 4 minutes at 150^{o}C and 2 minutes at 180^{o}C ranged from 13.4 to 15.6% (Mesías *et al*., 2017). Almost 75% of total oil was absorbed in the first 1 to 4 minutes and 1 to 6 minutes for non-blanched and blanched crisps and it remained almost constant to reach moisture of 1.8, low frying temperature increased frying time and total oil (Pedreschi *et al*., 2008). Frying chips at 180^{o}C revealed that 38% of the total oil content of salted and blanched crisps penetrated into their microstructure and almost 62% remained on the product's surface (Duran *et al*., 2007). However, once the product was removed from the fryer (cooling stage beginning), the oil partition was inverted and around 65% of total oil content was absorbed and around 35% remained on its surface (Duran *et al*., 2007). It was reported that less oil is absorbed

during frying and increased at the end of frying and during cooling and oil uptake and water removal are not synchronous phenomena (Pedreschi *et al*., 2008). Oil absorption during frying is higher for crisps than French fries and in both cases surface oil tends to be more than internal oils. This is due to larger surface area for crisps which is thin. The core of French fries does not absorb oil, it is limited to the surface area which imparts its less oil content comparing to crisps.

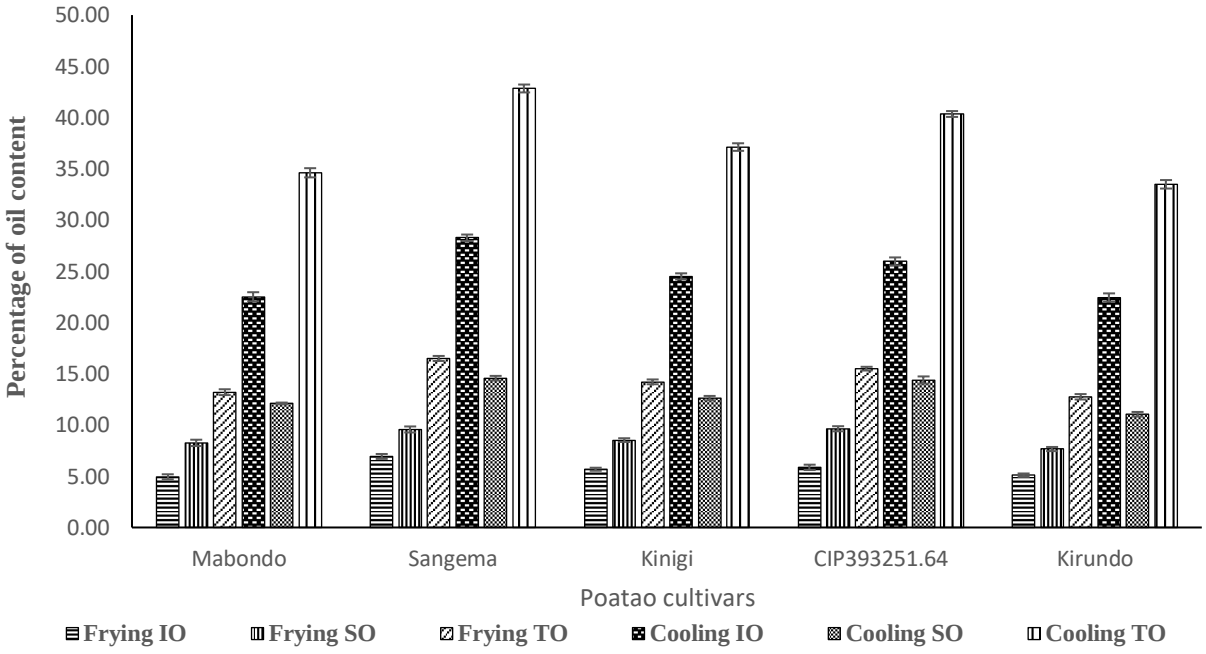


Figure 6. Oil content of crisps

IO: internal oil, SO: Surface oil, TO: Total oil, error bars represent standard error of the means

4.2.4 Oil content of fried French fries and crisps during cooling

During cooling internal oil increases faster than surface oil. Internal oil for French fries was 8.49% for Kirundo to 11.67% for CIP393251.64, surface oil was 3.48% for Kirundo to 7.50% for CIP393251.64. Total oil for French fries ranged from 11.97% for Kirundo to 18.48% for CIP393251.64. The difference was statistically significant for internal, surface and total oil at ($P < 0.05$). Similarly, for crisps, internal oil varied from 22.44% for Kirundo to 28.27 % for Sangema, while the surface oil was from 11.05% for Kirundo to 14.57% for Sangema. Total oil for crisps ranged from 33.49% for Kirundo to 42.84% for Sangema. The difference was statistically significant for internal, surface and total oil at ($P < 0.05$). Two different oil fractions were reported to be present in potato which include structural oil (STO) which is absorbed in microstructure and surface oil (SO) which remains on the surface (Bouchon *et al*.,

2003). High oil absorption was also reported by other authors (Bouchon *et al*., 2003; Duran *et al*., 2007; He *et al.*, 2013). Oil that persists on the surface of the product promptly enters the porous structure during cooling (He *et al.*, 2013). The crust developed during frying provides the void space which are filled with oil during cooling and the oil on the surface can either be drained, absorbed or remain on the surface *(*He *et al*., 2013). Capillary forces created by porous on the crust are the main driving forces for oil absorption (He *et al*., 2013). He *et al*. (2013) reported that STO increased steadily from 4.5 to 7.65% during frying and within 60 second of cooling it increased from 7.6 to 22% to reach 26.3% after 600 seconds of cooling to room temperature and counted for 70% of total oil (He *et al.*, 2013). Moreover, it was reported that 38% of total oil is absorbed during frying while after cooling the situation is reversed where 65% of total oil is absorbed and 35% remains at the surface (Duran *et al*., 2007). Oil content of fried potato products was reported to be higher in thin products ranging from 30% to 40% and lower in thick products rounding to 15% (Ziaiifar *et al*., 2008). Frying oil is a heat transfer medium and ingredient where it can be up to 40% of total mass in thin products (Ziaiifar *et al.*, 2008). Absorbed oil plays a role of maintaining integrity of the product by preventing collapsing and by helping to evaporate water (Arslan *et al*., 2018). The average oil content of potato crisps is 35.5% to 44.5% on wet basis and it is responsible for texture and flavour of the products (Garayo and Moreira, 2002). Ziaiifar *et al.*(2008) claimed that oil does not enter potato chips during frying, it rather enters during cooling. On the other hand Bouchon *et al*. (2003) reported that structural oil could enter during frying which can depend on drying rate or frying period. Mehta and Swinburn (2001) confirmed that there is little oil absorption during frying when the product is still in hot oil and steam still escaping. During frying oil absorption is at very low rate which increases immediately in the first cooling minute up to 4 while surface oil reduces (Ziaiifar *et al*., 2008). Oil absorbed by potato products during frying remains at the surface of potatoes. French fries comprise two different regions including external which is dehydrated and crispy like where oil is localized and internal cooked core free from oil (Pedreschi, 2012).The characteristics of the surface of fries and oil viscosity are thought to influence in oil absorption (Arslan *et al*., 2018). Pedreschi *et al*. (2008) confirmed existence of two distinct regions including central layer which is tender and saturated with water as well as crust which is dry, oily, porous and crispy. Oil does not penetrate cells, it rather enters in void spaces emanating from breakdown of adhesive force when water escapes from the product (Ziaiifar *et al*., 2008). Oil absorption is reduced under vacuum, at normal atmosphere of 100 KPa oil absorption was 37. 5% and it reduced to 13.6% where pressure was 80 KPa (He *et al*.,

2013). During frying dynamic emission of moisture creates internal pressure which inhibits oil from entering the food structure (Haizam *et al.*, 2013). To reduce surface oil absorption, super-heated steam can be blown on the fries, vacuum cooling or adsorbed paper can be used to remove oil (Arslan *et al*., 2018). Coating was also reported to reduced oil absorption (Mellema, 2003). High amount of oil in fried products is not healthy to consumers. More oil was absorbed during cooling and it varies with cultivars.

4.2.5 Sensory evaluation of potato French fries

The results showing sensory evaluation of French fries are shown in Tables 13, loading matrix in Table 14, Figure 7 shows scree plot, Figure 9 shows principal components and Figure 9 shows discriminate analysis. The overall acceptability of potato French fries was statistically significantly different among cultivars at ($P < 0.05$). The acceptability ranged from 6.57 for Mabondo to 8.09 for Kinigi. Mabondo was the only cultivar which was different from the others. Concerning colour, Mabondo and CIP393251.64 were significantly different from the others at ($P < 0.05$). Colour varied from 5.11 for Mabondo to 6.91 for Sangema. For sweetness all the cultivars were not significantly different from each other at ($P > 0.05$). For Flavour, there was a significant difference among cultivars at ($P < 0.05$). The least score for flavour was for Mabondo with 5.60 and the highest was for CIP393251.64 with 7.20. For crispness, there was a significant difference among cultivars at ($P < 0.05$). Crispness ranged from 4.80 for Mabondo to 6.91 for Sangema. For dryness, there was a significant difference among cultivars at ($P < 0.05$). Mabondo had the least score of 5.09 and Sangema had the highest score of 7.23. Potatoes contain precursor of sensory characteristics which include sugars, amino acids, RNA, and lipids (Jansky, 2010). Moreover, sensory characteristics is influenced by factors like plant genotype, environment, and storage conditions along with enzymes which react with them to produce compounds responsible for sensory characteristics (Jansky, 2010). During cooking sensory precursors react to produce Maillard reaction compounds and the degradation products of sugars, lipid and RNA contribute to the sensory quality (Duckham *et al*., 2002). All cultivars in this study produced French fries which are acceptable by consumers except for crispness of Mbondo which was not acceptable. The least accepted was Mabondo in all studied attributes and other varieties can be used interchangeably with slight difference in some attributes.

Table 13. Sensory attributes of potato French fries

Cultivars	Overall acceptability	Colour	Sweetness	Flavour	Crispiness	Dryness
Kinigi	8.09 ± 0.37^{a}	6.83 ± 0.34^{a}	6.37 ± 0.46^{a}	7.00 ± 0.29^{a}	6.69 ± 0.44^{ab}	6.91 ± 0.48^{a}
Kirundo	7.51 ± 0.39^{a}	6.46 ± 0.35^{a}	5.51 ± 0.51^{a}	6.63 ± 0.32^{ab}	6.43 ± 0.43^{ab}	6.57 ± 0.48^{ab}
Mabondo	6.57± 0.39^{b}	5.11± 0.39^{b}	5.57 ± 0.54^{a}	5.60 ± 0.32^{c}	4.80 ± 0.50^{c}	5.09 ± 0.54^{c}
Sangema	7.49 ± 0.38^{a}	6.91 ± 0.38^{a}	6.00 ± 0.51^{a}	6.14 ± 0.37^{bc}	6.91 ± 0.49^{a}	7.23 ± 0.41^{a}
CIP393251.64	7.83 ± 0.35^{a}	5.63 ± 0.36^{b}	6.26 ± 0.49^{a}	7.20 ± 0.35^{a}	5.51 ± 0.47^{bc}	5.29 ± 0.48^{bc}
CV	16.89	18.51	35.54	16.20	32.88	32.98
MSD	0.8368	0.7572	1.3959	0.6976	1.3189	1.3549

MSD: Minimum significant difference (Tukey at 5%), Means followed by the same letter in the column do not differ by Tukey's test at 5%.

Principal component analysis reduced five variables into three principal components (PCA1, PCA2 and PCA3) which had eigenvalues more than one and retained for rotation. The factor pattern was rotated using varimax. The principal component one comprised colour, crispness and dryness which accounted for 39.2 % of total variations, the principal component 2 comprised sweetness which accounted for 18. 8% of total variations. The third principal component was made of flavour. Panda and Ray (2007) reported PCA to reduce six variables into two accounting for 74% for PCA1 and 18% for PCA2. Based on classification of Liu *et al*. (2003), attributes load as strong above 0.75, moderate between 0.5 and 0.75 and weak between 0.3 and 0.5. Therefore, all the attributes loaded moderately in their respective principal components. Based on this classification, all attributes in this study loaded moderately. The higher the loading, the stronger the correlation among attributes in the same principal component (Panda and Ray, 2007). Attributes in the same principal components correlate to each other and in all cases PCA1 account for the highest variations and should be given the first priority during manufacturing.

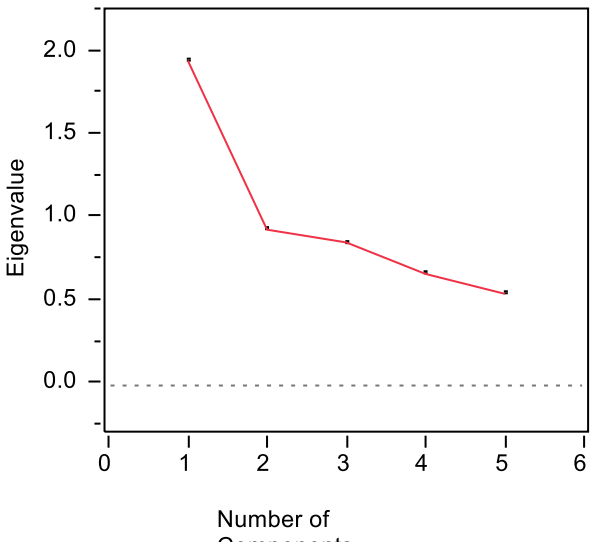


Figure 7. Scree plot for French fries

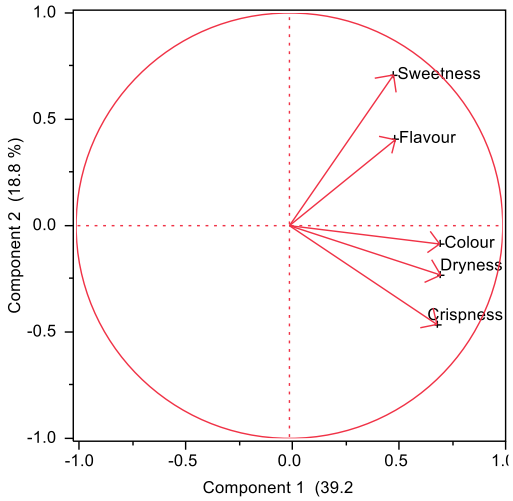


Figure 8. Principal components for French fries

Table 14. Loading Matrix on Principal component for French fries

Potato attributes	Prin1	Prin2	Prin3	Prin4	Prin5
Colour	**0.70386**	-0.08622	-0.07170	**-0.68960**	-0.12830
Sweetness	0.48804	**0.70868**	-0.43040	0.08440	0.25928
Flavour	0.49645	0.40383	**0.74480**	0.11231	-0.15203
Crispness	**0.69124**	-0.46430	0.15852	0.15726	0.15067
Dryness	**0.70921**	-0.23225	-0.30853	0.39443	-0.43853

Prin: principal component

Discriminate analysis showed that there was overlapping of all studied potato cultivars. This suggests that they were not signigicantly different from one another at ($P < 0.05$). Therefore, they can be used interchangeably in processing of French fries.

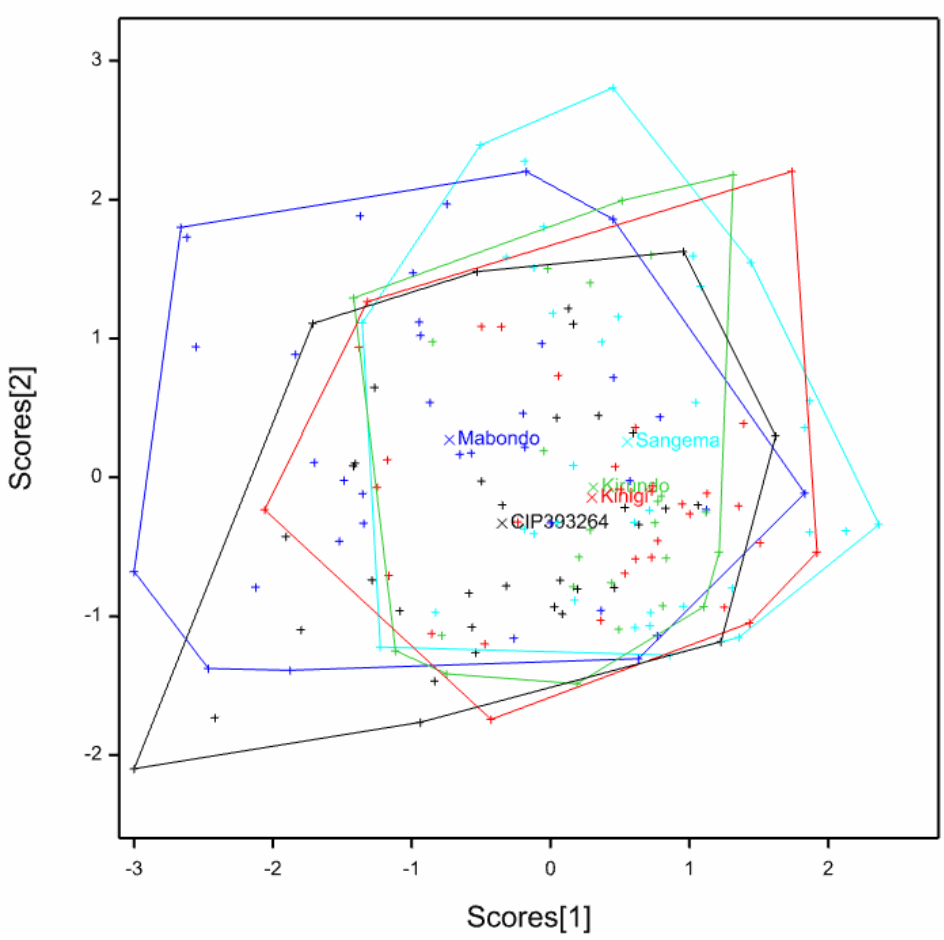


Figure 9. Discriminant analysis of French fries

4.2.6 Sensory evaluation of potato crisps

The results of sensory evaluation of crisps are shown in Table 15 and Table 16 for loading matrix. Scree plot is shown in Figure 10, principal components in Figure 11 and discriminant analysis in Figure 12. There was a significant difference in overall acceptability of studied cultivars at ($P < 0.05$). The acceptability ranged from 6.68 for Sangema to 8.32 for Kinigi. The difference was statistically significant in all studied attributes at ($P < 0.05$). For colour it ranged from 5.62 for Mabondo to 8.35 for Kinigi, sweetness ranged from 6.30 for Mabondo to 7.73 for Kinigi, Flavour varied from 5.38 for Sangema to 6.84 for CIP393251.64. For crispness, it varied from 6.51 for CIP393251.64 to 7.14 for Sangema. For dryness, it varied from 6.14 for Sangema to 7.05 for Kinigi. It was reported that potatoes with high amount of

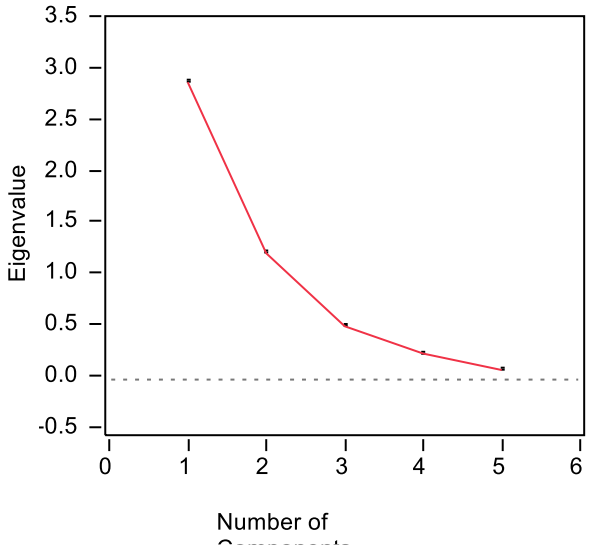
Table 15. Mean of Hedonic ratings for overall acceptability and sensory attributes of potato crisps

Cultivars	Overall Acceptability	Colour	Sweetness	Flavour	Crispness	Dryness
Kinigi	8.32 ± 0.36^{a}	8.35 ± 0.39^{a}	7.73 ± 0.32^{a}	6.14 ± 0.38^{ab}	7.22 ± 0.30^{a}	7.05 ± 0.31^{a}
Kirundo	7.78 ± 0.43^{a}	6.24 ± 0.49^{bc}	7.38 ± 0.38^{ab}	6.30 ± 0.43^{ab}	6.70 ± 0.32^{bc}	6.49 ± 0.37^{ab}
Mabondo	7.62 ± 0.42^{ab}	5.62 ± 0.43^{c}	6.30 ± 0.35^{c}	6.70 ± 0.38^{a}	6.62 ± 0.28^{c}	6.32 ± 0.30^{b}
Sangema	6.68 ± 0.52^{b}	6.86 ± 0.48^{b}	6.92 ± 0.38^{bc}	5.38 ± 0.43^{b}	7.14 ± 0.30^{ab}	6.14 ± 0.32^{b}
CIP393251.64	7.95 ± 0.46^{a}	6.27 ± 0.46^{bc}	6.51 ± 0.37^{c}	6.84 ± 0.38^{a}	6.5 ± 0.29^{c}	6.27 ± 0.31^{b}
CV	22.33	26.38	16.89	23.17	11.45	14.09
MSD	1.1003	1.1302	0.7553	0.933	0.5031	0.5839

MSD: Minimum significant difference (Tukey at 5%), Means followed by the same letter in a column do not differ by Tukey's test at 5%.

sugars have a poor/soft texture after cooking (Duckham *et al.*, 2002). Mealiness and waxy contribute to the texture. Size and structure of starch granule influence texture. Moreover, when potato tubers are cooked, fatty acids degrade to produce aldehydes and ketones, which contribute to flavour (Duckham *et al.*, 2002). Dry metter and reducing sugars contribute to the quality of fried potato. Potatoes with high dry matter absorbs less oil which improves crispness of fried potatoes (Marwaha *et al.*, 2010). Potato crisps in all cultivars were accepted where different attributes contributed differently. On overall, Sangema was the least accepted and Kinigi was the most accepted.

Principal component analysis classified potato crisps in two main components (PCA1 and PCA2) with Eigenvalues larger than one and retained for rotation. The factor pattern was rotated using varimax. The first principal component comprised colour, sweetness, crispness and dryness accounting for 57.9% of total variations. Flavour was in the second principal component and represented 24.6% of total variations. The two principal components accounted for 82.5% of total variations. Mohapatra *et al.* (2007) used PCA to reduced 12 variables into 4 principal components accounting for 60%, 17%, 12% and 7% for PCA1, PCA2, PCA3 and PCA4, respectively.



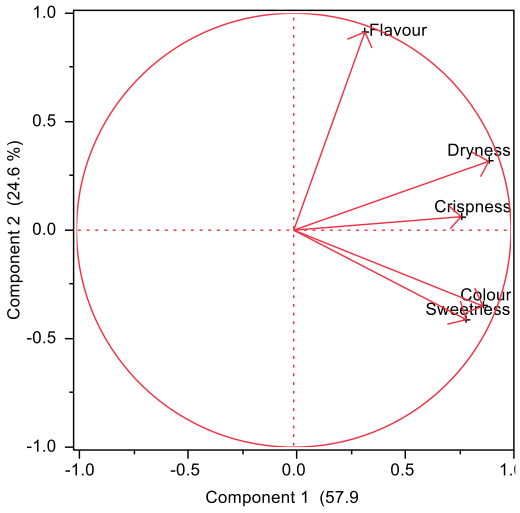


Figure 10. Scree plot for crisps **Figure 11. Principal component for crisps**

Liu *et al.* (2003) categorized components load as strong above 0.75, moderate between 0.5 and 0.75 and weak between 0.3 and 0.5. Therefore all the attributes loaded strongly in their respective principal components. Attributes with strong loading in the same principal component correlate strongly among themselves. During crisps manufacturing, attributes in the first principal components should be given priority as they are responsible for the highest

variations and the ones in the second principal component follow. In this study the first emphasis should be put on colour, sweetness, crispness and dryness while flavour comes as the second priority.

Table 16. Loading Matrix for crisps

Potato attributes	Prin1	Prin2	Prin3	Prin4	Prin5
Colour	**0.87090**	-0.34989	0.12399	-0.26975	0.17599
Sweetness	**0.79429**	-0.41222	0.26332	0.35973	-0.02101
Flavour	0.32771	**0.91365**	0.16565	0.11446	0.13155
Crispness	**0.77046**	0.06218	-0.62741	0.09253	0.01784
Dryness	**0.89760**	0.31731	0.12476	-0.17782	-0.21551

Prin: Principal

Discriminate analysis showed overlapping of all cultivars. This means they were not significantly different at ($P < 0.05$) in production of potato crisps. Therefore, they can be used interchangeably in crisps making.

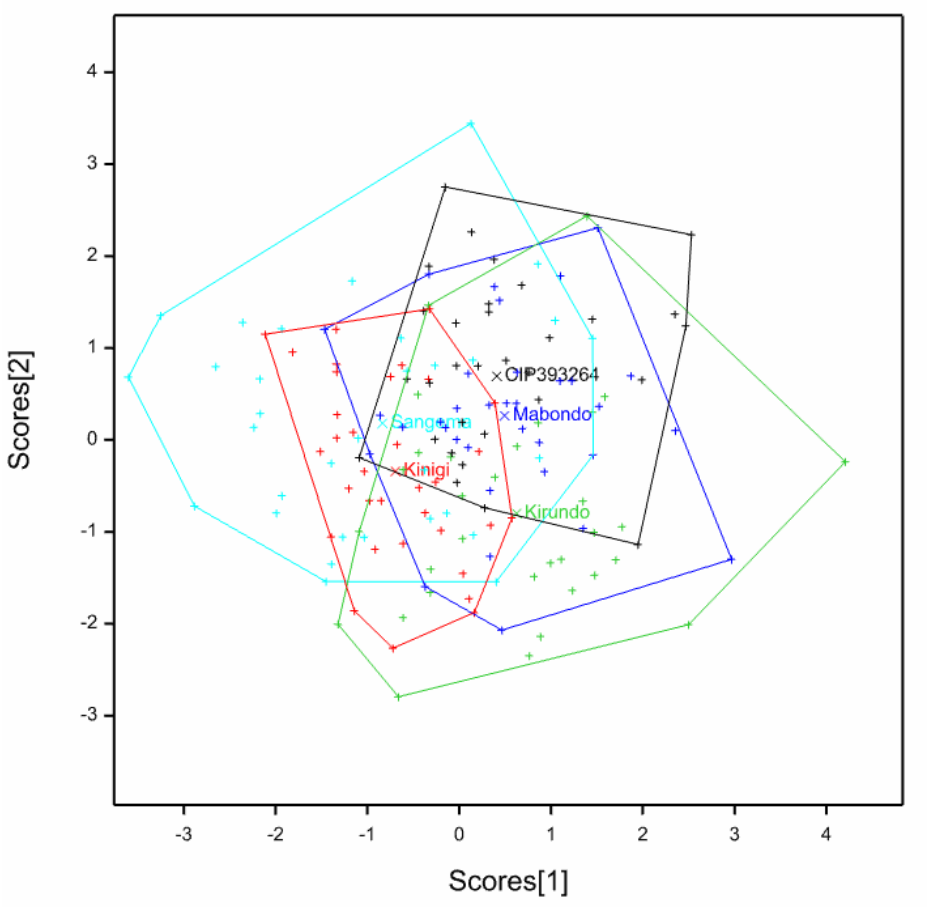


Figure 12. Discriminant analysis of crisps

4.3 Effect of potato fermentation on chemical and sensory properties of potato products

Fermentation reduced pH and it increased acidity. Nutrients also reduced during fermentation. Fermenting microorganisms might have been caused reduction in in nutrients or nutrients might have been leached in fermenting medium. Results for pH are presented in Figure 13, lactic acid in Figure 14 and microbial count in Table 17.

4.3. 1 Change in pH during fermentation

Lactic acid fermentation is a process where lactic acid bacteria metabolize sugars into other compounds where the main by product is lactic acid which causes decrease in pH. During fermentation, pH of fermented potatoes reduced from 7.30 for Sangema to 4.31 for Mabondo. The effect of fermentation with time was statistically significant at ($P < 0.05$). After adding brine solution to potatoes, a slight increase in pH was observed which may be related to the alkaline nature of salt used. Decrease in pH was faster in potato with high sugar content that in potato with low sugar content.

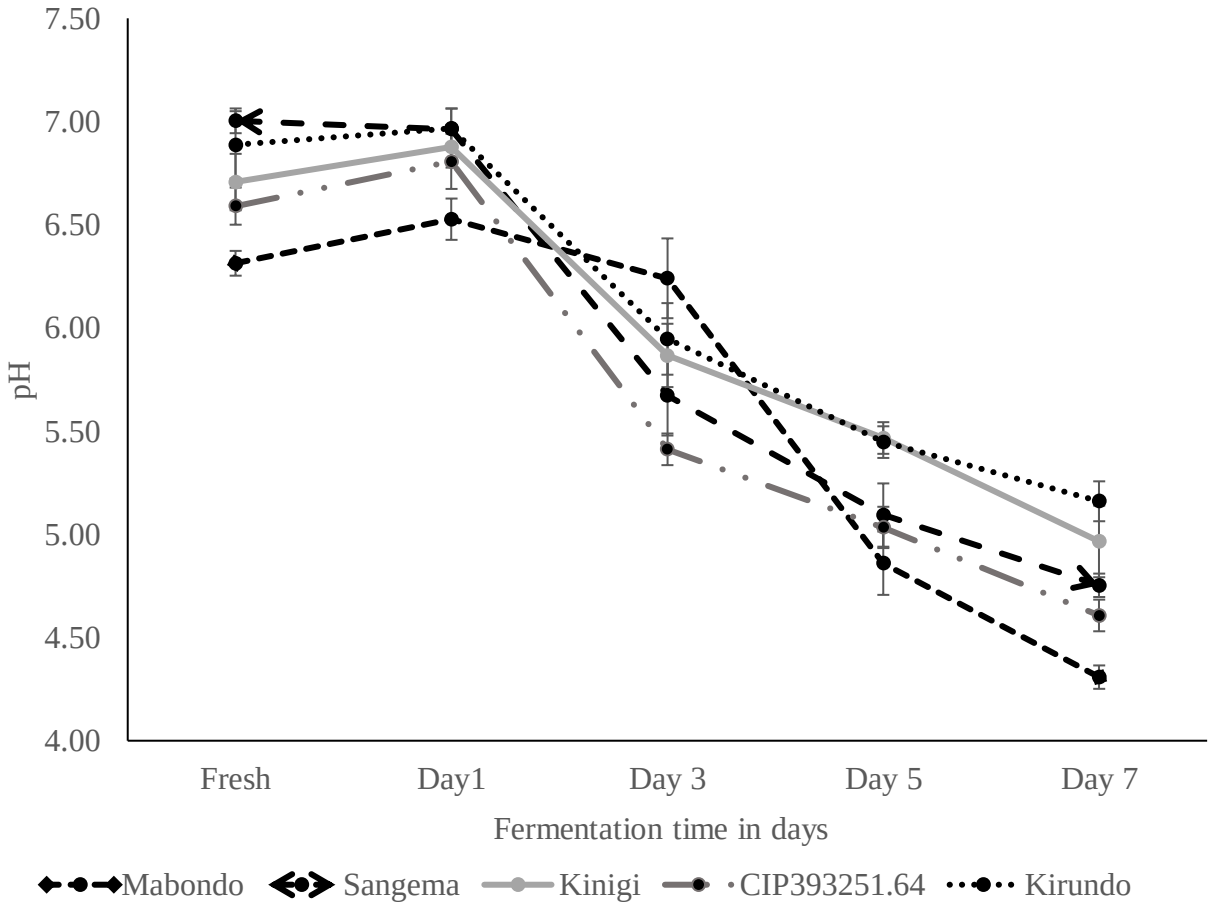


Figure 13. pH of potatoes during fermentation period

During lactic acid fermentation there is reduction of pH and increase of acidity which together help to preserve food. Reduction in pH was also observed during fermentation of cabbage with 2.25% brine solution where it reduced from 6.9 to 4.1 and 3.8 for natural and controlled lactic fermentation respectively (Pandey and Garg, 2015). pH of fermented sweet potatoes with *Lactobacillus plantarum* was reported to reduce from 5.5 to 2.6 after seven days of fermentation and after 28 days pH remained constant (Panda *et al.*, 2007). Similarly, fermentation of boiled and non-boiled sweet potatoes with *L. plantarum* showed reduction in pH from 6.1 to 3.3 for boiled and from 5.8 to 2.2 for non-boiled sweet potatoes (Panda and Ray, 2007). Fermentation of potatoes with *L. plantarum* of 10^9 CFU/ml reduced pH from 5.70 to 4.05 after 3 hours of fermentation (Baardseth *et al.*, 2006). Moreover, fermentation of carrots showed pH reduction from 5.5 to 3.8 and at pH of 4.5 bacteria were inhibited to grow and entered stationary phase (Demir *et al.*, 2006). Reducing pH to 4 or less increases stability and safety of products due to suppression of harmful bacteria (Montet *et al.*, 2014). Lowering pH by lactic acid or acetic acid had bactericidal and bacteriostatic effect, and in addition there is production of H_2O_2 and bacteriocins which also play a role of microbial inhibition (Agrawal, 2005). Fermentation improves food security, nutrition quality, aroma, flavour, texture and removes anti-nutrients from fermented vegetables (Demir *et al.*, 2006). pH is responsible for the development of aroma and flavour of fermented fruits and vegetables (McFeeters, 2004). Low pH helps to stabilize food due to microbial growth inhibition and contributes to the flavour and aroma of fermented products.

4.3. 2 Change in titratable acidity of fermented potatoes

Titratable acidity increased during fermentation time. There was a significant increase of titratable acidity with fermentation time of potatoes at ($P < 0.05$). Initial titratable acidity of potatoes in this study ranged from 0.01 for Kirundo and Sangema to 0.02% for Kinigi, Mabondo and CIP393251.64 and after seven days of fermentation it was 0.10 for Kirundo to 0.16% for Mabondo.

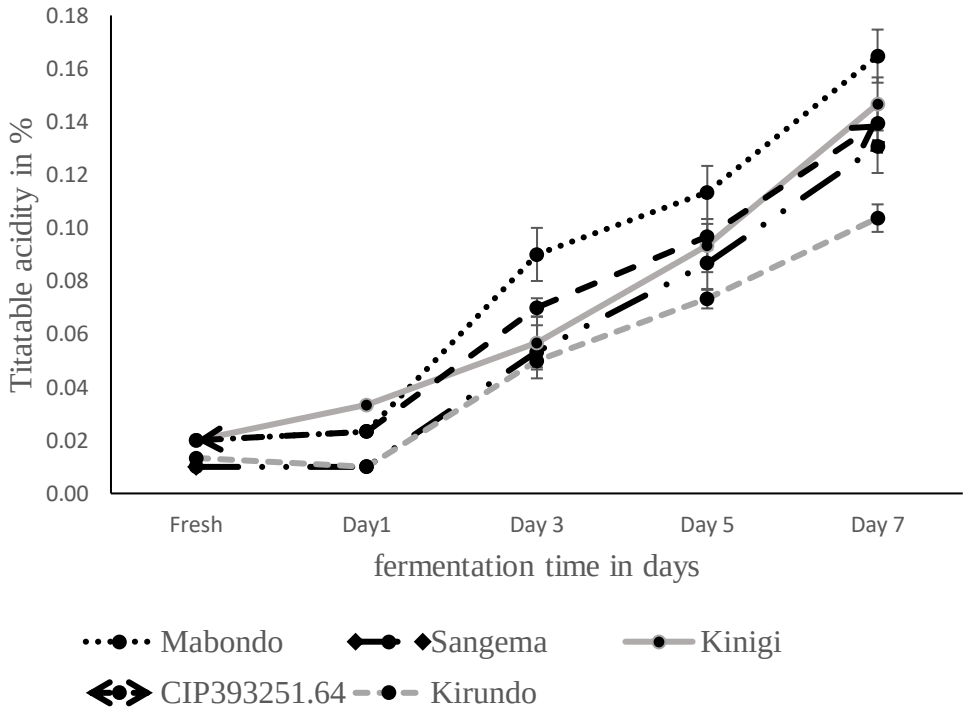


Figure 14. Titratable acidity of potatoes during fermentation period

Acidity icreased gradually during fermentation period. Increase was faster in potatoes with high sugar content than in potatoes with low sugar content. Similarly, titratable acidity during seven days of roots fermentation was reported to be 0.8 g/kg before fermentation and increased in the range of 2.3-6.6 g/kg and the increase in titratable acidity was inversely proportional to the concentration of brine solution and the titratable acidity remained the same after 28 days of fermentation (Panda *et al.*, 2007). Low concentration of brine solution 2% was observed to have higher lactic acid than higher brine concentration of 8-14% (Panda *et al.*, 2007). Titratable acidity increased from 0. 45% to 0.6% and 2 % for natural and controlled sauerkraut in 15 days of fermentation (Pandey and Garg, 2015). Fermentation of boiled and non-boiled sweet potatoes with *L. plantarum* showed titratable acidity from 0.8 to 1.23 g /kg for boiled and from 0.7 to 1.46 g/kg for non-boiled (Panda and Ray, 2007). Controlled fermentation increases acidity much faster than natural one. Lactic acid fermentation increases acidity by converting sugars into acid where the main byproduct is lactic acid. High acidity contributes to the stability of fermented products due to its ability to prevent microbial growth.

4.3. 3 Microbial population of fermented potatoes

During fermentation microbial population was evaluated after fermentation time. Total viable bacteria count was the highest which ranged from 8.12 $\log_{10}$ CFU/g for Sangema to 7.56 $\lg_{10}$ CFU/g for Kirundo.

Cultivars	Total viable count log_{10}	Yeast and mould log_{10}	LAB log_{10}
Mabondo	8.12 ± 0.06^{a}	4.91 ± 0.00^{a}	7.13 ± 0.05^{b}
Sangema	8.22 ± 0.04^{a}	4.53 ± 0.10^{b}	6.22 ± 0.03^{c}
Kinigi	7.56 ± 11^{b}	4.55 ± 0.01^{b}	7.39 ± 0.02^{a}
CIP393251.64	7.57 ± 0.03^{b}	4.56 ± 0.03^{b}	6.50 ± 0.02^{c}
Kirundo	7.56 ± 0.01^{b}	4.40 ± 0.03^{b}	6.43 ± 0.02^{c}
Minimum	7.56	4.40	6.22
Maximum	8.22	4.91	7.39
CV	1.12	1.73	0.63
MSD	0.2466	0.2234	0.119

MSD: Minimum significant difference; Means followed by the same letter in a column do not differ by Tukey's test at 5%.

The total count represents all types of living microorganisms in fermented potatoes. The number of total microbial count in different potato cultivars was statistically significantly different at ($P < 0.05$). It was likely to be high where sugars were high and sugars might have facilitated their quick development. Yeast and mould ranged from 4.91 log_{10} CFU/g for Kirundo to 4.40 log_{10} CFU/g for Mabondo. Yeast and mould also participate in fermentation. Lactic acid bacteria ranged from 7.39 log_{10} CFU/g for Sangema to 6.43 log_{10} CFU/g for Kinigi. The number of lactic acid bacteria, yeast and mould in all cultivars was statistically significantly different at ($P < 0.05$). Coliforms and *E. coli* were detected but were too few to count. This suggests that their growth might have been inhibited by lactic acid bacteria. Fermentation of yam showed reduction in total viable microbial count from 6.02 for the first day to 5.75 log_{10} CFU/ml for the fifth day, lactic acid bacteria increased from 1.90 for the first day to 3.90 log_{10} CFU/ml at the fifth day, coliforms reduced from 4.48 at the first day to 4.60 log_{10} CFU/ml at fifth day (Aderiye and Ogunjobi, 1998). Growth of lactic acid bacteria is responsible for production of lactic acid and acetic acid which reduced pH and impended growth of Gram-negative and sporulating bacteria (Montet *et al.*, 2014). Fermentation is initiated by *Lactobacillus mesenteroides* which is heterofermentative able to utilize glucose and fructose in fermentation which quickly lowers pH that inhibits growth of undesirable microorganisms and activity of their enzymes (Pandey and Garg, 2015). Along with lactic and acetic acids, hydrogen peroxide and carbon dioxide are produced and they also have bactericidal effect (Montet *et al.*, 2014). Carbon dioxide produced inhibits growth of aerobes

like *Bacillus*, *Pseudomonas* and *Micrococcus* (Pandey and Garg, 2015). It was reported that coliforms were not detected after fermentation due to their inhibition by LAB byproducts (Pandey and Garg, 2015). Inhibition of coliforms growth was also reported by Swain *et al.* (2014). Moreover, *E.coli* were not found after 48 hours of fermentation and even after 30 days (Panda and Ray, 2007). Lactic acid bacteria help to preserve food by producing lactic acid and other byproducts which help to suppress growth of harmful microorganisms.

4.3. 4 Chemical changes of fermented potato

Results of chemical changes during fermentation of potato crisps are presented in Tables 18, 19 and 20 for interaction between cultivars and fermentation, effect of cultivars on chemical composition in Table 21, 22 and 23, while the effect of fermentation on chemical composition is in Table 24. During fermentation there was change in chemical composition of fermented crisps. The effect of cultivars and fermentation was statistically significant at ($P < 0.05$) for all studied parameters except the effect of cultivars on moisture content. The interaction effect between cultivars and fermentation for moisture, starch, non-reducing sugars, protein, Mg, Fe, K and P was not significant at ($P > 0.05$), while interaction effect was significant at ($P < 0.05$) for reducing sugars, total sugars, total glycoalkaloids, total phenols, total anthocyanins, vitamin C, Ca and Zn.

Moisture content was not statistically significantly different with ($P > 0.05$) among cultivars ranging from 76.39% for Kirundo to 79.31% for Sangema. Moreover, the effect of fermentation on moisture content was statistically significantly different at ($P < 0.05$) with moisture content of 77.31% for non-fermented potatoes and 79.45% for fermented potatoes. Interaction effect on moisture content was not statistically significantly different at ($P > 0.05$) varying from 75.89% for non-fermented Kirundo to 80.44% for fermented Mabondo. Fermentation increased moisture content of potatoes. This might have been caused by long period potatoes stayed in fermenting solution. Moisture content among eleven potato varieties was also reported to vary from 78.10 to 84.85% (Pal *et al.*, 2008). However, the amount of moisture absorbed during fermentation did not increase beyond unacceptable level as potatoes with moisture content of 80% or below are suitable for fried and dehydrated potato products (Marwaha *et al.*, 2010). Increase in moisture content is related to the long period potatoes stayed submerged into fermenting solution.

Table 17. Interaction effect between cultivars and fermentation on moisture, starch, protein and sugar content of fresh potato

Cultivars	Treatments	Moisture content %	Starch content %	protein content %	Reducing sugars %	Non-reducing sugars %	Total sugars %
Kinigi	Non-Fermented	77.23 ± 1.55^{a}	17.82 ± 0.18^{a}	1.92 ± 0.07^{a}	0.13 ±0.01^{b}	0.21 ± 0.02^{a}	0.33 ± 0.03^{b}
	Fermented	79.51 ± 1.14^{a}	16.28 ± 0.21^{a}	1.87 ± 0.23^{a}	0.05 ± 0.00^{e}	0.10 ± 0.01^{a}	0.14 ± 0.01^{def}
Kirundo	Non-Fermented	75.89 ± 1.55^{a}	18.87 ± 0.06^{a}	2.31 ± 0.06^{a}	0.08 ± 0.01^{cd}	0.14 ± 0.01^{a}	0.23 ± 0.02^{cd}
	Fermented	76.88 ± 1.36^{a}	17.16 ± 0.31^{a}	2.05 ± 0.01^{a}	0.03 ± 0.01	0.07 ± 0.01^{a}	0.09 ± 0.01f
Mabondo	Non-Fermented	77.11 ± 1.71^{a}	16.98 ± 0.16^{a}	2.08 ± 0.12^{a}	0.17 ± 0.02^{a}	0.28 ± 0.04^{a}	0.45 ± 0.06^{a}
	Fermented	80. 38 ± 0.68^{a}	14.65 ± 0.28^{a}	1.97 ± 0.03^{a}	0.06 ± 0.01^{cde}	0.13 ± 0.02^{a}	0.19 ± 0.3^{de}
Sagema	Non-Fermented	78.17 ± 1.63^{a}	16.35 ± 0.25^{a}	2.02 ± 0.16^{a}	0.09 ±0.00^{c}	0.19 ± 0.01^{a}	0.29 ± 0.01^{bc}
	Fermented	80. 44 ± 0.76^{a}	14.43 ± 0.43^{a}	2.09 ± 0.07^{a}	0.03 ± 0.00e	0.80 ± 0.00^{a}	0.12 ± 0.01^{f}
CIP393251.64	Non-Fermented	78. 11 ± 1.74^{a}	16.14 ± 0.13^{a}	2.13 ± 0.10^{a}	0.13 ±0.01^{b}	0.22 ± 0.01^{a}	0.35 ± 0.02^{b}
	Fermented	80.06 ± 1.19^{a}	14.87 ± 0.29^{a}	1.96 ± 0.07^{a}	0.05 ± 0.01^{de}	0.10 ± 0.00^{a}	0.15 ± 0.01^{def}
CV		1.85	3.09	9.43	14.55	16.35	12.81
MSD		4.2423	1.359	0.5631	0.0354	0.0721	0.0882

MSD: Minimum significant difference at 5% Tukey; Means followed by the same letter in a column do not differ by Tukey's test at 5%

Table 18. Interaction effect between cultivars and fermentation on mineral composition of peeled fresh potato

Cultivars	Treatments	Calcium mg/100g	Magnesium mg/100g	Iron mg/100g	Zinc mg/100g	Potassium mg/100	Phosphorus mg/100g
Kinigi	Non-Fermented	4.47 ± 0.02^{bc}	17.59 ± 0.71^{a}	0.81 ± 0.03^{a}	0.32 ± 0.01^{a}	466.55 ± 11.05^{a}	47.86 ± 2.94^{a}
	Fermented	2.99 ± 0.08^{de}	12.59 ± 0.56^{a}	0.55 ± 0.02^{a}	0.24 ± 0.00^{b}	323.32 ± 55.52^{a}	36.96 ± 1.95^{a}
Kirundo	Non-Fermented	3.71 ± 0.07^{cd}	20.48 ± 1.47^{a}	0.67 ± 0.04^{a}	0.30 ± 0.01^{a}	542.88 ± 2.95^{a}	69.77 ± 2.59^{a}
	Fermented	2.19 ± 0.10^{e}	15.70 ± 1.59^{a}	0.43 ± 0.03^{a}	0.23 ± 0.01^{b}	435.68 ± 2.95^{a}	48.92 ± 3.42^{a}
Mabondo	Non-Fermented	8.21 ± 0.31^{a}	19.59 ± 0.60^{a}	0.34 ± 0.02^{a}	0.23 ± 0.01^{b}	519.61 ± 12.34^{a}	40.52 ± 1.55^{a}
	Fermented	5.34 ± 0.42^{b}	14.03 ± 0.48^{a}	0.17 ± 0.01^{a}	0.16 ± 0.01^{c}	431.92 ± 10.6^{a}	31.91 ± 1.30^{a}
Sagema	Non-Fermented	3.43 ± 0.04^{cd}	19.68 ± 0.77^{a}	0.66 ± 0.03^{a}	0.12 ± 0.01^{d}	372.71 ± 11.43^{a}	36.12 ± 1.53^{a}
	Fermented	2.15 ± 0.04^{e}	13.06 ± 0.30^{a}	0.42 ± 0.02^{a}	0.10 ± 0.00^{d}	304.72 ± 9.81^{a}	28.22 ± 1.28^{a}
CIP393251.64	Non-Fermented	4.51 ± 0.07^{bc}	11.32 ± 0.35^{a}	0.36 ± 0.01^{a}	0.14 ± 0.01^{cd}	365.83 ± 11.10^{a}	39.88 ± 3.40^{a}
	Fermented	2.92 ± 0.16^{de}	7.40 ± 0.28^{a}	0.19 ± 0.01^{a}	0.11 ± 0.01^{d}	299.19 ± 9.71^{a}	32.21 ±3.26 ^{a}
CV		9.40	8.33	6.91	6.52	9.05	9.84
MSD		1.0984	3.6924	0.0932	0.0372	107.67	11.879

MSD: Minimum significant difference at 5% Tukey; Means followed by the same letter in a column do not differ by Tukey's test at 5%

Table 19 Interaction effect between cultivars and fermentation on phytochemical composition of fresh peeled potato

Cultivars	Treatments	Total glycoalkaloids mg/100g	Total phenols mg/100g	Total anthocyanins mg/100	Vitamin C mg/100g
Kinigi	Non-Fermented	0.78 ± 0.03^{a}	13.90 ± 0.40^{abcd}	0.79 ± 0.05^{a}	12.14 ± 0.27^{a}
	Fermented	0.48 ± 0.05^{d}	11.98 ± 0.36^{f}	0.27 ± 0.01^{b}	6.72 ± 0.33^{b}
Kirundo	Non-Fermented	0.85 ± 0.01^{a}	14.90 ± 0.18^{a}	0.24 ± 0.02^{bc}	6.35 ± 0.38^{bc}
	Fermented	0.65 ± 0.01^{bc}	13.01 ± 0.15^{cdef}	0.13 ± 0.01^{bcd}	4.02 ± 0.51^{de}
Mabondo	Non-Fermented	0.77 ± 0.01^{ab}	13.15 ± 0.28^{bcde}	0.79 ± 0.04^{a}	6.93 ± 0.80^{b}
	Fermented	0.57 ± 0.01^{cd}	12.56 ± 0.28^{ef}	0.05 ± 0.01^{d}	4.52 ± 0.27^{cde}
Sagema	Non-Fermented	0.74 ± 0.03^{ab}	13.45 ± 0.04^{bcde}	0.92 ± 0.04^{a}	2.87 ± 0.42^{ef}
	Fermented	0.07 ± 0.01^{e}	12.86 ± 0.04^{def}	0.09 ± 0.01^{cd}	1.29 ± 0.08^{f}
CIP393251.64	Non-Fermented	0.74 ± 0.04^{ab}	14.29 ± 0.26^{ab}	0.90 ± 0.07^{a}	5.04 ± 0.25^{bcd}
	Fermented	0.50 ± 0.03^{d}	14.06 ± 0.45^{abc}	0.20 ± 0.01^{bcd}	2.80 ± 0.13^{ef}
CV		7.28	2.94	13.91	13.53
MSD		0.1309	1.1533	0.1787	2.0857

MSD: Minimum significant difference at 5% Tukey; Means followed by the same letter in a column do not differ by Tukey's test at 5%

Table 20. Effect of cultivars on moisture, starch, protein and sugar content of fresh potato

Cultivars	Moisture %	Starch %	protein %	Reducing sugars%	Non-reducing sugars %	Total sugars %
Kinigi	78.37 ± 0.95^{a}	17.05 ± 0.36^{b}	1.90 ± 0.11^{a}	0.09 ± 0.02^{b}	0.15 ± 0.03^{b}	0.24 ± 0.04^{b}
Kirundo	76.39 ± 0.95^{a}	18.01 ± 0.41^{a}	2.18 ± 0.07^{a}	0.06 ± 0.01c	0.11± 0.02^{c}	0.16 ± 0.03^{c}
Mabondo	78. 75 ± 1.10^{a}	15.81 ± 0.54^{c}	2.02 ± 0.07^{a}	0.12 ± 0.07^{a}	0.20 ± 0.04^{a}	0.32 ± 0.06^{a}
Sagema	79.31 ± 0.95^{a}	15.39 ± 0.49^{c}	2.06 ± 0.08^{a}	0.06 ± 0.01^{c}	0.14 ± 0.02^{bc}	0.21 ± 0.04^{bc}
CIP393251.64	79.09 ±1.04^{a}	15.51 ± 0.32^{c}	2.04 ± 0.06^{a}	0.09 ± 0.02^{b}	0.16 ± 0.03^{b}	0.25 ± 0.05^{b}
CV	2.37	2.69	9.43	14.55	16.35	12.81
MSD	3.2416	0.7669	0.3358	0.0211	0.043	0.0526

MSD: Minimum significant difference at 5% Tukey; Means followed by the same letter in a column do not differ by Tukey's test at 5%

Table 21. Effect of cultivars on mineral composition of fresh potato in mg/100g

Cultivars	Calcium	Magnesium	Iron	Zinc	Potassium	Phosphorus
Kinigi	3.73 ± 0.33^{b}	15.09 ±1.19^{b}	0.68 ± 0.06^{a}	0.28 ± 0.2^{a}	394.94 ± 40^{b}	42.41 ± 2.90^{b}
Kirundo	2.95 ± 0.35^{c}	18.09 ±1.44^{a}	0.55 ± 0.06^{b}	0.27 ± 0.02^{a}	489.28 ± 24.63^{a}	59.34 ±5.04^{a}
Mabondo	6.77 ± 0.70^{a}	16.81 ± 1.29^{ab}	0.26 ±0.04^{c}	0.19 ± 0.02^{b}	475.76 ± 20.92^{a}	36.22 ± 2.13^{bc}
Sagema	2.79 ± 0.29^{c}	16.37 ± 31.53^{ab}	0.54 ± 0.05^{b}	0.11± 0.00^{c}	338.72 ± 16.63^{b}	32.17 ± 1.98^{c}
CIP393251.64	3.72 ± 0.37^{b}	9.36 ± 0.90^{c}	0.28 ± 0.04^{c}	0.13 ± 0.01^{c}	332.51 ± 16.30^{b}	36.04 ± 2.72^{bc}
CV	9.40	8.33	6.91	6.52	9.05	9.84
MSD	0.655	2.202	0.0556	0.0222	64.21	7.0841

MSD: Minimum significant difference at 5% Tukey; Means followed by the same letter in a column do not differ by Tukey's test at 5%

Table 22. E**ffect of cultivars on phytochemical composition of fresh potato in mg/100g**

Cultivars	Total glycoalkaloids	Total phenols	Total anthocyanins	Vitamin C
Kinigi	0.63 ± 0.18^{b}	12.94 ± 0.49^{b}	0.53 ± 0.12^{a}	9.43 ± 1.23^{a}
Kirundo	0.75 ± 0.04^{a}	13.96 ± 0.44^{a}	0.19 ± 0.03^{c}	5.18 ± 0.59^{b}
Mabondo	0.67 ± 0.05^{ab}	12.86 ± 0.22^{b}	0.42 ± 0.17^{b}	5.73 ± 0.66^{b}
Sagema	0.41 ± 0.15^{c}	13.15 ± 0.13^{b}	0.51 ± 0.19^{ab}	2.08 ± 0.40^{d}
CIP393251.64	0.62 ± 0.06^{b}	14.17 ± 0.24^{a}	0.55 ± 0.16^{a}	3.92 ± 0.52^{c}
CV	7.28	2.94	13.91	13.53
MSD	0.0781	0.6878	0.1066	1.2438

MSD: Minimum significant difference at 5% Tukey; Means followed by the same letter in a column do not differ by Tukey's test at 5%

Starch content of potato cultivars was statistically significantly different at ($P < 0.05$) among cultivars ranging from 15.39% for Sangema to 18.01% for Kirundo. The effect of fermentation was statistically significant at ($P < 0.05$) where starch content ranged from 15.48% for fermented crisps to 17.23% for non-fermented crisps. Interaction effect between cultivars and fermentation was not statistically significantly different at ($P > 0.05$) ranging from 14.43% for fermented Sangema to 18.87% for non-fermented Kirundo. A study done on fermentation of boiled and non-boiled sweet potatoes with *L. plantarum* showed reduction in starch from 141 to 84 g/kg for boiled and 145 to 98 g/kg for non-boiled sweet potatoes (Panda and Ray, 2007) which aligns with the results of this study. Starch content was low in fermented than non-fermented potatoes. Moreover, it was reported that during fermentation starch reduced from 148.0 to 23.5 g/kg and reduction might have been caused by amylolactic bacteria *(*Panda *et al.*, 2007). Hydrolyzed starch can be used as source of energy by fermenting bacteria. Potatoes with starch content of 15% and above are suitable for starch production, chips 16-20%, French fries 15-18% and dehydrated products 15-19% (Lisiěska *et al*., 2009). Kirundo and Kinigi had starch content above 15% after fermentation, while it reduced below 15% for other cultivars. Continuous fermentation can reduced starch content to the unacceptable level. Reduction in starch content might have been caused by leaching or their utilization as source of energy by fermenting microorganisms. Fermentation reduces starch content due to their leaching or utilization by bacteria during fermentation.

Table 23. Effect of fermentation on chemical composition of fresh potato

Chemical composition	Cultivars			
	Non-fermented	**Fermented**	**CV**	**MSD**
Moisture %	77.31 ± 0.65[b]	79.45 ± 0.54[a]	2.37	1.4245
Starch %	17.23 ± 0.28[a]	15.48 ± 0.31[b]	2.69	0.337
Reducing sugars %	0.12 ± 0.01[a]	0.04 ± 0.00[b]	14.55	0.0093
Non-reducing sugars %	0.21 ± 0.01[a]	0.09 ±0.01[b]	16.35	0.0189
Total sugar %	0.33 ±0.02[a]	0.14 ± 0.01[b]	12.81	0.0231
Protein %	2.09 ± 0.05[a]	1.99 ± 0.05[b]	9.43	0.1476
Glycoalkaloids mg/100g	0.78 ± 0.1[a]	0.45 ± 0.05[b]	7.28	0.0343
Total phenols mg/100	13.94 ± 0.19[a]	12.89 ± 0.21[b]	2.94	0.3022
Total anthocyanins mg/100g	0.73 ± 0.07[a]	0.15 ± 0.02[b]	13.91	0.0468
Vitamin C mg/100g	6.67 ± 0.84[a]	3.87 ± 0.50[b]	13.53	0.5466
Calcium mg/100g	4.87 ± 0.47[a]	3.12 ± 0.32[b]	9.40	0.2878
Magnesium mg/100g	17.73 ± 0.95[a]	12.56 ± 0.81[b]	8.33	0.9676
Iron mg/100g	0.57 ± 0.05[a]	0.36 ± 0.04[b]	6.91	0.0244
Zinc mg/100g	0.22 ± 0.02[a]	0.17 ± 0.02[b]	6.52	0.0097
Potassium mg/100g	453.52 ± 20.04[a]	358.97 ± 19.19[b]	9.05	28.216
Phosphorus mg/100g	46.83 ± 3.37[a]	35.64 ± 2.13[b]	9.84	3.1129

MSD: Minimum significant difference at 5% Tukey; Means followed by the same letter in a row do not differ by Tukey's test at 5%

Protein content of studied potato cultivars was not statistically significantly different at ($P > 0.05$) ranging from 1.90% for Kinigi to 2.06% for Sangema. Fermentation effect on protein content was statistically significantly different at ($P < 0.05$) with protein content ranging from 1.99% for fermented cultivars to 2.09% for non-fermented cultivars. There was no interaction effect between potato cultivars and fermentation at ($P > 0.05$) on protein content which ranged from 1.87% for fermented Kinigi to 2.09% for fermented Sangema. Protein content reduced with fermentation. The reduction in protein content may be due to their hydrolysis by proteolytic enzymes and are utilized by microorganisms for their growth. Fermentation of potato with *L. plantarum* showed reduction in free amino acids (Baardseth *et al*., 2006). Amino acids are utilized by bacteria for their growth. Potato protein varies from one cultivar to another and during fermentation protein reduced and it might have been utilized by microorganisms to grow.

Sugar content reduced during fermentation period. Reducing sugars of studied potato cultivars were statically significantly different at ($P < 0.05$) ranging from 0.06% for Kirundo to 0.12% for Mabondo. Fermentation effect on reducing sugars was statistically significantly different at ($P < 0.05$) ranging from 0.09% for fermented to 0.12% for non-fermented potatoes. There was interaction effect between cultivars and fermentation on reducing sugars at ($P < 0.05$) with reducing sugars varying from 0.03% for fermented Kirundo and fermented Sangema to 0.17% for non-fermented Mabondo. For non-reducing sugars, there was a significant difference at ($P < 0.05$) for studied cultivars ranging from 0.11% for Kirundo to 0.20% for Mabondo. Fermentation effect on non-reducing sugars was statistically significant at ($P < 0.05$) ranging from 0.09 for fermented to 0.21% for non-fermented potato crisps. There was no interaction effect between cultivars and fermentation of crisps ($P > 0.05$) for non-reducing sugars varying from 0.07% for fermented Kirundo to 0.28% for non-fermented Mabondo. For total sugars, there was a significant difference at ($P < 0.05$) for studied cultivars ranging from 0.16% for Kirundo to 0.32% for Mabondo.

Fermentation effect was statistically significant at ($P < 0.05$) varying from 0.14% for fermented crisps to 0.33% for non-fermented crisps. The interaction effect was statistically significant between cultivars and fermentation at ($P < 0.05$) ranging from 0.09% for fermented Kirundo to 0.45% for non-fermented Mabondo. There was reduction in all types of sugars during fermentation. The amount of total sugars in fermented sauerkraut increased from 1.8 to 3.8% after six days and reduced to 1.15% after 15 days of fermentation (Pandey and Garg, 2015). Moreover, reducing sugars decreased from 0.3% to 0.18% after 15 days of fermentation (Pandey and Garg, 2015). Fermentation of boiled and non-boiled sweet potatoes with *L. plantarum* showed reduction in total sugars from 21. 0 to 11.2 g/kg for boiled and 21.4 to 11.9 g/kg for non-boiled, reducing sugars reduced from 7.5 to 3.5 for boiled and 8.0 to 4. 2 g/kg for non-boiled sweet potatoes (Panda and Ray, 2007). It was further reported that during fermentation total sugars reduced from 6.6 g/kg to 1.2 g/kg after 28 days of fermentation (Panda *et al.,* 2007). Likewise, for fermented potato with *L. plantarum*, glucose reduced from 610.8 mg/100g to 29.2 mg/100ml, fructose reduced from 457.8 mg/100g to 0.0 mg/100g, sucrose reduced from 132.0 mg/100g to 29.2 mg/100g (Baardseth *et al.*, 2006). Reduction of sugars during fermentation is related to their utilization as source of energy for fermenting bacteria. They are fermented by sugars into lactic acid and other byproducts. Sugars in both fermented and non-fermented potatoes are ideal for dehydrated, fried and canned potato products

(Marwaha *et al.*, 2010). Potato fermentation is important for reduction of sugars due to their contribution on quality of products which is objectionable if high.

Phytonutrients of potato cultivars in this study were statistically significantly different at ($P < 0.05$). Total glycoalkaloids ranged from 0.41 mg/100g for Sangema to 0.75 mg/100g for Kirundo, total phenols ranged from 12.86 mg/100 for Mabondo to 14.17 mg/100g for CIP393251.64, total anthocyanins ranged from 0.19 mg/100g for Kirundo to 0.55 mg/100g for CIP393251.64, vitamin C ranged from 3.92 mg/100g for CIP393251.64 to 9.43 mg/100g for Kinigi. Moreover, the effect of fermentation on phytochemicals was statistically significant at ($P < 0.05$). Total glycoalkaloids was 0.45 mg/100g for fermented crisps and 0.78 mg/100g for non-fermented crisps, total phenols were 12.89 mg/100g for fermented crisps and 13.94 mg/100g for non-fermented crisps, total anthocyanins were 0.15 mg /100g for fermented crisps and 0.73 mg/100g for non-fermented crisps, vitamin C was 3.87 mg/100g for fermented crisps and 6.67 mg/100g for non-fermented crisps. Furthermore, there was a significant interaction effect between cultivars and fermentation of studied potato cultivars at ($P < 0.05$). Total glycoalkaloids varied from 0.07 mg/100g for fermented Sangema to 0.85 mg/100g for non-fermented Kirundo, total phenols varied from 11.98 mg/100g for fermented Kinigi to 14.90 mg/100g for non-fermented Kirundo, total anthocyanins varied from 0.05 mg/100g for fermented Mabondo to 0.92 mg/100g for non-fermented Sangema, vitamin C ranged from 1.29 mg/100g for fermented Sangema to 12.14 mg/100g for non-fermented Kinigi. It was reported that vitamin C in raw cabbage was 27.5 mg/100g and it reduced to 17.5 mg/100g after 90 days of fermentation (Pandey and Garg, 2015). Fermentation of boiled and non-boiled sweet potatoes with *L. plantarum* showed reduction in total phenols from 350 to 317 mg/kg for boiled and from 450 to 365 mg/kg for non-boiled sweet potatoes (Panda and Ray, 2007). Lactic acid fermentation was reported to increase anti-oxidant activity, anthocyanin content and sensory characteristics of fermented sweet cherries (Montet *et al.*, 2014). Phytonutrients are utilized by bacteria for growth. During fermentation, phytonutrients reduced and they might have been utilized by fermenting microorganisms or leached in fermenting solution. Fermentation induces production of different types of bioactive compounds which are beneficial to consumers.

Minerals content of studied potato cultivars were statistically significantly different at ($P < 0.05$). Calcium ranged from 2.79 mg/100g for Sangema to 6.77 mg/100g for Mabondo, magnesium ranged from 9.36 mg/100g for CIP393251.64 to 18.09 mg/100g for Kirundo, iron ranged from 0.28 mg/100g for CIP393251.64 to 0.68 mg/100g for Kinigi, zinc varied from

0.11 mg/100g for Sangema to 0.28 mg/100g for Kinigi, potassium varied from 332.51 mg/100 for CIP393251.64 to 489.28 mg/100g for Kirundo and phosphorus ranged from 32.17 mg/100g for Sangema to 59.34 mg/100g for Kirundo. Moreover, effect of fermentation on minerals was statistically significant at ($P < 0.05$) for potato crisps. Calcium content was 3.12 mg/100g for fermented crisps and 4.87 mg/100g for non-fermented crisps, magnesium content was from 12.56 mg/100g for fermented crisps and 17.73 mg/100g for non-fermented crisps, iron was from 0.36 for fermented to 0.57mg/100g for non-fermented crisps, zinc content was from 0.17 mg/100g for fermented crisps and 0.22 mg/100g for non-fermented crisps, potassium was from 358.97 mg/100g for fermented crisps and 453.52 mg/100g for non-fermented crisps, phosphorus was from 35.64 mg/100g for fermented crisps and 46.84 mg/100g for non-fermented crisps. The interaction effect was statistically significant at ($P < 0.05$) for calcium and zinc, while it was not statistically significant for iron, magnesium, potassium and phosphorus with ($P > 0.05$). Calcium varied from 2.15 mg/100g for fermented Sangema to 8.21 mg/100g for non-fermented Mabondo, zinc varied from 0.10 mg/100g for fermented Sangema to 0.32mg/100g for non-fermented Kinigi, magnesium ranged from 7.40 mg/100g for fermented CIP393251.64 to 20.48 mg/100g for non-fermented Kirundo, iron ranged from 0.17 mg/100g for fermented Mabondo to 0.86 mg/100g for non-fermented Kinigi, potassium ranged from 299.19 for fermented CIP393251.64 to 542.88 mg/100g for non-fermented Kirundo, phosphorus ranged from 28.22 for fermented Sangema to 69.77 mg/100g for non-fermented Kirundo. Variability in minerals content of different potato cultivars was also reported by other authors (Pal *et al*., 2008; Furrer *et al*., 2018). Lactic acid bacteria are the least represented microorganisms in fresh fruits and vegetables with around 0.1% of total microbial population and they require nutrients like fatty acids, amino acids, vitamins and minerals to grow (Montet *et al*., 2014). Sometimes vegetables may not contain all the required nutrients for LAB to grow and supplementation is done to promote their growth (Montet *et al*., 2014). Reduction in minerals might have been caused by their utilization by bacteria during growth or some might have leached in fermenting solution due to their solubility in aqueous solution. During fermentation, microorganisms utilize minerals and this might have caused their reduction or reduction might have been caused by leaching in fermenting medium.

4.3. 5 Acrylamide formation during frying of fermented and non-fermented French fries and crisps

Results of acrylamide content in fermented and non-fermented crisps and French fries are presented in Figure 15. Acrylamide is among byproducts of Maillard reaction due to the

reaction between asparagine and reducing sugars. The difference in acrylamide of potato tubers analyzed was statistically significant at ($P < 0.05$). Acrylamide of French fries ranged from 376.52µg/kg for Kinigi to 629.63µg/kg for CIP393251.64 and after fermentation it ranged from 267.73 µg/kg for Kirundo to 306.00 µg/kg for Mabondo. For crisps, acrylamide ranged from 767.00 µg/kg for Kirundo to 855.30 µg/kg for Mabondo. Fermented crisps had 339.59 µg/kg for Kirundo to 468.05 µg/kg for Sangema. Acrylamide in fried French fries and crisps was reported to range from 30 to 2300 µg/kg, where it is around 424 µg/kg for French fries and 1739 µg/kg for crisps (Singh and Kaur, 2009) which aligns with the results of this study. Ordinary, the range of acrylamide in French fries is 300 to 700 µ g/kg with extreme of 300 to 3500 µg/kg, while for crisps is from 600 to 2000 µg/kg with extreme values of 170 to 2300 µg/kg (Lingnert *et al*., 2002). Acrylamide content ranged from 200 to 6151 ng/g in ten commercial potatoes used for chips and French fries (Gökmen *et al*., 2007). Potato powder heated at 180^{o} C for 25 minutes was found to have 134 to 1268 µg/kg of acrylamide in 16 commercial potato varieties and it was revealed that hydroxycinnamolquinic phenolic compound correlated negatively with acrylamide (Zhu *et al*., 2010). Acrylamide formation can be reduced when factors which influence its formation are taken into consideration during frying.

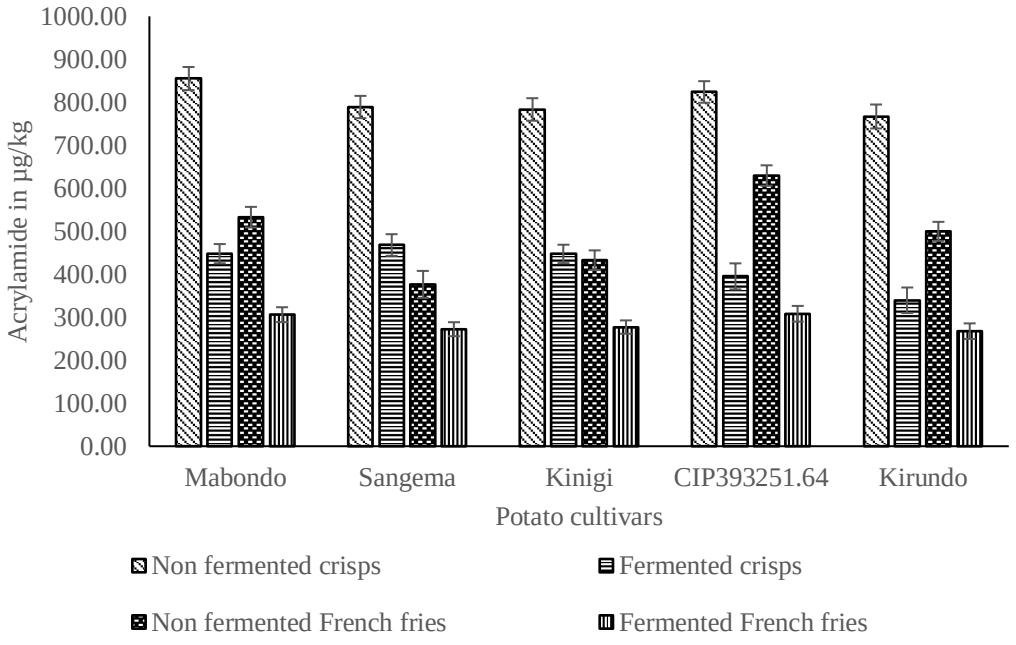


Figure 15. Level of acrylamide in fermented and non-fermented French fries and crisps in µg/kg of wet weight.

Error bars indicate standard error of means

Acrylamide formation is influenced by factors like agronomic factors, recipe factors and processing factors (Stojanovska and Tomovska, 2015). Agronomic factors include cultivars genetic makeup like the amount of glucose, fructose and free asparagine, harvesting time, climatic conditions, soil composition and agronomic practices (Stojanovska and Tomovska, 2015). Sucrose can be hydrolyzed to give glucose and fructose which are precursor of acrylamide, addition of amino acids and salt in frying medium were found to increase level of acrylamide, while lowering pH using organic acid reduced acrylamide formation, addition of asparaginase reduces acrylamide formation due to hydrolysis of asparagine, while high temperature and low moisture content favour acrylamide formation and acrylamide reduces with pretreatment like soaking, and blanching (Stojanovska and Tomovska, 2015). It was further reported that acrylamide formation is favoured by low moisture content, high temperature, reducing sugars like glucose and fructose and it is inhibited by starch; fructose accelerated acrylamide formation than glucose where at 140^{o} C fructose favoured acrylamide formation, while glucose required temperature above 140^{o} C and it was found that acrylamide formation starts as soon as sugar starts to melt, melting temperature for fructose was found to be 127^{o} C and 150^{o} C for glucose (Ciesarová *et al.,* 2006). Reducing sugars like fructose and glucose were reported to positively correlate with acrylamide and negative correlation for sucrose a non-reducing sugars (Zhu *et al.,* 2010). Asparagine was reported to correlate positively with acrylamide, while other amino acids did not or correlated poorly with acrylamide and total amino acids did not also correlate with acrylamide (Zhu *et al.,* 2010). Asparagine provides the backbone of acrylamide molecule and reducing sugars (glucose and fructose) are co-reactants for the formation of N-glycoside intermediates which leads to acrylamide formation (Singh and Kaur, 2009). Acrylamide reduced when potatoes were soaked in citric acid followed by blanching (Pedreschi *et al.,* 2004). It is aligned with this study where acrylamide was low in fermented potatoes which might have been caused by acid produced during fermentation. The threshold for acrylamide formation is 100^{o} C, high temperature like 170^{o} C accelerates both acrylamide formation and its decomposition (Biedermann *et al.,* 2002). French fries fried at 150^{o} C to 180^{o} C for 9 minutes showed core temperature of 103^{o} C to 104^{o} C after frying, while the surface temperature was higher (Gökmen *et al.,* 2006). Acrylamide on the surface was 72, 2747 and 6476 ng/g after 9 minutes of frying at 150, 170 and 190^{o} C, respectively, temperatures of 150^{o} C and 170^{o} C did not show acrylamide formation in core after 9 minutes and it was 376 ng/g at 190^{o} C, surface temperature did not exceed 120^{o} C when fried at 150^{o} C and it was suggested that acrylamide starts to form at temperature

above 120° C (Gökmen *et al*., 2006). Frying at 115° C for 40 minutes showed acrylamide formation of 320 ng/g and it was attributed to the fact that Maillard reaction can form even at low temperature when the moisture is low (Gökmen *et al.*, 2006). Moreover, antioxidant compounds in potatoes influence Maillard reaction and reduction in the level of acrylamide (Zhu *et al.*, 2010). Phenolic compounds correlated negatively with acrylamide (Zhu *et al*., 2010). Some compounds of phenols were reported to reduce levels of acrylamide and chlorogenic acid was reported to reduce level of acrylamide and it predominates other phenols in potato (Zhu *et al*., 2010). Acrylamide formation is affected by raw materials and processing conditions which should all be controlled for production of products with low amount of acrylamide.

4.3. 6 Sensory evaluation of fermented potato French fries

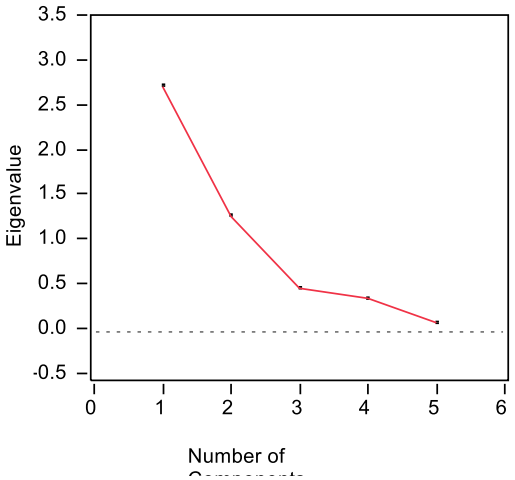
Results showing sensory analysis of fermented French fries are presented in Table 25 for hedonic characteristics, Table 26 for loading matrix, Figure 16 for scree plot, Figure 17 for PCA and Figure 18 for discriminant analysis. There was a significant difference in acceptability and in all attributes of studied potato cultivars at $(P < 0.05)$ except for sweetness where the difference was not statistically significant at $(P > 0.05)$. Overall acceptability ranged from 5.94 for Mabondo to 7.03 for Kinigi, colour ranged from 5.51 for Mabondo to 6.691 for Kinigi, sweetness ranged from 5.94 for Mabondo to 6.74 for Kinigi, flavour ranged from 6.00 for Mabondo to 6.83 for Kinigi, crispness ranged from 5.73 for Mabondo to 7.46 for Sangema, dryness ranged from 5.97 for Mabondo to 7.83 for Sangema. Sucrose and reducing sugars were reported to contribute to the flavour of potato (Vainionpaa *et al*., 2000). Ribonucleotides is considered as precursors for flavour potentiators, known as umami compounds which are associated to the desirable flavor. Glutamate and guanosine 5'-monophosphate (GMP) influence sensory score in potatoes (Jansky, 2010). The most important ribonucleotides which boost flavour are inosine 5'-monophosphate (IMP) and GMP. A synergic effect is detected when 5'ribonucleotides intereract with amino acids, especially glutamate. The products of interactions between amino acids and 5'ribonucleotides are considered to be mainly responsible for sensory quality of potatoes (Jansky, 2010). French fries of fried potatoes were accepted in all attributes. Mabondo was the least accepted in all attributes, while Kinigi was the most accepted.

Table 24. Hedonic characteristics of fermented French fries

Cultivars	Overall Acceptability	Colour	Sweetness	Flavour	Crispness	Dryness
Mabondo	5.94 ± 0.22[b]	5.51 ± 0.20[c]	5.94 ± 0.25[a]	6.00 ± 0.21[b]	5.74 ± 0.27[c]	5.97 ± 0.27[b]
Sangema	6.77 ± 0.17[a]	6.57 ± 0.17[ab]	6.37 ± 0.2[5a]	6.14 ± 0.19[ab]	7.46 ± 0.24[a]	7.83 ± 0.18[a]
Kinigi	7.03 ± 0.16[a]	6.91 ± 0.13[a]	6.74 ± 0.20[a]	6.83 ± 0.18[a]	7.09 ± 0.22[a]	7.29 ± 0.22[a]
CIP393251.64	6.57 ± 0.15[ab]	6. 20 ± 0.16[b]	6.49 ± 0.20[a]	6.80 ± 0.17[a]	6.11 ± 0.25[bc]	6.14 ± 0.23[b]
Kirundo	6.60 ± 0.17[a]	6.43 ± 0.18[ab]	6.14 ± 0.26[a]	6.37 ± 0.22[a]	7.03 ± 0.20[ab]	7.03 ± 0.22[a]
CV	14.96	15.40	19.73	17.05	21.34	19.28
MSD	0.6507	0.6436	0.8264	0.7244	0.9431	0.8732

MSD: Minimum significant difference (Tukey at 5%), Means followed by the same letter in a column do not differ by Tukey's test at 5%

Principal component analysis showed that French fries attributes were in two principal components (PCA1 and PCA2) where Eigenvalues larger than one were considered and retained for rotation. Factor pattern was rotated using varimax method. All attributes were present in principal component one, while crispness and dryness were both in principal component one and two. Principal component one accounted for 54.5% of total variations, while principal component 2 represented 25.8% of total variations. Both principal components one and two accounted for 80.3% of total variations. Mohapatra *et al*., (2007) analyzed sensory characteristics of fermented sweet potatoes where they reduced seven variables into three principal components accounting for 70% of total variations. Liu *et al*. (2003) classified components loading as strong above 0.75, moderate between 0.5 and 0.75 and weak between 0.3 and 0.5. Colour, flavour and sweetness loaded strongly on principal component one, while crisps and dryness loaded moderately on principal one. On PCA 2, crispness and dryness loaded moderately. Attributes loading strongly in the same component are strongly correlated. PCA1 accounts for the most variations comparing to PCA2. Therefore, the first priority should be given to PCA1 during processing.



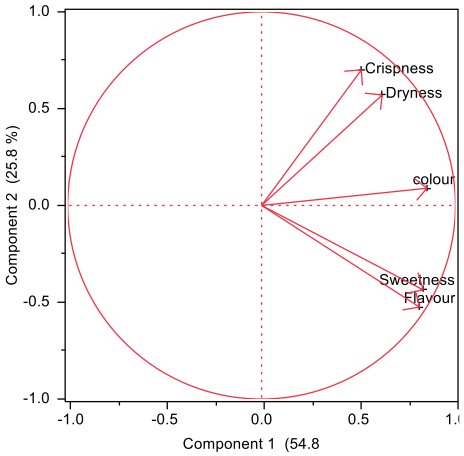


Figure 16. Scree plot of fermented French fries **Figure 17. PCA of fermented French fries**

Table 25. Loading matrix of fermented French fries

Potato attributes	Prin1	Prin2	Prin3	Prin4	Prin5
colour	**0.85351**	0.08908	0.02359	-0.50877	-0.06464
Sweetness	**0.83359**	-0.43646	0.03293	0.26567	-0.20726
Flavour	**0.81480**	-0.52494	0.03998	0.05474	0.23652
Crispness	**0.51478**	**0.70007**	0.46825	0.15700	0.03140
Dryness	**0.62233**	**0.57066**	-0.51615	0.14036	0.03063

Prin: principal

Discriminate analysis did not separate potato cultivars used in fermented French fries of this study at ($P < 0.05$). Therefore, the cultivars used were not different and they can be used interchangeably in French fries making.

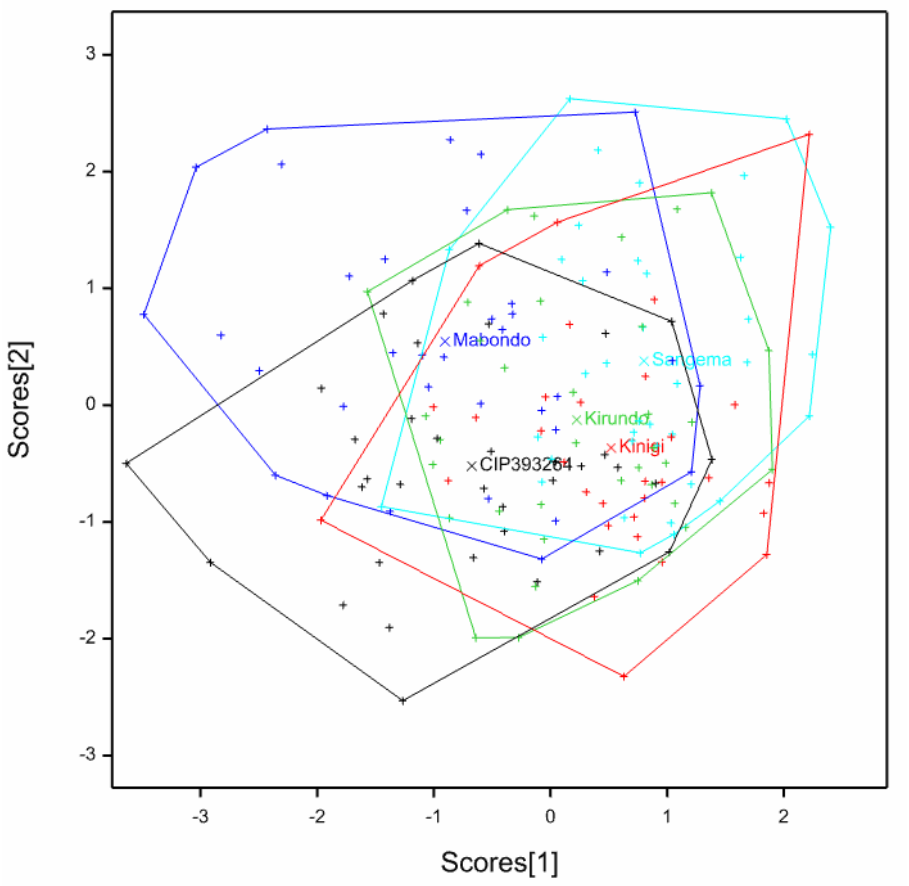


Figure 18. Discriminant analysis of fermented French fries

4.3.7 Sensory evaluation of fermented potato crisps

Results of sensory analysis of fermented crisps are shown in Table 27 for hedonic characteristics, Table 28 for loading matrix, Figure 19 for scree plot, Figure 20 for PCA and Figure 21 for discriminant analysis.There was a significant difference in all attributes evaluated at ($P < 0.05$). Overall acceptability ranged from 7.05 for Sangema to 8.03 for CIP393251.64. Colour varied from 5.97 for Mabondo to 7.51 for Kinigi, sweetness varied from 6.32 for Mabondo to 7.03 for Kinigi, flavour varied from 6.32 for Mabondo to 7.00 for Kinigi, crispness ranged from 6.11 for Mabondo to 7.35 for Sangema, dryness ranged from 6.46 for Mabondo to 7.76 for Sangema. Lipid degradation occurring during heating at temperature above 100^{o} C contributes to sensory characteristics of potato products. Byproducts of Maillard reaction include sulfur compounds and methoxypyrazines (Jansky, 2010).

Table 26. Sensory evaluation of fermented potato crisps

Cultivars	Overall Acceptability	Colour	Sweetness	Flavour	Crispness	Dryness
Mabondo	7.24 ± 0.36^{b}	5.97 ± 0.39^{b}	6.32 ± 0.28^{c}	6.32 ± 0.30^{bc}	6.11 ± 0.39^{c}	6.46 ± 0.32^{c}
Sangema	7.05 ± 0.40^{b}	6.24 ± 0.39^{b}	6.78 ± 0.30^{ab}	6.11 ± 0.32^{c}	7.35 ± 0.34^{a}	7.76 ± 0.31^{a}
Kinigi	7.97 ± 0.36^{a}	7.51 ± 0.42^{a}	7.03 ± 0.28^{a}	7.00 ± 0.31^{a}	6.97 ± 0.34^{ab}	7.14 ± 0.31^{b}
CIP393251.64	8.03 ± 0.29^{a}	6.43 ± 0.37^{b}	6.57 ± 0.28^{bc}	6.70 ± 0.28^{ab}	6.32 ± 0.37^{bc}	6.65 ± 0.32^{bc}
Kirundo	7.49 ± 0.33^{ab}	6.73 ± 0.40^{ab}	6.70 ± 0.30^{abc}	6.81 ± 0.34^{ab}	6.76 ± 0.34^{abc}	6.92 ± 0.30^{bc}
CV	14.51	21.21	10.67	12.59	16.85	12.48
MSD	0.7041	0.8961	0.4579	0.5328	0.7253	0.5597

MSD: Minimum significant difference (Tukey at 5%), Means followed by the same letter in a column do not differ by Tukey's test at 5%.

Pyrazines are considered to be among the most important and characteristics components of baked potato flavour (Jansky, 2010). There is a strong positive relationship between pyrazines and organoleptic quality in both baked and fried potatoes (Jansky, 2010). Production of methoxypyrazines can be increased by cell damage resulting in peeling losses. Moreover, methoxypyrazines can be produced by soil bacteria (*Pseudomonas taetrolens*) (Jansky, 2010). Methoxypyrazines are major contributers of potato sensory quality (Duckham *et al.*, 2002). Methoxypyrazines are not present in all potato cultivars, due to their high aroma impact, small change in methoxypyrazines levels are expected to have large effects on flavour (Jansky, 2010). Fermented potato crisps were acceptable by consumers for all cultivars in all attributes.

Principal component analysis revealed that there was two principal components where Eigenvalues larger than one were considered and retained for rotation. Factor pattern was rotated using varimax method. All the attributes contributed in principal component one which accounted for 53.8% of total variations and at the same time principal component two was made of colour and sweetness which accounted for 33.3% of total variations. Liu *et al*. (2003) classified components loading as strong above 0.75, moderate between 0.5 and 0.75 and weak between 0.3 and 0.5. In this regard, sweetness loaded strongly in PCA1, colour, flavour, crispness and dryness loaded moderately in PCA1, while colour and flavour loaded moderately in PCA2. Therefore, all attributes are of great importance during crisps manufacturing.

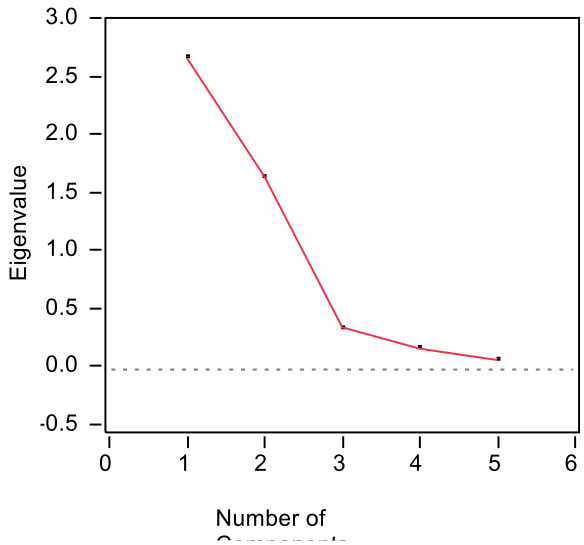


Figure 19. Scree plot of fermented potato crisps

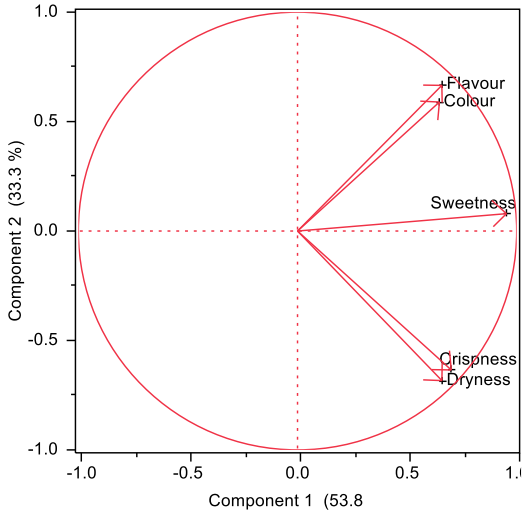


Figure 20. PCA of fermented crisps

Table 27. Loading Matrix of fermented crisps

Potato attributes	Prin1	Prin2	Prin3	Prin4	Prin5
Colour	**0.64747**	**0.58932**	0.48106	0.04524	0.00478
Sweetness	**0.95323**	0.07928	-0.18641	-0.01536	-0.22379
Flavour	**0.65860**	**0.66543**	-0.30875	-0.00945	0.16742
Crispness	**0.70142**	-0.63462	0.09562	-0.30016	0.07757
Dryness	**0.65884**	-0.68339	0.00378	0.30677	0.06915

Prin: principal component

Discriminate analysis revealed the overlapping of all cultivars. There was no signifant difference in analyzed cultivars and they can be used interchangeably in crisps making.

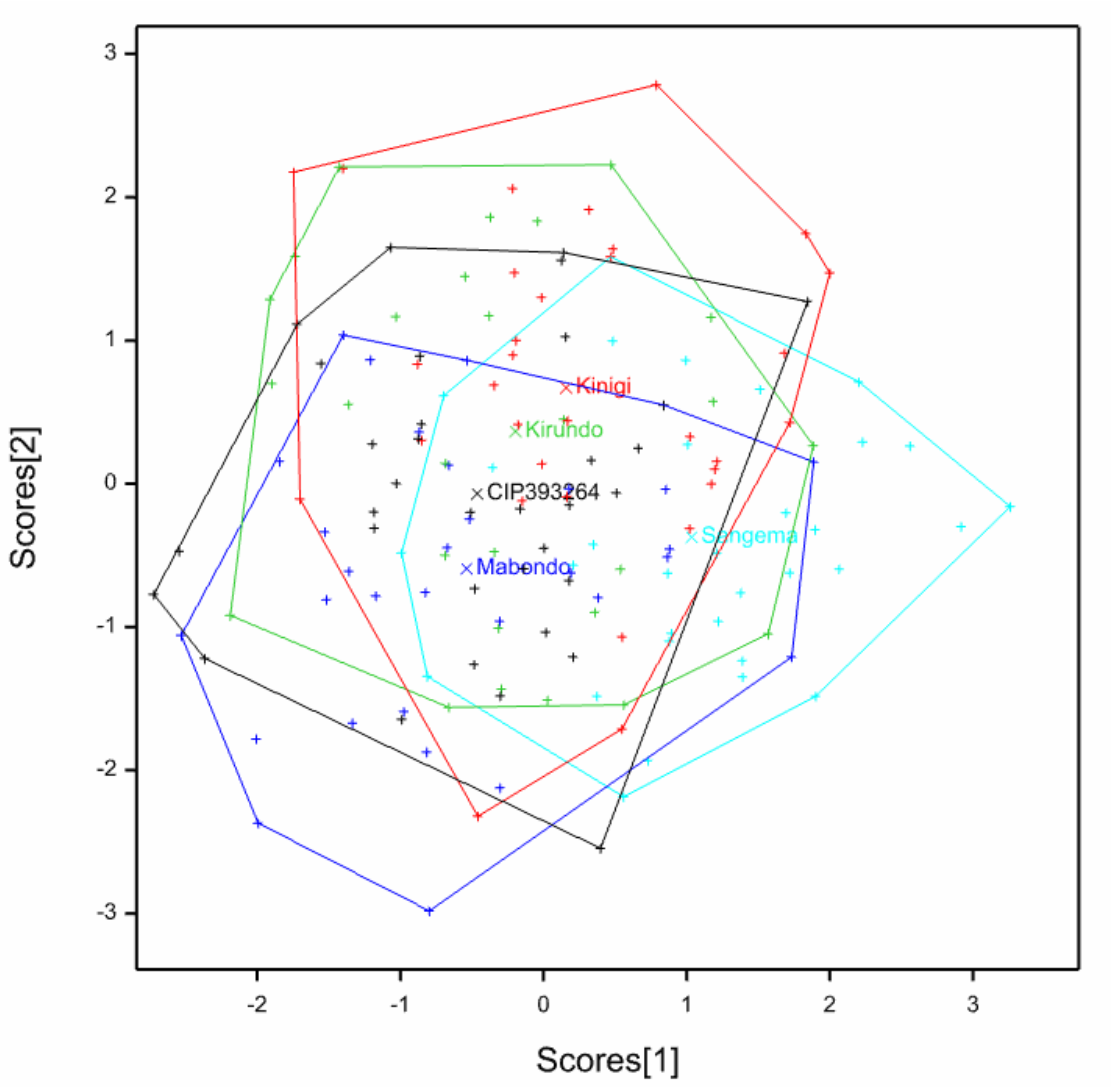


Figure 21. Discriminant analysis of fermented potatoes

4.4 Effect of potato cultivars on functional properties of potato flour

Results on functional properties of potato flour are presented in Table 29 for moisture content, pH, bulk density and water absorption capacity, while Table 30 represents oil absorption capacity, foaming capacity, foaming stability, emulsification capacity and emulsification stability.

4.4.1 Moisture content of potato flour

Potato flour is a product from potato which moisture content has been reduced and potato has been ground in small particles. The moisture content of potato is reduced to the level where it cannot easily tolerate microbial growth which increases its shelf life and it can be stored at room temperature for extended period of time. Moisture content of potato flour in the present study ranged from 9.71% for Sangema and CIP393251.64 to 11.26% for Mabondo. The moisture content of potato flours from the studied potato cultivars was not significantly different at ($P > 0.05$). This might have been caused by drying where all products were dried until equilibrium with environmental relative humidity was achieved. Chandra and Samsher (2013) reported moisture content of potato flour to be 9.60%. Similarly, Avula (2005) reported moisture content of 8% in potato flour. Moisture content was reported to be 3.06% for wheat flour and 3.68% for sweet potato flour (Adeleke and Odedeji, 2010). The moisture content of this study was slightly higher than the previous studies which might have been caused by high relative humidity in the drying environment. Microbial growth is low at low moisture content. Moisture content of the studied potato flour is less than 14% which is the acceptable limit for dried products (Adeleke and Odedeji, 2010). Long term storage favours moisture content of flour not more than 10% (Onimawo and Akubor, 2012) which agrees with this study except Mabondo which had slightly higher moisture content. High level of moisture content may promote the growth of microorganisms naturally present in flour leading to off odour and off flavour. Low moisture content extends storability of flour by preventing mould to grow and rate of chemical reactions in the products (Onimawo and Akubor, 2012). Low moisture content does not facilitate microbial deterioration to the product which increases shelf life of the products.

4.4.2 pH of potato flour

Stability of the product is related to its nature whether it is alkaline or acidic. Low acid products are more susceptible to microbial attack than acid foods. pH of the studied potato flour ranged from 5.15 for Kirundo to 5.65 for CIP393251.64. There was no significant difference in pH of potato flour of studied potato cultivars at ($P > 0.05$).

Table 28. Moisture content, pH, bulk density and water absorption capacity of potato flour

Cultivars	Moisture %	pH	Bulk density g/cm^3	WAC%
Mabondo	11.26 ± 1.69^a	5.37 ± 1.19^a	0.88 ± 0.01^a	277.25 ± 8.37^{bc}
Sangema	9.71 ± 0.90^a	5.41 ± 0.50^a	0.88 ± 0.01^a	265.39 ± 8.14^c
Kinigi	10.03 ± 1.45^a	5.37 ± 0.63^a	0.89 ± 0.05^a	292.86 ± 4.90^{ab}
CIP393251.64	9.71 ± 1.72^a	5.65 ± 1.11^a	0.87 ± 0.08^a	267.37 ± 7.55^c
Kirundo	10.21 ± 1.16^a	5.15 ± 0.60^a	0.84 ± 0.05^a	303.11 ± 8.75^a
Minimum	9.71	5.15	0.84	265.39
Maximum	11.26	5.65	0.89	303.11
CV	6.19	10.89	4.85	2.22
MSD	1.7787	1.6554	0.1193	17.594

MSD: Minimum significant difference (Tukey at 5%), Means followed by the same letter in a column do not differ by Tukey's test at 5%.

WAC: Water absorption capacity

It was reported that pH of chickpea was 6.43 and it was 5.38 for wheat flour (Jagannadham *et al.*, 2014) which aligns with the results of this study. Flour pH ranged from 5.4 for sweet potato to 6.01 for wheat flour alone and mixing wheat flour and sweet potato flour reduced pH of wheat flour (Adeleke and Odedeji, 2010). Low pH reduces susceptibility of food to spoiling microorganisms which helps to preserve food. All potato flour in this study had acidic pH. Acidic pH is an indicator for food to withstand microbial deterioration. The low pH of flour ensures its microbial stability during storage.

4.4.3 Bulk density of potato flour

Bulk density is the relationship of weight and volume of the product. Bulk density of potato flour in the studied potato cultivars ranged from 0. 84 for Kirundo to 0.89 g/cm^3 for Kinigi. The difference in bulk density of the studied flours was not statistically significant at ($P > 0.05$). The bulk density of potatoes in this study were higher than the ones reported in Mauritanian potato flours which was 0.745 g/ml for course and 0.62 for fine flour in exodus cultivar and 0.748 in course and 0.862 g/ml for fine flour in Spunta cultivar (Kulkarni *et al.*,

1996). Bulk density of chickpea flour was 0.78 g/ml and 0.83 g/ml for wheat flour (Jagannadham *et al*., 2014). Bulk density of maize flour was reported to vary from 0.80 to 0.93 g/cm^3 and bulk density increased with decrease of flour particles (Bolade *et al.*,2009). Moreover, bulk density of banana flour was 0.48 g/ml and it increased to 0.92 g/ml after supplementation with sweet potato flour (Ohizua *et al*., 2017). Bulk density of food depends on combination of factors like attractive inter particle forces, geometry, particle size and preparation techniques (Onimawo and Akubor, 2012). It was reported that flour with high bulk density has small particle size and particle size are responsible for physicochemical properties of flour like water absorption capacity (Kulkarni *et al.,* 1996). Moreover, bulk density is important for determination of packaging requirements of potato flour (Kulkarni *et al*., 1996). Low bulk density is important for preparation of complementary foods as high bulk limit caloric and nutrients intake as infants are not able to consume enough to facilitate energy intake (Badifu *et al*., 2000; Omueti *et al*., 2009). High bulk density has good physical attributes for mixing quality in some food applications (Onimawo and Akubor, 2012). High bulk density flour is used as thickener in food application (Adebowale *et al*., 2005). Bulk density was reported to be influenced by the structure of starch polymers where loose structure of starch polymers are related to low bulk density (Iwe *et al*., 2016). Bulk density of the studied potato flour was high and it is good for food requiring intense mixing and can be used as thickener in different food products.

4.4.4 Water absorption capacity of potato flour

Water absorption capacity is the ability of potato flour to absorb and retain water. There was a significant difference of water absorption capacity of potato flour at *($P < 0.05$)*. Water absoption capacity ranged from 265.39% for Kirundo to 303.11% for Sangema. Chandra and Samsher (2013) reported water absorption capacity of potato flour to be 752%. Water absorption capacity of maize flour varied from 190 to 210% (Bolade *et al*., 2009). Similarly, water absorption capacity was reported to be 245% for wheat flour and 127% for sweet potato flour (Adeleke and Odedeji, 2010). Moreover, water absorption of potato flour was 375 and 357.61g/100g for coarse particles and 388 to 405.61 for fine particles (Kulkarni *et al*., 1996). Water binding capacity was reported to be 101.81% for chickpea and 113.43 for wheat flour (Jagannadham *et al*., 2014). Water absorption capacity is the ability to associate with water in the environment where there is restricted amount of water. Water absorption is related to chemical properties of the product like carbohydrates such as starch and fibers as well as protein. It is also related to the presence of hydrophilic groups which bind water molecules and

gel forming capacity of molecules (Mohd-Hanim *et al*., 2014; Brou *et al*., 2018). Fibers are characterized by high water absorption capacity (Onimawo and Akubor, 2012). High lipid content reduces water absorption capacity (Brou *et al.*, 2018). Defatting of flour increased water absorption due to availability of hydrophilic groups of protein which were previously hidden by lipids (Adebowale *et al.*, 2005). High water absorption capacity may be related to the characteristics of potato starch with high amount of phosphorus on amylopectin group which exert repulsion of adjacent groups of phosphate there by increasing hydration and weakening bonds of crystalline starch (Hoover, 2001). Water absorption capacity is an important parameter for the products like dough where estimation of water needed is required (Mohd-Hanim *et al*., 2014). Small granules have more solubility which improves water absorption capacity (Onimawo and Akubor, 2012). Water absorption is of paramount important in the preparation of potato smash, extruded foods, and bakery products and high water absorption is preferred for mashing. Water absorption is related to starch, protein and particle size. Fine particles absorb more water than coarse ones.

4.4.5 Oil absorption capacity of potato flour

Oil absorption capacity is the ability of flour to absorb and retain oil. There was a significant difference in oil absorption of potato flour in this study at ($P < 0.05$). Oil absorption capacity of potato flour ranged from 99.21% for Sangema to 123.14% for CIP393251.64. Chandra and Samsher (2013) reported oil absorption capacity of potato flour to be 168%. Oil absorption capacity of chickpea was reported to be 81% and 117% for wheat flour (Jagannadham *et al*., 2014). Furthermore, oil absorption capacity of wheat flour varied from 170 to 210% and oil absorption capacity increased with decrease in flour particles (Bolade *et al*., 2009). Oil absorption capacity was reported to be 215% for wheat flour and 65% for sweet potato flour (Adeleke and Odedeji, 2010). Oil absorption capacity depends on nature of protein like its amino acids, protein formation and its surface hydrophilicity and hydrophobicity (Chandra and Samsher, 2013). Defatting increased oil absorption capacity (Adebowale *et al*., 2005). Flour containing high hydrophobic amino acids has high oil absorption capacity. Flour with high oil absorption capacity has the ability to bind flavours which increases mouth feel and it can be used in products like whipped toppings, sausages, chiffon dessert, angel and sponge cakes (Chandra and Samsher, 2013; Iwe *et al*., 2016). Oil absorption capacity of potato flour of this study was high and they can be used for manufacturing of different food products requiring flavour retention.

Table 29. Oil absorption capacity, foaming capacity, foaming stability, and emulsification capacity and emulsification stability of potato flour on dry weight basis

Cultivars	OAC %	FC %	FS %	EC %	ES %
Mabondo	117.14 ± 5.53^{a}	7.95 ± 0.63^{cd}	3.18 ± 0.25^{cd}	37.50 ± 1.30^{b}	35.33 ± 2.70^{b}
Sangema	100.39 ± 1.54^{b}	18.05 ± 0.67^{a}	7.22 ± 0.27^{a}	30.00 ± 0.43^{c}	28.00 ± 1.56^{c}
Kinigi	99.21 ± 1.13^{b}	6.27 ± 0.43^{d}	2.51 ± 0.17^{d}	37.50 ± 0.29^{b}	35.00 ± 2.58^{b}
CIP393251.64	123.14 ± 2.24^{a}	10.44 ± 0.28^{bc}	4.18 ± 0.09^{bc}	43.75 ± 0.29^{a}	40.83 ± 3.16
Kirundo	111.21 ± 1.72^{ab}	12.81 ± 0.63^{b}	5.12 ± 0.25^{b}	44.17 ± 0.83^{a}	41.56 ± 3.28^{a}
Minimum	99.21	6.27	2.51	30.00	28.00
Maximum	123.14	18.05	7.22	44.17	41.56
CV	5.10	9.39	9.36	2.09	3.32
MSD	15.854	2.9395	1.1734	2.2705	3.38

MSD: Minimum significant difference (Tukey at 5%), Means followed by the same letter in the column do not differ by Tukey's test at 5%.

OAC: Oil absorption capacity, FC: Foaming capacity, FS: Foaming stability, EC: Emulsification capacity, ES: Emulsification stability.

4.4.6 Emulsification capacity and emulsification stability of potato flour

Emulsification capacity and emulsification stability is the ability of flour to bind both hydrophilic and hydrophobic compounds. Emulsion capacity and emulsion stability of potato flour from the studied cultivars were statistically significantly different at ($P < 0.05$). Emulsification capacity ranged from 30% for Sangema to 44.17% for Kirundo, while emulsion stability ranged from 28.00 for Sangema to 41.22% for Kirundo. Potato flour was reported to have emulsion capacity of 39.05% and emulsification stability of 41.92% (Chandra and Samsher, 2013). Emulsification capacity was reported to be 25.40% for sweet potato flour and 14.68% for wheat flour (Adeleke and Odedeji, 2010). Hydrophobicity of protein was reported to influence emulsification properties (Iwe *et al.*, 2016). Emulsification activity is influenced by factors like solubility, pH and protein concentration (Adebowale *et al.*, 2005; Chandra and Samsher, 2013). Emulsification properties of flour was reported to be related to the hydrophobicity of its protein and fat binding property (Chandra and Samsher, 2013). Soluble proteins are surface active and enhance formation of oil in water emulsion (Onimawo and Akubor, 2012). High fiber content inhibits formation of emulsion (Badifu *et al.*, 2000; Omueti *et al.*, 2009). Emulsion stability is its capacity to withstand different process of food preparation. Increase in emulsion activity and stability are important for products like comminuted meat, salad dressing, frozen desserts and mayonnaise (Chandra and Samsher, 2013). Emulsification capacity and stability of studied potato flour was high and can be used in manufacturing food products requiring emulsion to stabilize colloidal food systems.

4.4.7 Foaming capacity and foaming stability of potato flour

Foaming capacity is the ability of protein to entrap air and retain it. Foaming capacity and foaming stability of flour of studied potato cultivars were statistically significantly different at ($P < 0.05$). Foaming capacity ranged from 6.27 for Kinigi to 18.05% for Sangema, while foam stability ranged from 2.51% for Kinigi to 7.22% for Sangema. Foaming capacity of potato flour was reported to be 6.84% and foam stability of 2.49% (Chandra and Samsher, 2013) which aligns with the results of this study. Foaming capacity of chickpea was 29.27%, while it was 14.83% for wheat (Jagannadham *et al.*, 2014). Moreover, foaming capacity of wheat flour was reported to be 4.12% and 1.28% for sweet potato flour (Adeleke and Odedeji, 2010). Foaming is a property of protein to form a continuous cohesive film around air bubbles (Chandra *et al.*, 2015). Foam is likely to be enhanced by protein with more coiled structure which is flexible that reduces surface tension rather than globular protein (Itumay and Loreto, 2017). It was further reported that foaming capacity is related to the nature of protein where

flexible protein have a good foaming capacity comparing to more ordered globular protein which gives low foaming capacity (Chandra *et al.*, 2015; Adebowale *et al.*, 2005). Poor foam formation may be due to the inability to form thick, cohesive and viscoelastic film to surround gas bubbles which will avoid foam from disintegrating (Itumay and Loreto, 2017). Foaming stability is related to the amount of native protein and it is low in denatured protein (Onimawo and Akubor, 2012; Brou *et al.*, 2018). Foams are responsible to enhance texture, consistency and appearance of foods (Onimawo and Akubor, 2012). Flour with high foam stability are important in manufacturing foods which require high porosity like ice cream, cakes and in non-food products as foaming agent (Brou *et al.*, 2018). Foaming capacity and stability of potato flour was low and they can be complemented with other flour to enhance foaming capacity and stability.

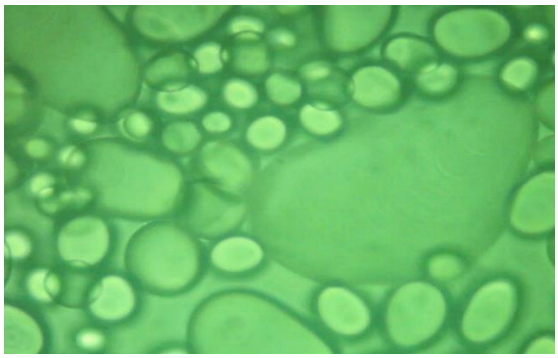
4.5 Starch characteristics and digestibility

Results for starch granules are presented in Figure 22 and phosphorus content is presented in Figure 23. Digestibility of raw potato is presented in Table 31 for digestibility of raw potato, Table 32 for digestibility of French fries and Table 33 for digestibility of crisps.

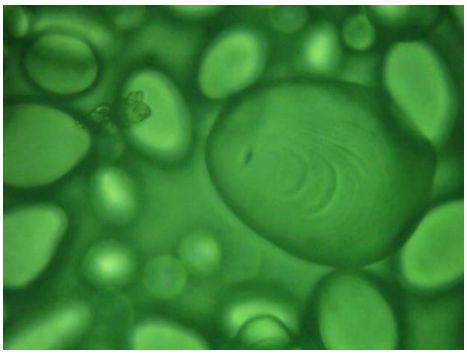
4.5.1 Starch granular size and shape

Starch is made of granules which are in different shapes and sizes and they have influence on its functional properties. Starch granules in this study were mainly oval and round to small extend with smooth surface. Starch granular size was not evaluated but they seem to be in different sizes in all potato cultivars. Sangema was dominated by large size, while Kinigi was dominated by medium size. Based on arrangement of starch granules, Mabondo and Sangema had more void spaces with large number of isolated granules, while few void spaces, less isolated granules were observed in Kinigi and CIP393251.64. Starch morphology varies from one plant species to another. It was reported that roots and tubers have starch granules which are oval, round, spherical, polygonal, and irregular (Hoover, 2001). Moreover, size of starch granule is 15 to 110 µm and they are oval and spherical for ordinary potatoes and for waxy potatoes granular starch size ranges from 14 to 44 µm and they are round and oval (Hoover, 2001). Particle size of monomodal for corn, tapioca, and potato as well as bimodal for rice and wheat were reported (Romano *et al.*, 2016). Potatoes were reported to have larger granules which are oval with flattened and ellipsoid granules ranging from 15 to 50 µm, while rice had small granules which are polygonal with well-defined edges ranging from 3 to 8 µm (Romano *et al.*, 2016). Larger granules tend to be ellipsoidal in shape. Starch granular size distribution can occur in two forms, where starch granules are aggregated or isolated, and starch

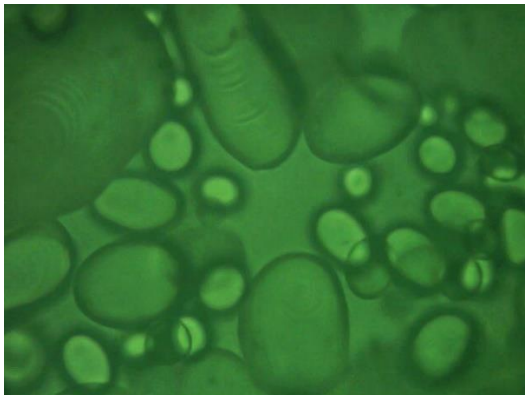
aggregation may result from biosynthesis or hydrophobic interaction of starch granules (Lindeboom *et al*., 2004; Romano *et al.*, 2016). The amylose/ amylopectin ratio and together with granular size and shape are the main contributors to the physico-chemical properties of starch (Lindeboom *et al*., 2004). Normally, granular size varies from below 1 µm to above 100 µm (Lindeboom *et al*., 2004). Granular size are classified as large if is above 25 µm, medium between 10 to 25 µm, small between 5 and 10 µm and very small if less than 5 µm (Lindeboom *et al*., 2004). Large granular size was associated with slower hydrolysis rate (Noda *et al*., 2008). Smaller starch granules have a larger surface area, surface pores, and channels that enhance water uptake, swelling, viscosity, and gelatinization ability of starch granules (Cornejo-ramírez *et al.*, 2018). Granular size and shape contribute to the functional properties of potato tubers and they varied among cultivars.



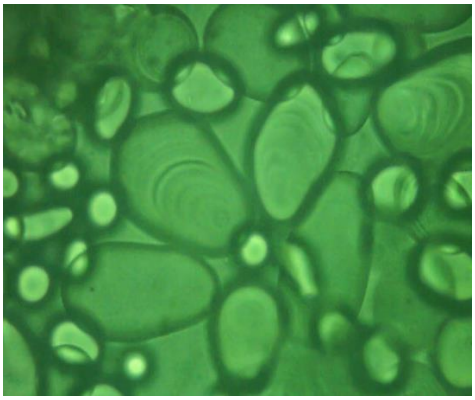
Kinigi



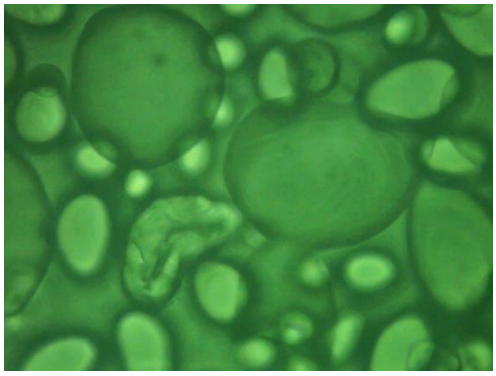
Sangema



Mabondo



Kirundo



CIP393251.64

Figure 22. Starch granules of potato cultivars

4.5.2 Phosphorus content of potato starch

Phosphorus in potato starch varies from one plant to another and it influences functional properties. Phosphorus of starch in the studied potatoes ranged from 43.37 mg/100g for Sangema to 55.63 mg/100g for CIP393251.64 DWB. The difference was statistically significantly different at ($P < 0.05$). Phosphorus in three potato varieties grown from two different locations ranged from 59 to 71 mg/100g and they varied with environment and variety Chung *et al*. (2014) which aligns with the results of this study. Moreover, phosphorus content of starch from potatoes was 89 mg/100g dry weight basis of organic phosphorus, and 1mg/100g dry weight basis of inorganic phosphorus, while waxy potatoes had 69 mg/100g of organic phosphorus and 1 mg/100g db of inorganic phosphorus (Hoover, 2001). Phosphorus in cereals is present in form of phospholipid and as phosphate monoester in roots and tubers (Cornejo-ramírez *et al*., 2018). Noda *et al.* (2007) classified potatoes in three categories based on phosphorus starch, low phosphorus starch is between 30.8 to 39.5 mg/100g, medium phosphorus starch is between 71.10 to 71.60 mg/100g, and high phosphorus starch which is between 111.00 to 124.4 mg/100g. Phosphorus content varied from 500 to 1132 ppm in 36 potato starches, the average value was 760 ppm (Absar *et al*., 2008). Phosphate content is associated to physico-chemical characteristics like starch pasting properties, and viscosity (Karim *et al.*, 2007). Increase in phosphorus content was associated with reduction of hydrolysis rate (Noda *et al*., 2008). Potato with higher amount of phosphorus in starch has higher amount of resistant starch (Absar *et al*., 2008). The difference in starch content may be related to cultivars, agricultural practices, soil, environmental conditions, and growing temperature (Absar *et al*., 2008). Phosphorus content varied among potato cultivars and influences pasting properties and digestibility of potato starch.

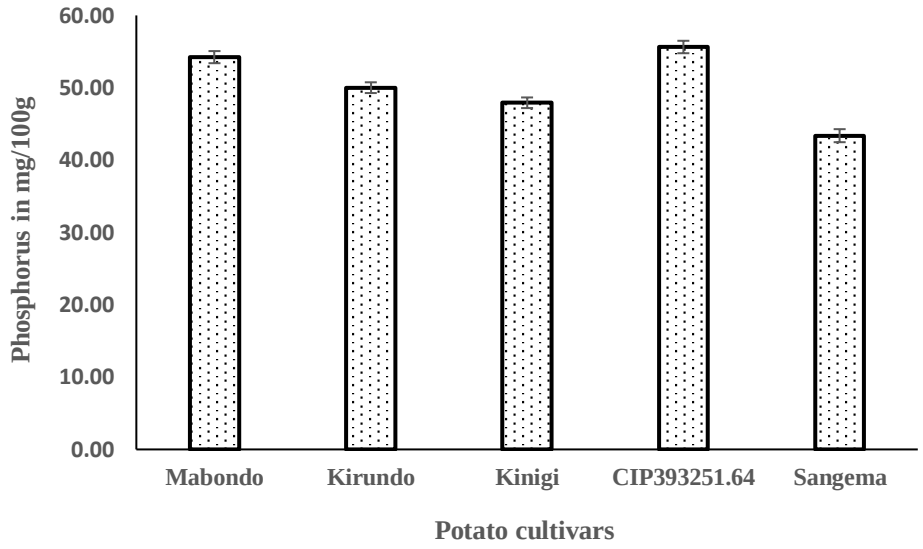


Figure 23. Phosphorus content in potato starch

Error bars indicates standard error of the mean

5.5.3 Rapidly digestible potato starch

Rapidly digestible starch varied among cultivars and with preparation methods. Rapidly digestible starch which is starch digested in the first 20 minutes of digestion. Rapidly digestible starch ranged from 0.82 for Kirundo to 2.00% for Mabondo in raw potatoes, from 46.71 for Sangema to 50.87% for Mabondo in French fries and from 69.66 for Sangema to 70.31% for Mabondo in crisps and in all cases the difference was statistically significant at ($P < 0.05$). Rapidly digestible starch (RDS) comprises principally of amorphous and dispersed starch, found in high amounts in starchy foods cooked by moist heat (Fernandes *et al.*, 2005). Similarly, rapidly digestible starch of less than 5% was reported in raw potatoes, cooking resulted in more than 95% of rapidly digestible starch in freshly cooked potato and reduced to 45% of RDS after cold storage (Mishra *et al.*, 2008). RDS in three potato cultivars ranged from 0.4 to 1.4% in raw potatoes and 52.0 to 56.4% in cooked potatoes (Donner *et al.*, 2009). For starch, RDS was 0.9 to 2.8 in raw starch, and 68.9 to 74.1% for cooked starch (Donner *et al.*, 2009). Moreover, raw potato starch was reported to have RDS of 2.83% (Romano *et al.*, 2016). Rapidly digestible starch are high in fleshly cooked food like boiled potatoes amounting up to 65% and they are considered as rapid source of energy (Lehmann and Robin, 2007). RDS is influenced by type of food and preparation conditions. RDS of conventionally grown potato was reported to be higher than the one of organically grown potatoes (Donner *et al.*, 2009). It was revealed that presence of natural pores in some starch facilitates starch digestion (Sujka and Jamroz, 2007). Pores are much developed in maize and much smaller in raw potato and

tapioca (Juszczaka *et al.*, 2003; Sujka and Jamroz, 2007). A type crystal starch have a channel allowing some reagents to penetrate in the starch, while B types have small holes which implies high digestibility of cereals starch than roots (Cornejo-ramírez *et al*., 2018). RDS such as in gelatinized waxy starch and most processed starchy foods is rapidly digested and absorbed in the duodenum and proximal regions of the small intestine leading to a quick increase of blood glucose and usually a subsequent episode of hypoglycemia (Zhang and Hamaker, 2009). Rapidly digestible starch was low in raw potatoes and increased with processing.

Table 30. Digestibility of raw potatoe starch

Cultivars	**TS %**	**Moisture %**	**RDS %**	**SDS %**	**RS %**
Mabondo	16.48±0.37^{b}	76.33±0.27^{ab}	2.00±0.10^{a}	14.40±0.72^{a}	83.61±0.81^{c}
Sangema	16.05±0.48^{b}	77.07±1.00^{a}	1.23±0.02^{b}	8.84±0.19^{b}	89.92±0.21^{b}
Kinigi	17.71±0.24^{ab}	76.12±0.79^{ab}	1.18±0.12^{b}	8.51±0.82^{b}	90.31±0.93^{a}
CIP393251.64	16.06 ± 0.51^{b}	76.67±1.21^{ab}	1.47±0.12^{b}	10.60±0.81^{b}	87.93±0.93^{b}
Kirundo	18.62±0.60^{a}	74.07±0.18^{b}	0.82±0.03^{c}	5.89±0.18^{c}	93.30±0.21^{a}
Minimum	16.05	74.07	0.82	5.89	83.61
Maximum	18.62	77.07	2.00	14.40	93.30
CV	3.48	1.22	8.60	8.42	1.04
MSD	1.6662	2.6148	0.3246	2.2918	2.6102

MSD: Minimum significant difference (Tukey at 5%), Means followed by the same letter in a column do not differ by Tukey's test at 5%.

TS: Total starch, RDS: Rapidly digestible starch, SDS: Slowly digestible starch, RS: resistant starch. TS and Mositure content are expressed in percentage of frech weight. RSD, SDS and RS are expressed in percentage of total starch.

4.5.4 Slowly digestible potato stach starch

Slowly digestible starch varies with cultivars and preparation methods. Slowly sdigestible starch is digested from 20 minutes to 120 minutes of onset of digestion. Slowly digestible starch ranged from 5.89 for Kirundo to 14.40% for Mabondo in raw potatoes, from 37.35 % for Kirundo to 38.58% for Kinigi in French fries and from 23.50% for Kinigi to 27.21% for CIP393251.64 in crisps and the difference was statistically significant in all cases at ($P < 0.05$). Slowly digestible starch in raw potatoes is less than 5% (Mishra *et al*., 2008). SDS in three varieties of potatoes varied from 15.0% -19.1 % for raw and 4.0-4.8% for cooked starch, while for dry matter it was 14.6-19.9% for raw potato and 4.3-5.7% for cooked potatoes

(Donner *et al.*, 2009). Slowly digestible starch in raw potato starch was reported to be 5.35% (Romano *et al.*, 2016). Freezing of cooked potatoes resulted in 35% of slowly digestible starch (Mishra *et al.*, 2008). SDS of organically grown potatoes was higher than conventionally grown potatoes (Donner *et al.*, 2009). SDS is supposed to be totally digested in the small intestine, but for one reason or another, it is digested more slowly (Fernandes *et al.*, 2005). They are digested slowly with sustained source of energy and blood glucose (Lehmann and Robin, 2007). Amylose-lipid complex reduces starch digestibility (Cornejo-ramírez *et al.*, 2018). High phosphorus content in starch may reduce digestibility in both gelatinized and raw starch as complete hydrolysis of starches with phosphate groups results in phosphoryl-oligosaccharides (Noda *et al.*, 2008). Slowly digested carbohydrates are commonly considered to be beneficial for management of metabolic disorders, such as diabetes and hyperlipidemia (Lehmann and Robin, 2007). Slowly digestible starch are important to sustain source of energy to the body and help in prevention of metabolic disorders.

4.5.6 Resistant starch of potato

Potato contains a fraction of starch which is not digestible and it is known as resistant starch. It ranged from 83.61 for Mabondo to 93.30% for Kirundo in raw potatoes, from 10.25 for CIP393251.64 to 14.53% for Sangema in French fries and from 2.91 for CIP393251.64 to 8.20% for Kirundo in crisps and the difference was statistically significant at ($P < 0.05$). Raw potatoes were reported to have 75% of resistant starch (Lehmann and Robin, 2007). Freezing after cooking of potatoes resulted in 4% of resistant starch (Mishra *et al.*, 2008). Resistant starch was reported to be 69.05% for raw potatoes, 1.18% for boiled potatoes, 4.63% for boiled and cooled, 2.80% for raw flakes, 2.08% for mashed, 3.70% for oven baked, 6.64% for French fries, 3.27% for crisps and 10.38% for retrograded potato flour (García-Alonso and Goňi, 2000). After cooking for 15 minutes, resistant starch was 5.79 for potato, 5.48 for cassava and 6.98 g/100g for yam (Bavaneethan *et al.*, 2015). Resistant starch in three varieties of potatoes was 80.0-85.5% for raw starch and 21.2-26.3% in cooked starch, while it was 49.5-57.3% for raw potatoes and 9.3-15.8% for cooked potatoes (Donner *et al.*, 2009). Resistant starch of potatoes was reported to reduce with cooking time where raw potatoes had resistant starch of 26.05 g/100g and 5.79 g/100g for cooked potatoes for 15 minutes, 5.55 g/100g for 20 minutes and it remained 5.55 g/100g after 30 minutes of cooking (Bavaneethan *et al.*, 2015). Resistant starch of organically grown starch was lower than the one of conventionally grown potato starch (Donner *et al.*, 2009).

Table 31. Digestibility of starch in French fries

Cultivars	TS %	RDS %	SDS %	RS %	GI	GL
Mabondo	45.62 ± 1.14^{b}	50.87 ± 1.42^{a}	37.95 ± 0.10b^{c}	11.17 ± 1.33^{ab}	64.84 ± 1.15^{ab}	11.39 ± 0.18^{b}
Sangema	37.94 ± 1.57^{c}	46.71 ± 0.92^{b}	38.76 ± 0.20^{a}	14.53 ± 0.72^{a}	59.44 ± 1.11^{c}	9.91 ± 0.38 ^{c}
Kinigi	39.47 ± 1.79^{bc}	48.82 ± 1.48^{ab}	38.58 ± 0.22^{ab}	12.60 ± 1.39^{ab}	61.08 ± 1.25^{bc}	11.32 ± 0.37^{b}
CIP393251.64	42.03 ± 1.75^{bc}	51.45 ± 1.45^{a}	38.30±0.18^{ab}	10.25 ± 1.38^{b}	63.45 ± 1.34^{bc}	10.69 ± 0.43^{bc}
Kirundo	53.81 ± 0.57^{a}	50.36±0.38^{ab}	37.35 ± 0.04^{c}	12.29 ± 0.35^{ab}	68.37 ± 0.44^{a}	13.36 ± 0.09^{a}
Minimum	37.94	46.71	37.35	10.25	59.44	9.91
Maximum	53.81	50.87	38.58	14.53	68.37	13.36
CV	5.62	2.79	0.72	10.26	2.51	3.65
MSD	6.9378	3.9033	0.7705	3.5224	4.4908	1.1676

MSD: Minimum significant difference (Tukey at 5%), Means followed by the same letter in the column do not differ by Tukey's test at 5%.

TS: Total starch, RDS: Rapidly digestible starch, SDS: Slowly digestible starch, RS: resistant starch, GI: Glycemic index, GL: Glycemic Load. TS and Mositure content are expressed in percentage of frech weight. RSD, SDS and RS are expressed in percentage of total starch. Glycemcic index is on scale of 0-100. Less than 55 is low, 56-69 is medium and above 70 is high. Glycemic Load less than 10 is low, 11-19 is medium, and above 20 is high.

Table 32. Digestibility of starch in potato crisps

Cultivars	TS %	RDS %	SDS %	RS %	GI	GL
Mabondo	60.40 ± 1.01^{a}	70.31 ± 0.06^{ab}	24.46 ± 0.12^{c}	5.23 ± 0.09^{c}	70.23 ± 0.51^{a}	12.33 ± 0.10^{abc}
Sangema	52.29 ± 0.85^{c}	69.66 ± 0.07^{c}	25.40 ± 0.13^{b}	4.94 ± 0.19^{c}	66.23 ± 0.53^{b}	11.05 ± 0.56^{c}
Kinigi	58.10 ± 0.73^{ab}	70.22 ± 0.07^{b}	23.50 ± 0.09^{d}	6.28 ± 0.16^{b}	68.50 ± 0.43^{a}	12.71 ± 0.55^{ab}
CIP393251.64	54.60 ± 0.43^{bc}	69.87 ± 0.03^{c}	27.21 ± 0.16^{a}	2.91 ± 0.19^{d}	68.32 ± 0.30^{ab}	11.54 ± 0.64^{bc}
Kirundo	61.79 ± 0.69^{a}	70.52 ± 0.02^{a}	21.27 ± 0.30^{e}	8.20 ± 0.31^{a}	69.44 ± 0.40^{a}	13.57 ± 0.03^{a}
Minimum	52.29	69.66	21.27	2.91	66.23	11.05
Maximum	61.79	70.52	27.21	8.20	70.23	13.57
CV	2.29	0.15	1.27	6.50	1.13	4.40
MSD	3.7181	0.2893	0.8699	1.0105	2.1828	1.5199

MSD: Minimum significant difference (Tukey at 5%), Means followed by the same letter in the column do not differ by Tukey's test at 5%.

TS: Total starch, RDS: Rapidly digestible starch, SDS: Slowly digestible starch, RS: resistant starch, GI: Glycemic index, GL: Glycemic Load. TS and Mositure content are expressed in percentage of frech weight. RSD, SDS and RS are expressed in percentage of total starch. Glycemcic index is on scale of 0-100. Less than 55 is low, 56-69 is medium and above 70 is high. Glycemic Load less than 10 is low, 11-19 is medium, and above 20 is high.

Consumption of resistant starch enhances glucose and lipid metabolism and it is linked to the reduction of diabetes and related diseases (Bavaneethan *et al*., 2015). Resistant starch stimulates growth of desirable bacteria in the intestine and inhibits growth of harmful bacteria and it is known as prebiotic fiber (Bavaneethan *et al*., 2015). It is a substrate of probiotic bacteria. Resistant starch is high in raw potatoes, reduced with processing and cooling of processed food enhances reformation of resistant starch. They protect the body against different metabolic disorders.

4.5.7 Glycemic index of potato

Glycemic index of studied potatoes ranged from 59.44 for Sangema to 68.37 for Kirundo in French fries and from 66.23 for Sangema to 70.23 for Mabondo in crisps. There was a significant difference in GI of studied potato cultivars at ($P < 0.05$). Glycemic index of boiled potato was estimated to be 107.5 for mashed potatoes, 67.8 for oven-baked potatoes, 74.3 for crisps and 56.6 for French fries comparing to the white bread having 100 (García-Alonso and Goňi, 2000). Similarly, GI was 76.5 for baked potatoes, 87.7 for instant mashed potatoes, 56.2 for boiled red potato after cooling and 63.6 for fresh fried potatoes (Fernandes *et al.*, 2005). Further study reported glycemic index of 63 for boiled potatoes, 72 for boiled at 120^{o} C, 69 for boiled and treated with acetic acid, 59 for boiled and stored for 24 hours at 6^{o} C and with acetic acid, and 72 for boiled at 120^{o} C and treated with acetic acid (Udagawa *et al*., 2017). GI was 74, 69 and 103 for fried, stir-fried and boiled potatoes respectively (Tian *et al.*, 2018). GI is calculated based on the area under glucose response curve after consumption of 50 g of carbohydrate food divided by area under curve after consumption of 50 g of carbohydrate from control like white bread or glucose, GI is divided in three categories high if above 70, intermediate between 55 and 70, and low GI below 55 (Dona *et al.*, 2010). Therefore, in the current study crisps had higher glycemic index than French fries had intermediate GI. Variation of GI in potatoes may be related to potato cultivars, maturity, and structure of starch, processing and storage conditions with more influence on processing (Singh and Kaur, 2009). Food with high GI are considered as potential contributors of type 2 diabetes (Eleazu, 2016). Food with low glycemic index helps for prevention of various diseases like obesity, type 2 diabetes, coronary heart diseases and many types of cancer (Eleazu, 2016). Processing conditions which enhance reduction of GI are encouraged for the well-being of consumers as they are becoming reluctant for food with high GI.

4.5.8 Glycemic load of potato

Glycemic load varied from cultivars to cultivar and with preparation methods. Glycemic load was from 9.91 for Sangema to 13.36 for Kirundo in French fries and from 11.05 for Sangema to 13.57 for Kirundo in crisps and the difference was statistically significant at ($P < 0.05$). GL is related to the amount of carbohydrates in the food and how each gram affects raise of blood glucose, it is calculated based on available carbohydrates rather than total carbohydrates, available carbohydrates comprises starch and sugars. GL is low if less than 10, intermediate from 11 to 19 and high if above 20 (Eleazu, 2016). Based on this classification, the data in the current study are in intermediate GL for both crisps and French fries. Crisps had higher GL than French fries. Potatoes with high stach content had ghigher GL than those with low starch content. Glycemic load is used to control weight loss and diabetes (Eleazu, 2016). Consumption of food with low GL is advantageous as it reduces loading of blood with high amount of glucose which reduces metabolic disorders.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. Potatoes in this study have different morphological characteristics. Kinigi and CIP392617.54 have deep eyes which can increase peeling losses. Biochemical charactrisicts shows that Kirundo is the best for processing quality followed by Kinigi.

2. Oil content is higher in crisps than in French fries. Potatoes with high dry metter absorbs less oil than potato with high moisture content. Sensory attributes are different for five cultivars, while discriminate analysis shows no significant difference. This suggests that one cultivars can be used in stead of another.

3. Brine fermentation increases acidity and reduces nutrients. Acrylamide reduces during fermentation and acrylamide content of French fries is lower than the one in crisps.

4. Potato flour from five cultivars have high bulk density, high water absorption capacity and high oil absorption capacity. They are suitable in food application as thickners, to increase bulky of product, increase of flavor and oil retention.

5. Potato starch granules are oval with smooth surface. Phosphorus content is moderate and they all influence on starch digestibility. Cooking increases digestibility of starch. Glycemic index and glycemic load of potato crisps and French fries are moderate.

5.2 Recommendations

The following recommendations can be made to:

1. Researchers: It is recommended to grow potatoes in different locations and seasons and see how they influence quality of potatoes. Further studies are necessary to investigate different ways to reduce postharvest losses of potatoes focusing on those which can be affordable by people for different socio-economic classes. It is also recommended to investigate changes and chemical reactions which take place during processing and their influence on sensory characteristics of processed potato products.

2. Relevant institutions: This research provides information on cultivars suitable for each product. This is important for the government to advice people on which cultivars to produce and also provide a useful information to processors as they can know which cultivars are suitable for which product. The information can also be used for education purpose.

3. Potato producers: This information is important to the potato producers as it can be a baseline for providing information on which variety to produce and for which purpose.

4. Potato consumers: consumers will get information on nutritional quality of potatoes by having idea on its chemical composition. The information related to GI and GL is also provided and it is useful for consumers who want to control metabolic disorders.

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APPENDICES

Appendix 1: Scientific contribution of the current study/Journal Publication

Title of the paper: Morphological and phytochemical composition of selected potato (*Solanum tuberosum L.*) cultivars grown in Rwanda

Journal: Annals. Food Science and Technology, 2019, 20 (1): 393 - 401

Authors: Ndungutse, Vedaste[1,2], **Ngoda,** Peninah Muthoni Njiraine[2], **Vasanthakaalam,** Hilda[1], **Shakala,** Eduard Kokan[3], **Faraj,** Abdul Kipruto[2]

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Abstract

The aim of this study was to investigate morphological and functional properties of six varieties and four potato clones grown in Rwanda and their potential utilization in food products. The experiment was arranged in Randomized Complete Block Design (RCBD) with three replications. The research was conducted in Busogo farm in the year 2016/17. Morphological and phytochemical composition of potatoes were analyzed. Collected data were subjected to Analysis of variance (ANOVA) using SAS version 9.2. Means separation was done using Tukey's test at 5% level of significance. The skin colours included red, white, yellow, pink and purple, while the flesh was yellow and white. Shapes were oval, oblong and round. They had shallow and medium eyes with deep eyes for Kinigi and CIP392617.54. Number of eyes were 6-12. All cultivars had potato size > 40 mm exceptCIP399075.22 with 90% of <40mm. Phytochemicals on fresh weight basis (FWB) were17.80-21.52 mg/100g for total phenols, 0.24-1.46 mg/100g for total anthocyanins, 0.05- 0.19mg/100g for total carotenoids, 5.31-26.60 mg/100g for vitamin C. Orthogonal contrast revealed that varieties and clones were statistically significantly different at *(P* < 0.05). On average varieties had higher phenols and higher anthocyanins, while clones were higher in carotenoids and vitamin C. Skin and flesh colours were associated with phytochemicals which are good for health. Potato cultivars in this study can be used for manufacturing of different potato products due to morphological characteristics required for each product and they are source of phytonutrients with antioxidant properties.

Keywords

Phytochemicals, Phytonutrients, potato morphology, Rwanda

Appendix 2: Scientific contribution of the current study/Journal Publication

Title of the paper: Processing quality of selected potato (*Solanum tuberosum L.*) cultivars grown in Rwanda.

Journal: Potato Journal, 2019, 46 (1):48-55

Authors: Vedaste Ndungutse[1,2*], Peninah Muthoni Njiraine Ngoda[2], Hilda Vasanthakaalam[1], Eduard Kokan Shakala[3], Abdul Kipruto Faraj[2]

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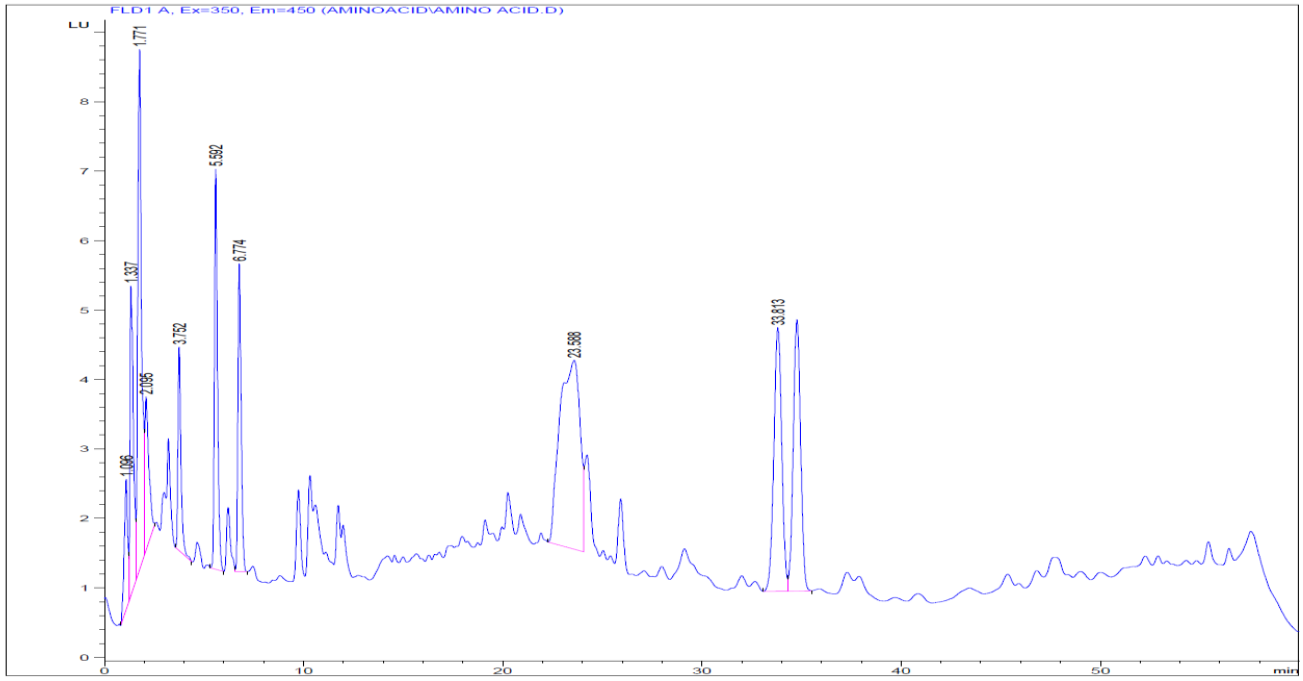
ABSTRACT

The aim of this study was to investigate processing quality of ten potato cultivars grown in Rwanda and their potential utilization in food products. Potatoes were grown in Busogo farm in 2016/17. Specific gravity (SG), dry matter (DM), starch and sugars were analyzed. There was a significant difference in all studied parameters at ($P < 0.05$). Specific gravity ranged from 1.075 for Kigega to 1.099 for Kinigi. Dry matter ranged from 20.45% for CIP392617.54 to 25.93% for Kirundo. Starch content was 14.33% for CIP392617.54 to 19.28% for Kirundo on Fresh Weight Basis (FWB). There was a significant positive correlation among SG, DM and starch. Reducing sugars were 0.10% for Kirundo and Sangema to 0.20% for Mabondo, non-reducing sugars ranged from 0.16% for Kirundo to 0.35% for Mabondo and total sugars from 0.26% for Kirundo to 0.55% for Mabondo on FWB. Most of tested varieties/clones have high DM and low reducing sugars and are suitable for processing into fried and dehydrated products. Kigega and CIP392617.54 are more suitable for boiling.

KEYWORDS

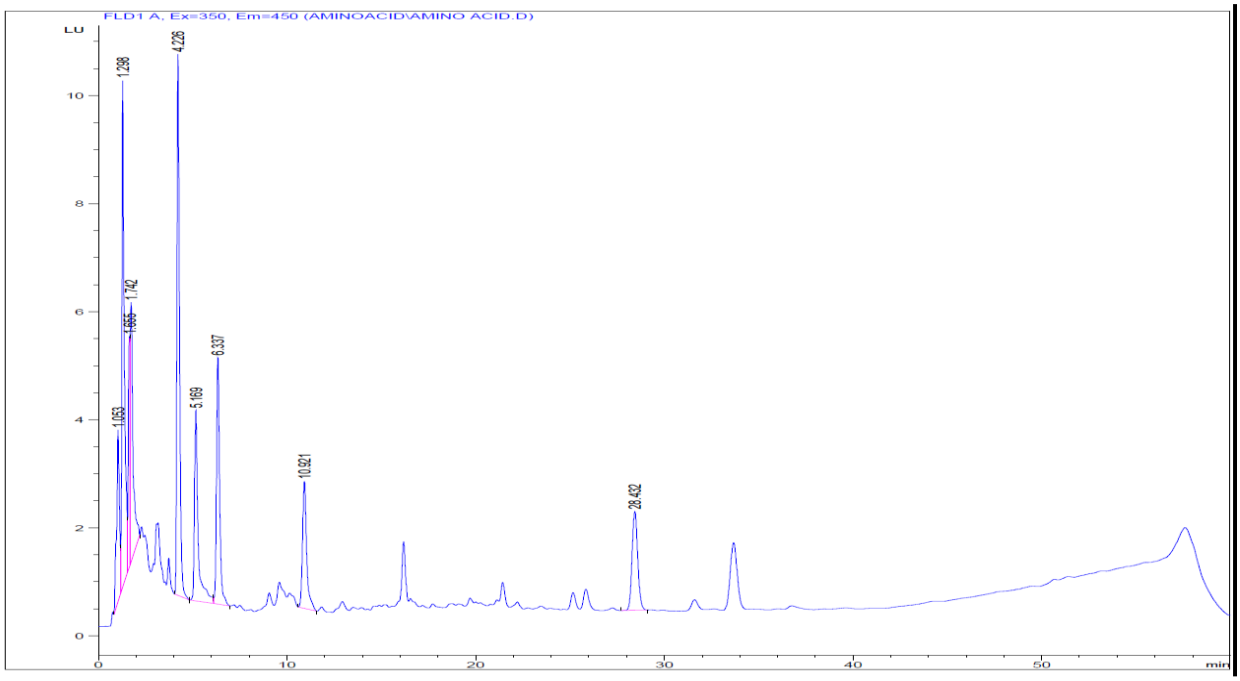
Dry matter; potato cultivars**;** specific gravity; sugars; starch

Appendix 3: HPLC analysis of amino acids



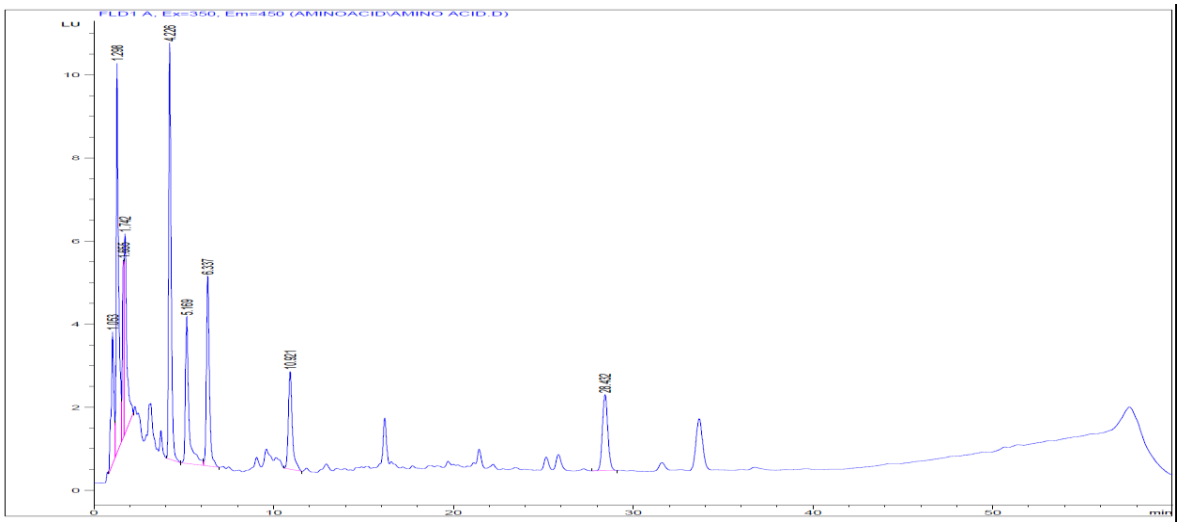
Retention time in minutes

Kirundo



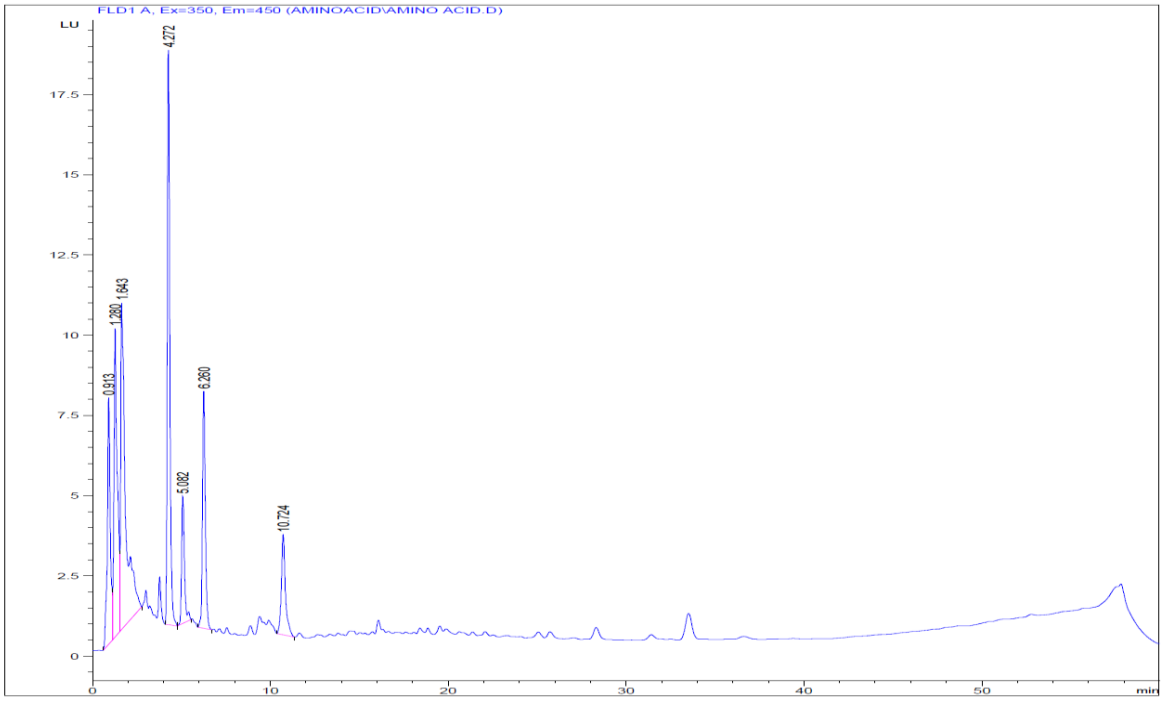
Retention time in minutes

CIP399075.22



Retention time

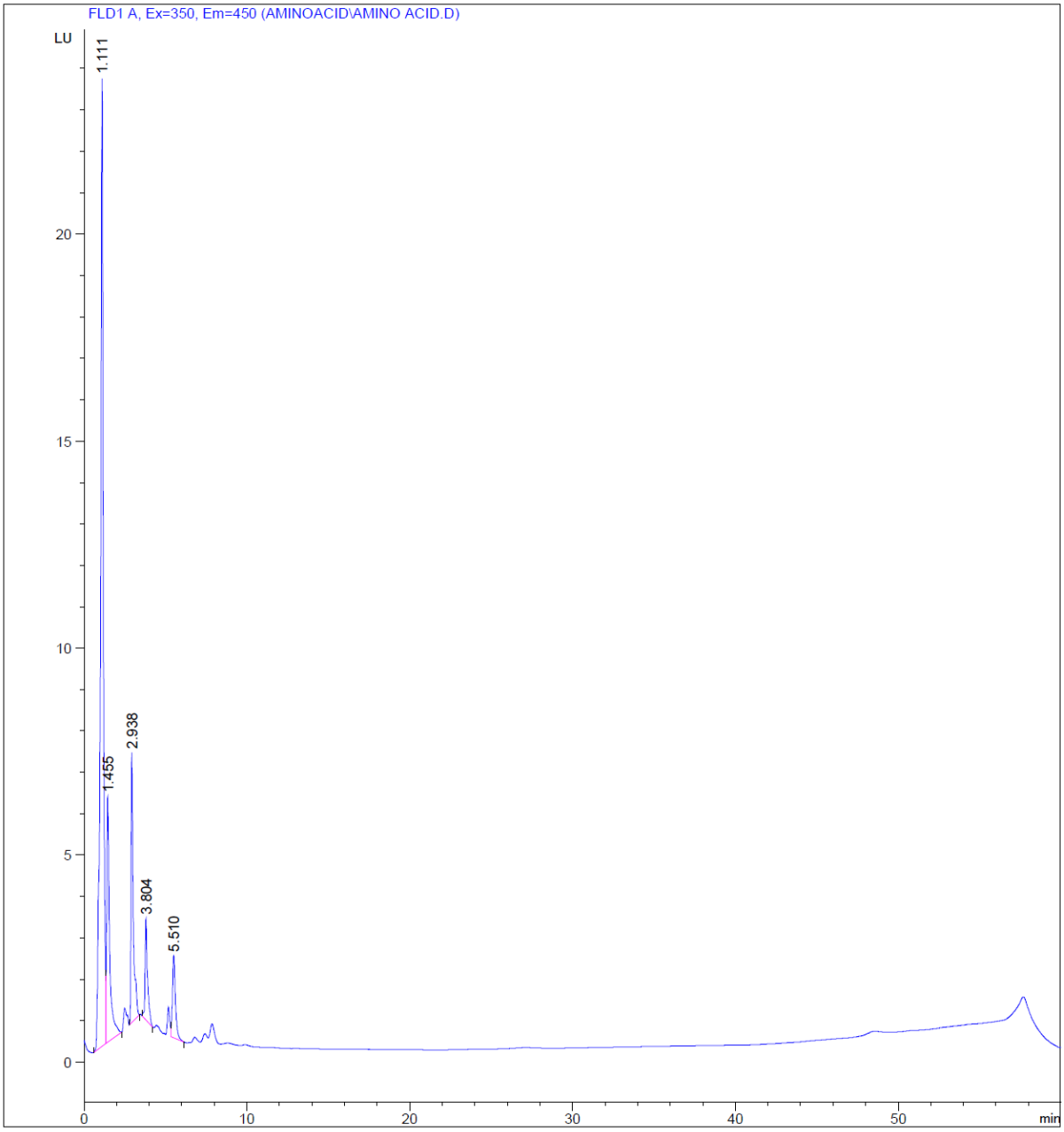
Gikungu



Retention time in minutes

Mabondo

Appendix 4: Standard of amino acids



Retention time in minutes

Standards	Retention time in minutes
Aspartic acid	1.111
Glutamic acid	1.455
Arginine	2.938
Methionine	3.804
Arginine	5.510

Appendix 5: Sensory evaluation of crisps and French fries

Name :……Date…….

Age……..Gender: ( ) Female ( ) Male

You are receiving a coded sample of potato crisps or French fries. Evaluate its overall acceptability, colour, sweetness, taste, flavour, crispness, and dryness by marking using the scale below to describe your feelings in accordance to the attributes mentioned. Drink water between samples.

Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extrememly
1	2	3	4	5	6	7	8	9

Sample code	Overall acceptability value	Colour value	Sweetness value	Flavour value	Crispness value	Dryness value

Suggestions/comments……
……
……
…….

Appendix 6: Statistical analysis

The GLM Procedure
Dependent Variable: Starch content

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	62.60875667	5.69170515	20.06	<.0001
Error	18	5.10599333	0.28366630		
Corrected Total	29	67.71475000			

R-Square	Coeff Var	Root MSE	Starch Mean
0.924596	3.230836	0.532603	16.48500

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	1.25574000	0.62787000	2.21	0.1382
Treat	9	61.35301667	6.81700185	24.03	<.0001

The GLM Procedure
Dependent Variable: Dry matter

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	11	74.58650667	6.78059152	18.03	<.0001
Error	18	6.76828000	0.37601556		
Corrected Total	29	81.35478667			

R-Square	Coeff Var	Root MSE	DM Mean
0.916805	2.697682	0.613201	22.73067

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	2.75978667	1.37989333	3.67	0.0461
Treat	9	71.82672000	7.98074667	21.22	<.0001

The GLM Procedure
Dependent Variable: Moisture content of French fries

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	179.0091867	29.8348644	4.61	0.0257
Error	8	51.8207733	6.4775967		
Corrected Total	14	230.8299600			

R-Square	Coeff Var	Root MSE	Moistureremain Mean
0.775502	6.727051	2.545112	37.83400

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	1.6153600	0.8076800	0.12	0.8845
Treat	4	177.3938267	44.3484567	6.85	0.0107

The GLM Procedure

Dependent Variable: Total oil content of French fries

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	122.5996267	20.4332711	23.10	0.0001
Error	8	7.0755067	0.8844383		
Corrected Total	14	129.6751333			

R-Square	Coeff Var	Root MSE	TOF Mean
0.945437	5.736758	0.940446	16.39333

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	20.9510933	10.4755467	11.84	0.0041
Treat	4	101.6485333	25.4121333	28.73	<.0001

The GLM Procedure

Dependent Variable: Moisture content of crisps

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	179.0091867	29.8348644	4.61	0.0257
Error	8	51.8207733	6.4775967		
Corrected Total	14	230.8299600			

R-Square	Coeff Var	Root MSE	Moistureremain Mean
0.775502	8.254240	2.545112	30.83400

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	1.6153600	0.8076800	0.12	0.8845
Treat	4	177.3938267	44.3484567	6.85	0.0107

The GLM Procedure

Dependent Variable: Total oil of crisps

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	122.5996267	20.4332711	23.10	0.0001
Error	8	7.0755067	0.8844383		
Corrected Total	14	129.6751333			

R-Square	Coeff Var	Root MSE	TOF Mean
0.945437	5.736758	0.940446	16.39333

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Rep	2	20.9510933	10.4755467	11.84	0.0041
Treat	4	101.6485333	25.4121333	28.73	<.0001

Appendix 7: Phytosanitary certificates

No. 0585634

KP2016585634 5KE

PERMIT No. KEPHIS/3086/2017

REPUBLIC OF KENYA

MINISTRY OF AGRICULTURE & RURAL DEVELOPMENT

KENYA PLANT HEALTH INSPECTORATE SERVICE (KEPHIS)

PLANT IMPORTATION PERMIT

(Plant Protection Act Cap 324) Date 20 January, 2017

The importer must furnish the supplier with a copy of this import permit before plant material is despatched.

*Permission is hereby granted to PROF. ABDUL K. FARAJ DEPARTMENT OF DAIRY FOOD SCIENCE

of 536, CODE 20115

to import from DR. HILDA VASANTHAKAALAM DEPT. OF FOOD SCIENCE AND TECHNOLOGY,

the following Tubers

60 KGS Solanum tuberosum

subject to the following conditions

1) All Tubers to be the produce of and grown in

2) The consignment to be inspected on arrival and the importing authority reserves the right to treat, destroy or refuse the importation.

3) Plants or plantparts must be entirely free from soil, chaff and/or leaf mould.

4) Each consignment shall be accompanied by an original copy of this import permit and Phytosanitary Certificate (International Model or its equivalent) from country of origin;

Additional Declarations:

Permit shall include the following conditions:-

(a) Phytosanitary Certificate (International model or its equivalent).
(b) The tubers are only meant for research purpose in a confined area.

Failure to furnish the required certificates may result in prohibition of entry of the plant materials.

5) **Packaging** The following materials must **not** be used: banana leaves, maize, rice, sorghum, palm, wheat straw soil or leaf mould. If any other plant residue is used as packaging material, the consignment must be accompanied by a certificate stating: all seeds, pathogens and insects have been killed before use of the material either by heating to 180°F / 83°C for ten minutes or by chemical treatment (N.B:- Details to be stated on Phytosanitary Certificate).

This permit is valid for six months from date of issue, but may be cancelled at any time by the Director of Agriculture or by the officer issuing the permit on his behalf

(NAKURU)

Official Stamp 20 JAN 2017

Anne Cherutich

(Signed) .....

for Director of Agriculture

"Import of genetically modified material will require clearance from the National Biosafety Authority in compliance with the Biosafety Act"

The permission hereby granted is additional to any permission or licence required under any other law.
Full name and address of supplier to be stated

REPUBLIC OF RWANDA

MINISITERI
Y'UBUHINZI
N'UBWOROZI

MINISTRY OF
AGRICULTURE AND
ANIMAL RESOURCES

OFFICE OF AGRICULTURE AND LIVESTOCK INSPECTION AND CERTIFICATION SERVICES

PHYTOSANITARY CERTIFICATE *N° 146/03/2017/S.P.P.*

It is certified that the plants, parts of the plants or crop products described below, were thoroughly examined, entirely or on representative samples this **22/07/2017** *by* **UWUMUKIZA Beatrice** *, authorized agent of Services of agriculture and livestock inspection and certification of the Republic of Rwanda and, to its knowledge, are considered to be practically clean from diseases and dangerous pests, and that the export is in conformity with the plant health regulations currently into force in the importing countries, as it is specified in the declarations additional hereafter where in addition.*

Fumigation or Disinfection (to be filled on the request of the importing country)

Date: **N/A** ..... *Treatment:* **N/A** .....
Duration of treatment:. **N/A** .....
Chemical and concentration: **N/A** .....

Additional declaration: **For research purpose**.....

EXPEDITION'S DETAILS

Name and addresses of the shipper: **VEDASTE NDUNGUTSE**.....

Name and addresses of the recipient: **EGERTON UNIVERSITY**.....

Numbers and nature of the parcels: **3 BAGS OF IRISH POTATOES**.....

Marks of the parcels: **N/A**.....

Source: **RWANDA** ..... *Means of transport:* **AIR**.....

Entrance point: **BUSIA** .....

Quantity and nature of the product: **45 KGS NET WEIGHT OF IRISH POTATOES**.....

Botanical name (on the request of the importing country): **Solanum tuberosum** .....

Visas of the Legal Service

Done at Kigali....., on **22/03/2017**.

AUTHORIZED BY DIRECTOR GENERAL IN CHARGE OF AGRICULTURE AND LIVESTOCK INSPECTION AND CERTIFICATION SERVICES

MINAGRI