INFLUENCE OF DIFFUSED LIGHT SEED STORAGE AND PRODUCTION LOCATION ON PHYSICO-CHEMICAL CHARACTERISTICS AND PROCESSING SUITABILITY OF SELECTED KENYAN POTATO (*Solanum tuberosum*) VARIETIES

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DECLARATION

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

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This work is dedicated to my dear children: Faith, Joyce, Prudence, Harryjack and Timothy and to my husband Edward for their unceasing prayers, love, understanding and encouragement throughout my work. I most sincerely dedicate it to God Almighty for seeing me through and Glory and Honour is to YOU my GOD forever and ever, AMEN.

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LIST OF ABBREVIATIONS

DLS SEED	Diffused light seed potato storage
FRESH SEED	Freshly harvested potato seed
TREAT	Seed treatment
WARE POTATOES	Industrial potato tubers for processing
MoA	Ministry of Agriculture
ORG. CARBON	Organic carbon
DM	Dry matter content
MC	Moisture content
FWB	Fresh weight basis
me	Milliequivalent
ppm	Parts per million
KARI	Kenya Agricultural Research Institute
KMpya	Kenya Mpya potato variety
Dutch	Dutch Robjin potato variety

ABSTRACT

Potato varieties and different production sites can influence the quality of French fries and crisps. Planting well-sprouted potato seeds from diffused light storage (DLS) can lead to higher yields which can influence quality of tuber physico-chemical properties and hence the quality of processed French fries and crisps. The objective of the study was to determine the influence of diffused light seed potato storage (DLS) and production location on physico-chemical characteristics of Kenyan varieties (Kenya Mpya, Dutch Robjin, Tigoni and Cangi) and their processing suitability into French fries and crisps. The study areas included National Potato Research Centre KARI-Tigoni in Kiambu County and three farmers (Pyhort, Kagema and Hellen) located in Nyandarua County in Kenya. DLS was achieved through farmers' on-farm storage structures (ordinary wooden stores with iron-sheet roofs) exposing potato seeds to natural diffused light with good ventilation for 8 months. The study was carried out between April, 2013 and February, 2014.

The selected tubers were processed into French fries and crisps then analyzed for sensory quality, moisture and oil contents as influenced by seed potato storage, varieties and production location. Completely randomized block design was used in the study where production locations were considered as blocks; independent factors were production locations, potato seed storage and potato varieties; dependent factors were soil pH, soil and potato tuber minerals contents, tubers specific gravity, dry matter content, vitamin C content, reducing sugars content, French fries and crisps moisture and oil contents and their sensory parameters. All the dependent analyses were performed following standard analytical methods. The data was analyzed using statistical analysis system (version 9).

The soil pH and the rest of the soil minerals in the study areas differed significantly ($p \leq 0.05$) with production locations. Higher soil minerals contents led to higher potato tubers minerals contents except for Ca, Mn and Zn which showed reverse relationship.

There were negative significant correlations between potato tubers dry matter content and soil pH and phosphorus; positive significant correlations between soil pH and potato tubers dry matter and vitamin C contents which showed that plant locality affected the quality of ware potatoes. Potato tubers' specific gravity, dry matter, reducing sugars and vitamin C contents significantly ($p \leq 0.05$) differed with plant localities, potato varieties and seed potato storage. There were significant interactions among plant locality, variety and seed storage. DLS seed treatment caused production of potato tubers with higher specific gravity, dry matter content, vitamin C content, and minerals contents but with lower reducing sugars content.

French fries and crisps processed from DLS seed had the required lower oil contents, moisture contents and higher levels of consumer acceptability in comparison with those from fresh seeds. All the sensory attributes of freshly processed French fries and crisps, differed significantly ($p \leq 0.05$) with plant localities, varieties and with seed potato storage. There were significant interactions among plant locality, variety and seed treatment.

Diffused light seed potato storage and production location thus affect physico-chemical characteristics of Kenyan potato varieties and their processing suitability into French fries and crisps.

Ministry of Agriculture, Livestock and Fisheries should ensure diffused light seed potato storage is adopted by more farmers in Nyandarua County and the rest of the Kenyan Counties so as to yield more and better quality ware potatoes for the potato industry.

CHAPTER ONE

1.0 GENERAL INTRODUCTION

The potato (*Solanum tuberosum)* is a greatly shortened and swollen part of an underground stem commonly grown as starchy tubers (Ekin, 2011).The crop has its origins in the area around Lake Titicana located 3800m of altitude at the border of modern day Bolivia and Peru in Andes Mountain Range of South America from where it spread throughout the world (Jong et al., 2011). It is the fourth world largest crop in terms of fresh produce after rice, wheat and maize (Kabira and Lemaga, 2006; MoA, 2005). Over 45% of potato production in Sub-Saharan Africa is contributed by East and Central Africa which is from 52% of the area harvested (Scott et al., 2013).The potato in Kenya is the second most important crop after maize in terms of food security and utilization is concerned. The potato crop is grown in most highland areas (1800-3000m) like Nyandarua County where it performs better in terms of yield in comparison to other staple foods such as maize (MoA, 2005).

Potato's importance in Kenya continues to rise due to the high population in Kenya (40 million people), increased urbanization and uptake of processed potato products (French fries and crisps), its high contribution to food security; poverty eradication; economic development, its high nutritional value, high market for ware potatoes and an income generation for the farmers have seen so many small scale potato farmers venture into potato growing (Ooko and Kabira, 2011; Muthoni and Nyamongo, 2009; Scott et al., 2013; Obado, 2009; Abong' et al., 2009). Although potato growing area has been increasing steadily over the years due to these small scale farmers, on farm yields have been low on average (<10 tonnes/ ha) as compared to 40-60 tonnes/ha as expected yield achieved under optimal farming conditions. This is due to lack of affordable clean potato seed, following the collapse of certified seed potato multiplication and distribution system by the early 1990; the limited certified and disease free seed tubers which account for <5% of the whole potato seed market in Kenya; high bulky seed tubers needed for planting (two to three tonnes per hectare is the typical seed requirement) have habitually forced such farmers to plant own-saved tubers (from pit or dark room) from previous harvests or sourced from markets or even from neighbours. Such seeds are usually of poor status often leading to loss of seed quality through weight loss, excessive sprouting, pests and disease attacks are usually common which often result in low yields (Kabira and Lemaga, 2003). Introduction of good quality well-sprouted diffused light stored potato seed by the National Potato Centre-Tigoni, to be planted by selected farmers in Nyandarua County has resulted in high yields (Kipkoech et al., 2012; Muthoni et al., 2014). However the harvested potatoes from DLS seed treatment have not been evaluated in terms of physico-chemical properties for ware and their processing suitability into French fries and crisps.

Physico-chemical properties of potato tuber such as specific gravity, dry matter content, minerals content, reducing sugars content and vitamin C content determine both nutritional and sensory quality of processed potato products such as French fries and crisps (Kabira and Lemaga, 2003; 2006). The properties are in turn affected by potato variety, environmental and soil conditions in a production locality and cultural practices (Ooko and Kabira, 2011; Ekin , 2011).

1.1 The problem statement

Diffused light seed potato storage produces seeds with delayed physiological aging, reduced apical dormancy leading to formation of short and firm sprouts which have high vigor for growth and results in increased number of stems per tuber when planted yielding highly (Gachango et al., 2008; Muthoni et al., 2014). However, the quality of such high yielded harvested potato tubers from DLS seeds of various varieties from different locations has not been investigated to determine their suitability as raw material for processing into French fries and crisps.

1.2 Justification of the study

This DLS technology if found to produce potatoes suitable for manufacture of French fries and crisps, will improve availability of raw materials to processors because of higher yields. This will contribute to increased profitability of the processing firms. Farmers will also have increased income. Consumers will also benefit from lower priced and more nutritious French fries and crisps. This study will also form a basis for selection of potato production locations that produce good quality tubers that are suitable for manufacture of French fries and crisps.

1.3 Objectives

1.3.1 Broad objective

To determine the influence of DLS and production location on physico-chemical properties and processing suitability of selected Kenyan potato varieties.

1.3.2 Specific objectives

1. To determine the effect of soil characteristics in production location on potato tuber mineral composition.
2. To determine the effect of DLS potato storage and production location on the physico-chemical properties (specific gravity, dry matter content, reducing sugars content and vitamin C content) of potato tubers and hence their suitability for processing.
3. To determine the effect of DLS seed potato storage and production location on the quality of French fries and crisps.

1.4 Research questions

1. Can soil characteristics affect potato tuber mineral composition in production location?
2. Can DLS seed potato treatment and production locality affect physico-chemical properties of ware potatoes?
3. Can DLS seed potato treatment and growth locality affect the quality of fresh processed French fries and crisps?

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The production and distribution of potato in Kenya

The potato (*Solanum tuberosum*) has its origins in the area around Lake Titicana located 3800m above sea level at the border of modern day Bolivia and Peru in Andes Mountain Range of South America from where it spread throughout the world (Jong et al., 2011). When Europeans discovered that the potatoes were useful and nutritious, they made them an important culinary staple and this made them to be the mainstay of Irish diet in the late eighteenth century and to date they are referred to as Irish potatoes (Jong et al., 2011). The potato is the most widely grown food crop after maize, wheat and rice worldwide (MoA, 2007; MoA, 2009). Over 45% of potato production in Sub Saharan Africa comes from East and Central Africa which is reflected into about 52% of the area harvested (Scott et al., 2013).

In Kenya, the potato was introduced at the beginning of the last century by the European settlers and is currently the second most valuable cash and staple food crop after the cereals (MoA, 2009).The potato production is mainly confined to the high altitude areas (≥2000 m) where the crop has higher production potential than cereals per unit area (MoA, 2006). Nyandarua County, being one of the largest potato producing Counties in Kenya has 2011km^2 out of its 3523km^2 area for potato production (Kabira, et al., 2013). The crop is grown twice annually following two distinct rainfall seasons as follows: during long rains between April and May and during short rains between October and November (MoA, 2005).

2.2 Soil characteristics

Potato plants acquire mineral elements primarily from the soil through their roots as the low-transpiring tuber receives minerals and other nutrients primarily through redistribution from above-ground tissues via phloem (Woolfe, 1987). Low fertility of some soils where crops are grown and the poor uptake and translocation of some mineral elements to edible portions contribute to low mineral levels in several staple food crops like potato tubers (White and Broadley, 2009). Potato tubers having been from well drained soil with optimum soil nutrients, moderately acid soils (Table 1) and under ambient rainfall will contain right amounts of minerals in the right proportions, Burton (1989).

Table 1: Types of soil reactions based on pH values

pH VALUES	SOIL REACTIONS
3.1-4.0	Very strongly acid soil
4.1-5.0	Strongly acid soil
5.1-6.0	Moderately acid soil
6.1-7.0	Slightly acid soil
7.1-8.0	Slightly alkaline soil
8.1-9.0	Moderately alkaline soil
9.1-10.0	Strongly alkaline soil
10.1-11.0	Very strongly alkaline soil

Source: Jackson (1958)

N, P and K are required for potatoes growth and production which are usually obtained from the soil and so the soils with adequate nutrients enable potatoes to grow well making tubers to acquire essential minerals for human nutritional quality (MoA, 2005). P in soil solution occurs mainly as inorganic anions $H_2PO^{-}_4$, HPO^{2-}_4 and PO^{3-}_4 needed for potatoes' root development and growth, tuber production, playing an important role in carbohydrate biosynthesis and control of maturity, it is also an essential component of adenosine triphosphate (ATP) which is an important coenzyme needed in all biosynthetic and catabolic cell reactions (Tan, 2005). Higher pH (>7.0) reduces solubility of P in the soil leading to its deficiency, Table 1. Excessive P in the soil causes deficiency in micronutrients in the potato plants (Singer and Munns, 1987; Tan, 2005). It is also one of the important non-carbohydrate components present in starch, which significantly affects its functional properties. Phosphorus tends to increase starch synthesis and the higher the starch content in the tuber the better the quality of processed potato products such as French fries and crisps (Ekin, 2011). Phosphorus deficiency causes potato plants to typically produce tubers with lower specific gravity compared to those with adequate phosphorus nutrition (Woolfe, 1987).

K is needed for early potato growth, water utilization efficiency, protein synthesis and pest and disease resistance. Too low soil K causes grey discoloration of potato French fries after blanching and pre-frying due to increased sugars (Kabira and Lemaga, 2006). Boron, Cu and Zn are needed for potato's metabolic and enzymatic functions but excessive macronutrient levels, cool temperatures and low pH levels can affect their absorption by potato plants. Usually oxygen and copper deficiencies with excess aluminium cause stunted potato root growth. Nitrogen and phosphorus are the two nutrients limiting potato production in the Kenyan highlands (Recke et al., 1997). Soil N if too high leads to faster potato growth causing tuber growth cracks and formation of hollow hearts that are unsuitable for processing into French fries and crisps (Kabira and Lemaga, 2006).

2.3 Diffused light seed potato storage (DLS) technology

Well sprouted potato seed which can lead to early crop establishment and hence higher yields can be obtained through simple and low-cost diffused light stores (Kabira, et al., 2013; Kipkoech et al., 2012; Gachango et al., 2008; Muthoni et al., 2014). Such stores use natural indirect light with good ventilation to control excessive sprouting and to produce sprouts which are short, stout, green colored and with higher vigor for growth in comparison to those stored in darkness as have been the tradition (Gachango et al., 2008). These conditions allow the potato seeds to break their dormancy naturally though for a long period of time (eight months) establishing the crop faster when planted. Planting non-sprouted seed takes too long to establish leading to fewer yields and of inferior quality especially when low and erratic rainfall is experienced as has been the case in Nyandarua County in comparison with planting well sprouted DLS seed (Muthoni et al., 2014). This is so because the faster the potato plants emerge above the ground the sooner they will begin to photosynthesize and mature faster accumulating high dry matter content and hence increase in specific gravity.

2.4 Nutritional contribution of potato to the human diet

Table 2 indicates the average contents of major constituents of a potato tuber. The total solids content (dry matter content) is important for quality of processed French fries and crisps which should be at least 20% majorly composed of starch constituting 60-80% of the dry matter (Ooko, 2008; Kabira and Lemaga, 2006).

Table 2: Average contents (FWB) of major constituents of a potato tuber

Constituent	Average weight (% of total tuber)	Range
Water	79.00	66.06-86.70
Dry matter	21.00	15.70-26.00
Carbohydrates	19.90	15.4-24.80
Protein	1.90	1.50-2.35
Lipid	0.08	0.05-0.10
Ash	1.00	0.07-2.00

Source: Ooko, (2008)

According to Ooko (2008), the potato is a moderately good source of iron and phosphorus comprising of 2.5-10 mg in 100 g of potato. Almost 200 g of potatoes provides 10% of phosphorus and iron as % RDA. The iron and zinc do participate in metabolic functions and also form constituents of enzymes, hormones and vitamins (Bowman and Russel, 2001). The potato is known to have high nutritive value and supplies considerable amounts of energy, minerals and vitamins (Woolfe, 1987; Abong' et al., 2009). A single, medium-sized potato weighing 200 g fresh weight can provide about 26% of the US dietary reference intake (DRI) of Cu, 17 to 18% of the DRI of K, P and Fe and between 5 and 13% of the DRI of Zn, Mg and Mn (White et al., 2009). Potatoes are generally not rich in Ca (Karenlampi and White, 2009).

Table 3: Mineral composition of the potato tuber on dry matter basis in mg/100g

Mineral	Approximate normal range
Calcium	30-90
Copper	0.4-1
Iron	2.5-10
Magnesium	60-140
Manganese	0.5-9
Phosphorus	150-300
Potassium	2820
Sodium	20-300
Zinc	1.8

Source: Burton, 1989

Iron containing chemicals in the potato react with oxygen in the air to cause browning of the peeled potato (similar to rusting iron objects) through oxidation and this can be prevented by the availability of Vitamin C in the potato tuber as an antioxidant (Visakh et al., 2013).

Phosphorus is one mineral that performs a number of important functions: It combines with calcium to form a relatively insoluble compound calcium phosphate, which gives strength and rigidity to human beings' bones and teeth (Bowman and Russel, 2001). Phosphorus is needed not only for the growth of skeleton but also for its maintenance. The utilization of many nutrients that enter the human body involves the formation and degradation of phosphorus containing compounds (Bowman and Russel, 2001). The phosphorus-containing lipo-protein facilitates the transport of fats in the circulation. A series of phosphorus compounds are formed in the utilization of carbohydrates in the body. It is vital to the fundamental process of metabolism in the body. Phosphorus is a constituent of the nucleoproteins, the substances that control heredity (Visakh et al., 2013).

Potato plants acquire mineral elements primarily from the soil through their roots as the low-transpiring tuber receives minerals and other nutrients primarily through redistribution from above-ground tissues via phloem (Woolfe, 1987). Thus phosphorus, iron and zinc just like other minerals content of potatoes vary with variety, cultural practices, soil type, growth location as well as variability between potatoes grown under identical conditions (Visakh et al., 2013).

2.5 Effect of physico-chemical properties of ware potatoes on the quality of French fries and crisps

The dry matter content partly determines the texture and oiliness of French fries and crisps (Kabira and Lemaga, 2003) and hence determining the customer preference, in that if it is too high, then the products will be too hard and dry but when the dry matter is too low, then the products will be too soft or too wet forcing the customers to dislike them (Abong' et al., 2011). Potatoes with dry matter content of 20-24% are ideal for processing into French fries and crisps (Kabira and Lemaga, 2003). Tubers of high dry matter content are known to produce fries of high yield that absorb less oil and have good nutritive value (Smith, 1975).

The specific gravity determines the quality of potato products just like dry matter content such that the potato with specific gravity of less than 1.070 is not suitable as it tends to absorb too much oil giving a poor soggy texture in the French fries and crisps (Abong' et al., 2011).

Phosphorus tends to increase starch synthesis and it also hastens maturity and the higher the starch content the better the quality of processed potato products such as French fries and crisps, Ekin , (2011).Phosphorus deficiency causes potato plants to typically produce tubers with lower specific gravity compared to those with adequate phosphorus nutrition (Woolfe, 1987). The phosphorus/nitrogen (P/N) balance is also important and to a degree, adequate phosphorus can help counter low specific gravity associated with high N levels (Visakh et al., 2013). Phosphorus content in the potato tubers is influenced mainly by growth locality due to mineral content in the soil, cultivation practices and sampling procedures but is unaffected by nitrogen fertilization. Tuber sugar content is important because of its influence on fried product color. When tubers are fried, sugars combine with amino acids and reducing sugars to form the dark color and flavor associated with "burned" food, (Visakh et al., 2013). The reducing sugars (glucose and fructose) create the most serious problems during frying because they are chemically reactive, (Visakh et al., 2013). Sucrose contributes little to dark color development but is still important because it is the substrate for creating more reducing sugars under the right environmental and physiological conditions. The reducing sugar content influences the color of the final-fried product and hence its acceptability. For French fries and crisps, tubers sugar levels >0.5% and >0.25% respectively on fresh weight basis are not required (Kabira and Lemaga, 2006).

2.6 Potato processing in Kenya

Potato's importance in Kenya continues to rise due to the high population (40 million people), increased urbanization and uptake of processed potato products (French fries and crisps), (Abong' et al., 2009). Many potato processing industries in Kenyan urban areas have immensely increased due to the high urge for improvement in economic status, (Abong' et al., 2009). These have thus necessitated farmers to produce more high quality potato tubers for the much needed market demand.

CHAPTER THREE

3.0 EFFECT OF SOIL CHARACTERISTICS ON MINERALS CONTENT OF SELECTED KENYAN POTATO TUBER VARIETIES

3.1 Abstract

Soil minerals in different production locations exist in diverse levels which can cause variation in potato tubers minerals contents. The study was set up to evaluate the effect of soil characteristics on selected potato tuber minerals composition. The study was carried out between April 2013 and February 2014. The statistical design used was completely randomised block design (CRBD) where four growth localities (National Potato Research Centre KARI-Tigoni and three farmers in Nyandarua County: Pyhort, Kagema and Hellen) were considered as blocks. The independent factors considered were: plant localities, potato seed treatment (seeds from diffused light storage and freshly harvested tubers) and potato varieties (Kenya Mpya, Dutch Robjin, Tigoni and Cangi) while dependent factors were: soil and potato tubers minerals, soil pH, soil organic carbon and soil nitrogen. All the independent factors were analyzed using standard methods of analysis and the obtained data was analyzed using statistical analysis system (version 9).

The results showed that higher soil minerals contents caused higher potato tubers minerals contents but vice versa when soil minerals were lower except for Ca, Mn and Zn which showed negative relationships. Soil minerals differed significantly ($p \leq 0.05$) with potato production localities. Potato tuber minerals significantly ($p \leq 0.05$) differed with production localities, potato varieties and seed potato treatment. Potato minerals were thus affected by potato variety, seed storage and soil characteristics in a production locality.

DLS seed treatment should be adopted so as to produce improved nutritious potatoes for processing. Soil and potato tuber analyses should be extended to other potato growing areas in

Nyandarua County and in Kenya as a whole and this evaluation should be conducted regularly after every two years for potatoes nutritional improvement.

3.2 INTRODUCTION

The potato (*Solanum tuberosum*) is a greatly shortened and swollen part of an underground stem commonly grown as starchy tubers (Ekin, 2011). The potato crop is grown in most highland areas (1800-3000m) like Nyandarua County where it performs better in terms of yield in comparison to other staple foods such as maize (MoA, 2005). It is a short season crop maturing between three and four months and as such, it is grown twice annually and sometimes even thrice depending on the variety and weather conditions among other factors. The potatoes being rich in essential minerals provide both biological and nutritional value to human beings (Ekin, 2011).

Potatoes grow well in friable well-drained aerated and porous soils with pH close to 5.6 while containing essential nutrients in the right proportions for the following macronutrients: nitrogen, phosphorus, potassium, calcium, magnesium, sulphur and carbon and micronutrients such as: iron, manganese, zinc, copper, molybdenum, chlorine and boron(Singer and Munns, 1987). Potato requires rainfall in the range 500-700mm during the growth period of 100-150 days and it is sensitive to frost and temperature range of 15-20^{o}C according to Dent and Young (1993).

The minerals proportions in the soils vary considerably from soil to soil and from region to region (Tan, 2005) and so potatoes grown in different localities are likely to contain minerals in different proportions. Potato plants grown in poor soils can have stunted growth with reduced potato tuber production; leaf falloff occurs leading to death of the plants affecting potato quality (Singer and Munns, 1987).

According to Jackson (1958), most potatoes grow well in slightly acid soils. This is when nearly all plant nutrients are available in optimal amounts for plant growth. Acid soils are likely to be deficient in Ca, Mg and K. Strongly and very strongly acid soils make Al, Fe and Mn to exist in toxic amounts due to their increased solubility and will cause phosphates to react with these minerals to form insoluble phosphates through fixation leading to deficiency of P for the plant utilization (Jackson, 1958; Tan, 2005). The alkaline soils on the other hand make Fe, Mn, Zn and Cu to become unavailable for potatoes growth (Jackson, 1958; Tan, 2005; Kanyanjua and Agaya, 2006). Soils with adequate nutrients enable potatoes to grow well making tubers to acquire essential minerals (especially N, P and K) for human nutritional quality without artificial fertilization (MoA, 2005).

Adequate rainfall during potato development makes minerals to be easily available in the soil, (Singer and Munns, 1987). Excess rainfall in a location can cause leaching of the minerals since they tend to be washed away and some percolate further down the soil profile leading to their deficiency in the top soil thus affecting potato production and hence their tubers' nutritional condition.

Continuous cultivation of potato farms with improper crop rotation and without a fallow period can deplete the soil of important soil nutrients as is being experienced among small scale farmers in Kenya according to Recke et al., (1997) and (Kiiya et al., 2006). Proper crop rotation can help conserve soil fertility in small scale potato farms in Kenya according to Muthoni and Kabira (2010) and Kiiya et al., (2006).

Potato plants acquire mineral elements primarily from the soil through their roots as the low-transpiring tuber receives minerals and other nutrients primarily through redistribution from above-ground tissues via phloem (Woolfe, 1987). Low fertility of some soils where crops are grown and the poor uptake and translocation of some mineral elements to edible portions contribute to low mineral levels in several staple food crops like potato tubers (White and Broadley, 2009). The potato minerals can be affected by potato variety, environmental and soil conditions in a production locality and cultural practices (Ooko and Kabira, 2011; Ekin , 2011).

The potato tuber from well drained soil with optimum soil nutrients and under ambient rainfall will contain right amounts of minerals in the right proportions according to Burton (1989).

The objective of the present study was to determine the effect of soil characteristics on potato tuber mineral composition in selected potato growing areas in Nyandarua County.

3.3 MATERIALS AND METHODS

3.3.1 The study areas

The following were considered for the study: National Potato Research Centre KARI-Tigoni (a control station whose store for DLS was able to control intensity of diffused light, relative humidity and ventilation appropriately due to its more spacious store with a mesh wall) and three farmers who were: Pyhort (a farmers' group), Kagema (a farmers' group), Hellen (an individual farmer) whose store walls were wooden, Table 4. These farmers were purposively selected by respective District Agricultural Officers (DAO) based on their adequate knowledge and skills in potato production. This study was carried out between April 2013 and February 2014.The statistical design used was completely randomised block design (CRBD), where four growth localities were considered. The independent factors considered were: plant localities, potato seed treatment and varieties while dependent factors were: soil and potato tubers minerals, pH, organic carbon and total nitrogen.

Table 4: Summary of study areas

Study area	Sub County	County	Altitude (m)	Latitude (South)	Longitude (East)
Pyhort	Ol-joro-ok	Nyandarua	2672.791	0˚, 5.057 '	36˚, 17.183 '
Kagema	Ol-joro-ok	Nyandarua	2685.897	0˚, 5.122 '	36˚,16.969 '
Hellen	Kipipiri	Nyandarua			
	Githioro		2228.697	0˚, 27.719 '	36˚, 29.659 '
Tigoni KARI	Limuru	Kiambu	2131	1˚, 15 '	23˚, 46 '

According to GPS readings

All these sites are in highland areas that are suitable for high potato production.

3.3.2 Soil sampling and preparation

Random sampling method was used where individual soil samples were collected from locations that were randomly distributed across the representative portion of the field using a zigzag soil sampling method according to Carter and Gregorich (2008). The sampling was carried out manually by a hoe 0-25cm depth where fifteen soil cores were taken, bulked, mixed thoroughly and 250g packed in polythene bags. All the packed samples from each locality were taken for laboratory analysis.

Soil preparation involved air drying at 35^{o}C for a day followed by grinding and sieving with a 2mm sieve according to Tan (2005).

3.3.4 Soil analysis

Soil pH was determined in water in the ratio 1:2.5 (soil: water respectively) with ELL glass electrode pH meter according to Maclean (1965). Organic carbon was determined by calorimetric method and it was read on the spectrophotometer (Model-PU 8670, Pye Unicam Ltd, England) at 600nm according to Walinga et al. (1989). Total nitrogen was determined by Kjeldahl method according to AOAC (1980). Exchangeable cations (Magnesium, sodium, potassium, manganese, phosphorus and calcium) were determined according to Mehlich Double Acid method (Mehlich, 1959) as outlined in Walinga (1989). Iron, zinc and copper were determined by first being extracted in the oven-dry soil samples in 1:10 ratio (w/v) with 0.1M HCL and then using atomic absorption spectrophotometer (Model- AAnalyst 100, Perkin Elmer, USA) as outlined in Walinga (1989) and AOAC (1980).

3.3.5 Collection of data on amount of rainfall

Rainfall data was obtained from the Kenya Meteorological Department offices in the various districts where the study areas mentioned earlier are located and recorded in mm as shown in Table 5.

Table 5: Total rainfall (mm) in sub-Counties of study areas

MONTH 2013	Kagema, Pyhort	Hellen	Tigoni-KARI
March	124.6	107	49.1
April	295.1	227	690.1
May	106.7	189	375.2
June	98.5	52.5	521.3
July	214.1	91.2	26.7
August	229.4	108	100.3
September	66.8	72	113.2

Source: Kenya Meteorological Department, 2013

The rainfall in the study areas during the potato growth period of 100-150 days was adequate since they all had rainfall in the range 500-900mm that is sufficient according to Dent and Young (1993); Muthoni and Kabira (2010).

3.3.6 Potato tuber analysis

Sample preparation

Four potato plant localities; The National Potato Research Centre KARI-Tigoni (considered as a control station), Pyhort-a farmers'group, Kagema-a farmers'group, Hellen-an individual farmer were considered but others were left out in this study due to their inconsistency in the potato varieties as summarized in Table 4.Ten potato tubers about >35mm long from each variety, plant location and seed treatment were first washed, rinsed in deionized water and briefly air-dried. Three whole peeled tubers were sliced, oven dried and mixed before analysis.

Determination of potato tubers' Ca, Mg, Cu, Zn, Mn, Fe, P and K

The above prepared potato samples were first oxidized by hydrogen peroxide (30%) at a relatively low temperature (100°C). After decomposition of excess peroxide and evaporation of water the digestion was completed by concentrated sulphuric acid at elevated temperature (330°C) and selenium catalyst. Then Ca, Mg, Cu, Zn, Mn and Fe were determined using atomic absorption spectrometer (Model- AAnalyst 100, Perkin Elmer, USA); K was determined using a flame photometer (Corning 400, UK, Model M400) and P was determined calorimetrically on VIS/NIR spectrophotometer (Model-PU 8670, Pye Unicam Ltd, England) according to Walinga et al. (1989); AOAC (1980).

3.3.7 Statistical analysis

Analysis of variance (ANOVA) and least significant difference test for the soil and potato tubers minerals were conducted using Statistical Analysis System (SAS version 9). Pearson correlation analysis was also performed to determine linear relationships where necessary. Differences $p \leq 0.05$ were considered significant.

3.4 RESULTS AND DISCUSSION

3.4.1 SOIL ASSESSMENT

The soil pH in the study areas ranged from 4.0 at Pyhort to 5.2 at Kagema as outlined in Table 6. All the locations had moderately acid soils except for KARI- Tigoni and Pyhort which had strongly and very strongly acid soils respectively according to classification by Jackson (1956).

This could be due to acidic parent rock (Kiiya et al., 2006; Muthoni and Kabira, 2010. Soil pH values were significantly (p≤0.05) different in potato plant localities due to having originated from different parent rocks respectively (Recke et al., 1997). The optimum pH is >5.6 to 6.6. This high acidity in the affected soils may mean deficiencies in essential minerals like P, Ca, Mg and K which have negative effect on potatoes growth and hence tuber quality (Jackson, 1956; Tan, 2005).

Table 6: Soil characterization in potato production locations in terms of pH values, % Organic Carbon and % Total Nitrogen

Location	**pH**	**Soil value**	**%org. C**	**Adequacy**	**%N**	**Adequacy**
Pyhort	4.0±0g	V. strongly acid	2.69±0.01j	Adequate	0.27±0.01t	Adequate
Kagema	5.2±0.1c	Moderately acid	4.23±0.02h	Adequate	0.42±0.0r	Adequate
Hellen	5.04±0d	Moderately acid	1.79±0.01n	Moderate	0.18±0.02w	Low
TigoniKARI	4.57±0.01f	Strongly acid	1.92±0.1m	Moderate	0.19±0.01v	Low

Results are means of two determinations. Means with the same letter in the same column are not significantly (p>0.05) different. Key: V is very, Org. C is organic carbon and N is nitrogen.

Soil organic carbon in the study sites significantly (p≤0.05) differed with study area ranging from 1.79% at Hellen to 4.23% at Kagema. Pyhort and Kagema had optimum levels of organic carbon within the range 2.66 and 5.32 % except at Hellen and KARI according to Walingo et al., (1985).

Soil nitrogen in the study areas significantly (p≤0.05) differed ranging from 0.18% at Hellen to 0.42% at Kagema. Total nitrogen was low at KARI-Tigon and Hellen being <0.2% (Table 6) due to failure to incorporate legumes in the rotation cycle in potato farms affecting potatoes growth and tuber quality (Muthoni and Kabira, 2010).

Soil phosphorus ranged from 10ppm at Hellen to 20ppm at Pyhort/Tigoni-KARI as shown in Table 7. The phosphorus being a macronutrient, its content in the soils was generally low. This was affected by high soil pH (Table 8) found in the locations due to the soil parent rock differences (Recke et al., 1997; Muthoni and Kabira, 2010).

Soil iron ranged from 81.4 ppm at Tigoni-KARI to 144 ppm at Pyhort from Table 7. The soil iron significantly ($p \leq 0.05$) differed in all the locations due to differences in the parent rock but it was adequate (>10ppm) for the potatoes growth (Recke et al, 1997 and Walinga et al., 1985).

Calcium (Ca) content in the soil varied from 2.1me at Pyhort to 5.7me at Kagema. Soil Ca differed ($p \leq 0.05$) significantly in all the locations due to differences in the parent rock (Singer and Munns, 1987). However soil Ca content being in optimum range (2.0-15.0 me) was adequate for the potatoes growth in all the locations (Recke et al, 1997 and Walinga et al., 1985).

Table 7: Effect of potato production location on soil minerals

LOCALITY	P (ppm)	Fe (ppm)	Zn (ppm)	K (me)	Ca (me)
Pyhort	20±0.03d	144±0.01b	5.33±0.01h	0.68±0.01d	2.1±0.02f
Kagema	15±0.01e	127±0.01c	31.3±0.22b	0.88±0.03b	5.7±0.01a
Hellen	10±0.06f	97.1±0.14d	7.44±0.02d	0.9±0.02b	2.9±0.07d
Tigoni KARI	20±0.08d	81.4±0.14f	28.5±0.04c	1.16±0.02a	2.9±0.01d

Results are means of two determinations with ± standard deviation. Means with the same letter in the same column are not significantly ($p > 0.05$) different

Table 7: Cont.

LOCALITY	Mg (me)	Mn (me)	Cu (ppm)	Na (me)
Pyhort	2.83±0.01d	0.7±0.01e	1.97±0.01d	0.22±0.01e
Kagema	3.61±0.02a	1.17±0.01a	1.72±0.01e	0.42±0.01b
Hellen	3.37±0.01b	0.9±0.02c	11.7±0.07a	0.26±0.01d
Tigoni KARI	0.9±0.07e	0.75±0.01d	4±0.02b	0.24±0.01e

Results are means of two determinations with ± standard deviation. Means with the same letter in the same column are not significantly (p>0.05) different

Table 7 gives soil magnesium content ranging from 0.9 me lowest at Tigoni-KARI to 3.61 me highest at Kagema. It significantly ($p \leq 0.05$) differed in all the locations and it occurred in high / toxic levels at Kagema and Hellen (>3.0me) due to parent rock (Kanyanjua and Agaya, 2006; Recke et al, 1997).

Soil manganese ranged from 0.7 me at Pyhort to 1.17 me at Kagema and it was adequate since it was >0.1me; soil copper ranged from 1.72 ppm at Kagema to 11.7 ppm at Hellen was adequate (>1.0ppm); soil sodium ranged from 0.22 me at Pyhort to 0.42 me at Kagema and was optimum (0-2.0 me); soil zinc varied from 5.33ppm at Pyhort to 31.3ppm at Kagema was optimum (>5.0ppm); soil potassium varied from 0.68me at Pyhort to 1.16me at Tigoni-KARI was in the optimum range (0.24-1.5me) as shown in Table 7. All these minerals significantly ($p \leq 0.05$) differed in all the locations due to differences in the parent rock (Okalebo, 1985; Kanyanjua and Agaya, 2006 and Recke et al, 1997).

There was positive significant ($P<0.05$) correlation ($r= 0.17$) between pH and phosphorus. There was also positive significant ($P<0.05$) correlation ($r= 0.32$) between pH and potassium (Table 8). The positive correlations in both cases demonstrated that pH affects minerals contents.

Table 8: Pearson correlation coefficient (r) between pH and levels of phosphorus; pH and Potassium

Parameters	pH	Phosphorus	Potassium
pH	1.00	0.17[a]	0.32[a]
Phosphorus	0.17[a]	1.00	
Potassium	0.32[a]		1.00

[a]Significant correlation coefficient (P≤0.05) (N=32)

3.4.2 RESULTS AND DISCUSSION ON POTATO TUBERS MINERALS

Phosphorus (P) content in potato tubers ranged from 315mg/100g in DLS Kenya Mpya seed in Kagema to 495mg/100g in fresh planted Cangi seed in Pyhort. Phosphorus significantly differed (p≤0.05) with plant localities, potato varieties and treatment of the seed potato (fresh or DLS seed) and with interactions among plant locality, variety and seed treatment as indicated in Table 9.

Table 9: Effect of plant locality and potato seed treatment on mineral contents (mg/100g DWB) for four potato varieties

Locality	Variety	Treat	P	Fe	Zn	K	Ca
Hellen	Cangi	Fresh	385±0.01g	27.70±0.11a	1.91±0.07p	1825±0.02j	66.0±0.01b
		Stored	385±0.01g	27.70±0.11a	1.91±0.07p	1825±0.02j	66.0±0.01b
	Dutch	Fresh	445±0.01d	7.18±0.11s	1.85±0.07q	1445±0.01r	141.9±0.00a
		Stored	465±0.01b	8.12±0.11n	2.08±0.07h	1296±0.01w	6.6±0.00p
	KMpya	Fresh	325±0.01q	7.04±0.11t	1.47±0.07za	1297±0.01v	1.32±0.00s
		Stored	355±0.01l	6.73±0.11w	1.54±0.07x	1460±0.01q	7.26±0.00n
	Tigoni	Fresh	315±0.01t	12.22±0.11f	1.70±0.56u	2660±0.07a	19.8±0.00e
		Stored	335±0.01q	13.93±0.11e	2.23±0.64e	2075±0.04f	13.2±0.00h
Kagema	Cangi	Fresh	355±0.01l	8.91±1.41m	2.00±0.14n	1750±0.01k	13.5±0.00g
		Stored	355±0.01l	8.91±1.41m	2.31±0.14n	1750±0.01k	13.5±0.00g
	Dutch	Fresh	325±0.01r	6.00±0.71yt	1.44±0.14za	1605±0.01p	6.6±0.00p
		Stored	455±0.01c	16.18±0.71c	5.19±0.71b	2250±0.01d	13.2±0.00h
	KMpya	Fresh	325±0.01r	6.55±0.71wx	1.58±0.07w	2335±0.01c	1.98±0.00r
		Stored	315±0.01t	7.45±0.71p	1.45±0.14zb	1655±0.04m	6.60±0.00p
	Tigoni	Fresh	340±0.00p	9.16±0.71k	1.63±0.07v	2035±0.01g	12.50±0.00j
		Stored	375±0.01h	14.02±0.71d	2.17±0.14g	1875±0.01i	6.60±0.00p
Pyhort	Cangi	Fresh	495±0.01a	9.74±0.71i	2.08±0.07h	214±0.01za	6.30±0.00q
		Stored	495±0.01a	9.74±0.71i	2.08±0.07h	214±0.01za	6.3±0.00q
	Dutch	Fresh	375±0.01i	16.45±0.71b	2.71±0.14c	1445±0.01r	19.5±0.00f
		Stored	385±0.01g	16.22±0.71bc	6.49±0.07a	1425±0.01s	33.3±0.00c
	KMpya	Fresh	345±0.01n	10.73±0.71h	1.50±0.14y	1325±0.01t	1.3±0.00s
		Stored	395±0.01e	9.52±0.71j	1.81±0.07s	1625±0.02n	8.2±0.00k
	Tigoni	Fresh	385±0.01g	7.47±1.41q	1.81±0.21xy	1305±0.01u	2.0±0.00r
		Stored	365±0.01k	7.31±0.71r	1.76±0.07t	1295±0.01x	6.9±0.00m
TigoniKARI	Cangi	Fresh	395±0.01e	6.95±0.71u	2.24±0.07f	253±0.01y	13.5±0.00g
		Stored	395±0.01e	6.95±0.71u	2.24±0.07f	253±0.01y	13.5±0.00g
	Dutch	Fresh	375±0.01i	6.05±0.71y	2.37±0.07d	224±0.00z	13.2±0.00h
		Stored	370±0.00j	6.86±0.71v	1.94±0.07m	1885±0.01h	13.2±0.00h
	KMpya	Fresh	335±0.01q	9.34±0.71j	1.86±0.07r	203±0.01zb	1.3±0.00s
		Stored	350±0.00m	11.09±0.71g	1.94±0.14k	2425±0.01b	6.6±0.00p
	Tigoni	Fresh	355±0.01l	5.33±0.71z	1.96±0.04i	2245±0.01e	25.7±0.00d
		Stored	390±0.00f	6.50±0.71x	2.13±0.21j	187±0.01zc	12.9±0.00i

Results are means of two determinations with ± standard deviation. Means with the same letter in the same column are not significantly ($p>0.05$) different

Table 9: Cont.

Locality	Variety	Treat	Mg	Mn	Cu
Hellen	Cangi	Fresh	135±0.01c	4.11±0.14d	0.75±0.01c
		Stored	135±0.01c	4.11±0.14d	0.75±0.01c
	Dutch	Fresh	125±0.01d	2.38±0.07q	0.12±0.01zc
		Stored	800±0.00a	2.60±0.07n	0.67±0.14d
	KMpya	Fresh	75±0.01m	1.98±0.07v	0.60±0.01h
		Stored	61.5±0.00p	1.90±0.07w	0.60±0.01g
	Tigoni	Fresh	70±0.00n	2.58±0.07k	0.54±0.01j
		Stored	85±0.01j	2.68±0.07f	0.65±0.00e
Kagema	Cangi	Fresh	37.5±0.00t	2.47±0.14p	0.46±0.07p
		Stored	37.5±0.00t	2.47±0.14p	0.46±0.07p
	Dutch	Fresh	90±0.00i	1.56±0.35x	0.13±0.01zb
		Stored	85±0.01j	2.06±0.07v	0.81±0.01a
	KMpya	Fresh	95±0.01h	1.11±0.13y	0.44±0.07q
		Stored	470±0.54b	2.22±0.07u	0.18±0.01z
	Tigoni	Fresh	120±0.01e	2.25±0.07t	0.37±0.01u
		Stored	125±0.01d	2.22±0.07u	0.78±0.01b
Pyhort	Cangi	Fresh	85±0.01j	3.07±0.00f	0.55±0.01i
		Stored	85±0.01j	3.07±0.14f	0.55±0.01i
	Dutch	Fresh	80.5±0.01jk	2.36±0.07r	0.65±0.01f
		Stored	95±0.01h	2.62±0.07i	0.14±0.07za
	KMpya	Fresh	38±0.01s	2.12±0.07ua	0.53±0.02k
		Stored	80±0.00k	2.66±0.07g	0.37±0.01v
	Tigoni	Fresh	60±0.00r	2.30±0.14s	0.36±0.04w
		Stored	69.5±0.00p	2.62±0.07j	0.48±0.01m
TigoniKARI	Cangi	Fresh	100±0.01g	2.51±0.21n	0.45±0.71q
		Stored	100±0.01g	2.51±0.56n	0.40±0.00s
	Dutch	Fresh	120±0.01e	3.84±0.07e	0.42±0.01r
		Stored	90±0.00i	2.49±0.14na	0.3±02.01x
	KMpya	Fresh	80±0.00k	7.70±0.07b	0.48±0.07n
		Stored	90±0.00i	8.37±0.14a	0.50±0.01mn
	Tigoni	Fresh	80±0.00k	6.26±0.42c	0.38±0.01t
		Stored	101±0.00f	2.63±0.14h	0.30±0.01y

Results are means of two determinations with ± standard deviation. Means with the same letter in the same column are not significantly (p>0.05) different

Order of P level in a decreasing manner according to location was as follows: Pyhort, Hellen, Tigoni-KARI and lastly Kagema. Potato varieties differed in P content due to their differences in their genetic make-up and soil in agreement with Tan (2005).

Iron (Fe) content in potato tubers ranged from 5.33mg/100gDWB obtained from fresh planted Tigoni seed in Tigoni KARI to 27.7mg/100gDWB obtained from fresh planted Cangi seed in Hellen. Fe content significantly ($p \leq 0.05$) differed with plant localities, potato varieties and treatment of the seed potato (fresh or eight-month DLS seed). Interactions among plant locality, variety and seed treatment had significant ($p \leq 0.05$) effect on Fe content. Although Fe was within the range given by Burton (1989), it was generally higher in tubers from DLS seed treatment than in fresh seed. 17-18% of daily Fe requirements can be provided by a fresh 200g potato according to White et al (2009).

Zn content in potato tubers ranged from 1.44mg/100gDWB obtained from planted fresh Dutch Robjin seed in Kagema to 6.49mg/100gDWB obtained from planted DLS Dutch Robjin seed in Pyhort. Zn content significantly ($p \leq 0.05$) differed with plant localities, potato varieties and treatment of the seed potato (fresh or eight-month DLS seed). Interactions among plant locality, variety and seed treatment had significant ($p \leq 0.05$) effect on Zn content. 5-13% of daily Zn requirements can be provided by a fresh 200g potato (White et al., 2009).

K content in potato tubers ranged from 1295mg/100gDWB obtained from planted DLS Tigoni seed in Pyhort to 2660mg/100gDWB obtained from planted fresh Cangi seed in Tigoni KARI. In a decreasing order, Tigoni KARI had the highest, then Kagema, Hellen and lowest at Pyhort. 3500mg/day is required by an adult of whom 26.1% can be obtained from potatoes (Ekin, 2011).

Ca content in potato tubers ranged from 1.32mg/100gDWB from planted fresh Kenya Mpya seed in Pyhort, Hellen and Tigoni KARI to 66.0mg/100gDWB obtained from DLS/fresh Cangi seeds in Hellen. All the potato tuber varieties and seed treatment had lower Ca levels in all the production locations except Cangi from DLS/Fresh seeds at Hellen, Dutch Robjin from fresh seed at Hellen, and Dutch Robjin from DLS seed at Pyhort according to Burton (1989), Table 3. DRI for Ca in an adult is 1000mg of which high Ca quality potato Cangi tubers can contribute 66mg/100g DWB (WHO, 2004).

Mg content in potato tubers ranged from 38mg/100gDWB obtained from planted fresh/DLS Cangi seed in Kagema to 800mg/100gDWB obtained from planted DLS Dutch Robjin seed in Hellen. The variation in tubers magnesium content was statistically significant ($p \leq 0.05$).

Mn content in potato tubers ranged from 1.112mg/100gDWB obtained from planted fresh Kenya Mpya seed in Kagema to 8.37mg/100gDWB obtained from planted DLS Kenya Mpya seed in Tigoni KARI and was within the range given by Burton (1989), Table 3. The variation in tubers manganese content was statistically significant ($p \leq 0.05$) when basing on DLS seed storage, plant location, potato variety and interactions among themselves. 5-13% of daily Mn requirements can be provided by a fresh 200g potato (White et al, 2009).

Copper (Cu) content in potato tubers ranged from 0.118mg/100gDWB obtained from planted fresh Dutch Robjin seed in Hellen to 1.355mg/100gDWB obtained from planted DLS Dutch Robjin seed in Pyhort which is within Burton’s range as shown in Burton (1989). Daily copper intake for men and women is 1.2mg of which 0.34-0.55mg can be acquired from standard potato tubers (WHO, 2004) and thus the above Dutch Robjin can contribute too much to diet.

Generally the minerals potassium, Calcium, Magnesium, Manganese and Copper contents significantly (p≤0.05) differed with plant sites, potato varieties and potato seed storage (fresh or eight-month DLS seed) and their interactions. These tuber minerals varied according to localities in the increasing order as follows respectively: Pyhort, Hellen, Kagema, Tigoni-KARI; Pyhort/ Kagema, Tigoni-KARI, Hellen; Pyhort, Tigoni-KARI, Kagema, Hellen; Kagema, Pyhort, Hellen, Tigoni-KARI; Tigoni-KARI, Kagema, Hellen then Pyhort.

Regularly potato tubers obtained from planted DLS seeds had higher minerals content as compared with potatoes from planted fresh seeds. The potato minerals were affected by potato variety, environmental and soil conditions in a production locality and cultural practices including diffused light storage (DLS) seed treatment in agreement with Tan (2005); Abong' et al. (2011); Ekin (2011).

Table 10: Pearson correlation coefficient (r) between Soil P and Tuber P; Soil K and tuber K

Parameters	Soil P	Tuber P	Soil K	Tuber K
Soil P	1.00	0.13[a]		
Tuber P	0.13[a]	1.00		
Soil K			1.00	0.53[a]
Tuber K			0.53[a]	1.00

[a]Significant correlation coefficient (P≤0.05) (N=64)

There was significant (P≤0.05) correlation (r= 0.13) between soil phosphorus and tubers phosphorus could because of other prevailing factors such as soil acidity but there existed a higher significant correlation (r= 0.53) between soil K and tuber K (Table 10).The positive correlations in both cases implied direct relationship between soil minerals levels and tubers minerals.

There was a positive significant ($P \leq 0.05$) correlation ($r = 0.10$) between soil iron and potato tubers iron contents implying a direct relationship; there was a lower negative but not significant ($P > 0.05$) correlation ($r = -0.03$) between soil zinc and potato tubers zinc contents implying a weak inverse relationship (Table 11).

Table 11: Pearson correlation coefficient (r) between Soil Fe and Tuber Fe; Soil Zn and tuber Zn

Parameters	Soil Fe	Tuber Fe	Soil Zn	Tuber Zn
Soil Fe	1.00	0.10[a]		
Tuber Fe	0.10[a]	1.00		
Soil Zn			1.00	-0.03[b]
Tuber Zn			-0.03[b]	1.00

[a]Significant correlation coefficient ($P \leq 0.05$) (N=64) [b]Not significant correlation coefficient ($P > 0.5$)

Table 12 shows existence of a negative not significant ($P > 0.05$) correlation ($r = -0.13$) between soil calcium and potato tubers calcium contents, depicting an inverse relationship; magnesium in potato tubers positively correlated ($r = 0.16$) significantly ($P \leq 0.05$) with soil magnesium showing a direct association.

Table 12: Pearson correlation coefficient (r) between Soil Ca and Tuber Ca; Soil Mg and tuber Mg

Parameters	Soil Ca	Tuber Ca	Soil Mg	Tuber Mg
Soil Ca	1.00	-0.13[b]		
Tuber Ca	-0.13[b]	1.00		
Soil Mg			1.00	0.16[a]
Tuber Mg			0.16[a]	1.00

[a]Significant correlation coefficient ($P \leq 0.05$) (N=64) [b] Not significant correlation coefficient

Soil and potato tubers manganese contents significantly ($P \leq 0.05$) correlated (r=0.13) giving a direct association; there was positive significant correlation (r=0.56) between soil and tubers copper contents showing a strong direct relationship, Table 13.

Table 13: Pearson correlation coefficient (r) between Soil Mn and Tuber Mn; Soil Cu and tuber Cu

Parameters	Soil Mn	Tuber Mn	Soil Cu	Tuber Cu
Soil Mn	1.00	0.13[a]		
Tuber Mn	0.13[a]	1.00		
Soil Cu			1.00	0.53[a]
Tuber Cu			0.53[a]	1.00

[a]Significant correlation coefficient ($P \leq 0.05$) (N=64)

3.7 CONCLUSION AND RECOMMENDATION

Soils from the different locations significantly differ in minerals and pH levels. The potato minerals are affected by potato variety, soil characteristics in all production localities and the seed treatment. Higher soil minerals contents lead to higher potato tubers minerals contents except for Ca, Mn and Zn. This implies that potato minerals can be affected by soil characteristics/ level of minerals in a plant location.

Soil and potato tuber analyses should be extended to other potato growing areas in Nyandarua County and in Kenya as a whole and this evaluation should be conducted regularly after every two years.

CHAPTER FOUR

4.0 EFFECT OF DIFFUSED LIGHT SEED POTATO STORAGE AND PRODUCTION LOCATION ON THE PHYSICO-CHEMICAL PROPERTIES OF SELECTED KENYAN POTATO VARIETIES

4.1 Abstract

The study was conducted to evaluate the effect of diffused light storage (DLS) seed potato treatment and production on the physico-chemical properties of Kenyan potato varieties for their suitability in processing into French fries and crisps. The statistical design used was completely randomised block design (CRBD) where four growth localities (National Potato Research Centre KARI-Tigoni and three farmers in Nyandarua County: Pyhort, Kagema and Hellen) were considered as blocks. The independent factors considered were: plant localities, potato seed treatment (seeds from diffused light storage and freshly harvested tubers) and potato varieties (Kenya Mpya, Dutch Robjin, Tigoni and Cangi) while dependent factors were: potato tubers specific gravity, dry matter content, vitamin C content and reducing sugars content. All the independent factors were analyzed using standard methods of analysis and the obtained data was analyzed using statistical analysis system (version 9).

The results were as follows: There were negative significant correlations between potato tubers dry matter content and soil pH and phosphorus; positive significant correlation between soil pH and potato tubers dry matter and vitamin C contents show that plant locality affects the quality of ware potatoes. The plant locality can affect the quality of ware potatoes. DLS seed treatment produces tubers of better physico-chemical properties (having the recommendable higher dry matter, specific gravity, vitamin C and lower total reducing sugars) compared to those from fresh potato tuber seeds. The parameters significantly ($p \leq 0.05$) differed with plant localities, varieties

and with seed potato storage. There were significant interactions with locality, variety and seed treatment.

DLS seed potato treatment should be adopted by farmers so as to produce better quality ware potatoes for potato processing industry. Further research is recommendable for determination of post harvest quality of ware potatoes from DLS seed treatment on storage.

4.2 INTRODUCTION

The potato which's the fourth world largest crop in terms of fresh produce after rice, wheat and maize, is ranked in Kenya as the second most important crop after maize when basing on food security and utilization (Kabira and Lemaga, 2005; MoA, 2005). Although potato growing area has been increasing steadily over the years due to increased number of small scale farmers, on farm yields have been low on average (<10 tonnes/ ha) compared to 40-60 tonnes/ ha achieved under optimal farming conditions (Scott et al., 2013). This is due to lack of affordable clean potato seeds which often force farmers to plant non-sprouted or poorly-sprouted freshly harvested seeds which are low yielding (Kabira et al., 2013; Muthoni et al., 2013). Currently, selected farmers in Nyandarua County are being encouraged by KARI-Tigoni to plant well-sprouted potato seed which has led to early crop establishment, and consequently higher yields. This has been achieved through farmers' on-farm storage structures (ordinary wooden stores with iron- sheet roofs, mud-walled with iron roofs or wooden structures having a wire-mesh around their walls with iron roofs) where their potato seeds are exposed to diffused light with good ventilation for 8 months, as introduced by the National Potato Center (KARI), Tigoni (Kabira et al., 2013; Kipkoech et al., 2012; Muthoni et al., 2014). Such stores use natural indirect light with good ventilation to control excessive sprouting and to produce sprouts which are short, stout, green colored and with higher vigor for growth (Gachango et al., 2008). These conditions allow the potato seeds to break their dormancy naturally though after a long period of time (eight months) but when planted grow and establish faster. This is so because the faster the potato plants emerge above the ground the sooner they will begin to photosynthesize and the faster they will mature and accumulate high dry matter content and hence increase in specific gravity (Talburt and Smith, 1967). However, physico-chemical properties of the tubers from DLS treated seed have not been evaluated to determine their suitability for French fries and crisps processing. Physico-chemical properties of potato tubers such as specific gravity, dry matter, minerals, reducing sugars and vitamin C content determine the quality of processed potato products such as French fries and crisps (Kabira and Lemaga, 2003). The potato tubers with low specific gravity of less than 1.070, less than 20% dry matter content and reducing sugars of >0.5% and >0.25% are not suitable for processing into French fries and crisps respectively (Kabira and Lemaga, 2003). Potato tubers have high concentrations of promoter substances such as vitamin C (ascorbate) which can be 3-45% content on fresh weight basis, and tend to enhance the nutritional quality of potato tubers by preventing scurvy among consumers (White et al., 2009; Burton, 1989).

Phosphorus deficiency causes potato plants to typically produce tubers with lower specific gravity compared to those with adequate phosphorus nutrition (Woolfe, 1987).The tubers from such production sites have not been analyzed to determine their physico-chemical properties for their processing suitability into French fries and crisps.

This study was therefore conducted to evaluate the effect of diffused light storage (DLS) seed potato treatment and production location on the physico-chemical properties (specific gravity, dry matter, reducing sugars and vitamin C) of selected Kenyan ware potato varieties.

4.3 MATERIALS AND METHODS

4.3.1 Experimental design

The experimental design used was completely randomised block design (CRBD) where four growth localities: National Potato Research Centre (KARI) – Tigoni of Kiambu County, Pyhort-a farmers'group in Ol-joro-ok of Nyandarua County, Kagema-a farmers'group in Ol-joro-ok of Nyandarua County and Hellen-an individual farmer in Kipipiri-Githioro of Nyandarua County were considered as blocks. The independent factors considered were: varieties, DLS seed treatment and production plant localities while dependent factors were: specific gravity, dry matter, vitamin C and reducing sugars.

4.3.2 Potato for physico-chemical evaluation

Diffused light stored (DLS) potato seeds having been stored in farmers own stores for eight months at ambient temperatures under natural ventilation and freshly harvested seed from four potato varieties (Kenya Mpya, Tigoni, Cangi and Dutch Robjin), known to be suitable for processing into potato crisps and French fries, were grown under standard cultural conditions (Lung'aho and Kabira, 1999) at the National Potato Research Centre-Tigoni (KARI) which served as the control and at three farms in Nyandarua County (Hellen, Kagema and Pyhort) between March and April 2013. Harvesting of the tubers was done two weeks after dehaulming the mature potatoes in July/August 2013 (to allow the tubers skin to suberize) followed by sorting right sizes (≥40mm) for ware (Kabira and Lemaga, 2006). They were packed in net bags and then transported to KARI-Tigoni.

They were then cured for two weeks under ambient air conditions of 17-22^{o}C at 84-92% RH in a naturally ventilated ware potato store to allow healing of the potato tubers' wounds and bruises that occur during harvesting and handling. This relative humidity ensured minimal water loss from tubers. There was adequate natural airflow around tubers for ventilation.

After curing, the potato tubers were evaluated for specific gravity in the Food Science Laboratories at the Kenya Agricultural Research Station (KARI) in Tigoni and for dry matter, total reducing sugars and vitamin C at the College of Agriculture and Veterinary Sciences of the University of Nairobi.

4.3.3 Determination of specific gravity of raw tubers

The specific gravity was determined by weight under water method as described by Kabira and Lemaga (2006).

4.3.4 Determination of dry matter content

The dry matter content of raw tubers was determined by oven drying as described in AOAC (1980).

4.3.5 Determination of total reducing sugars contents

Total sugars were determined on duplicate samples by Luff-Schoorl method number 4 of the International Federation of Fruit Juice Producers (1985). Tubers having total reducing sugars content of $\leq 0.25\%$ were meant to be ideal for crisps and $\leq 0.5\%$ for French fries processing.

4.3.6 Determination of vitamin C

The vitamin C content was determined by AOAC method as described by International Federation of Fruit Juice Producers number 44 (1972).

4.3.7 Data analysis

Analysis of variance (ANOVA) and least significant difference test for specific gravity, dry matter content, vitamin C content, total sugars content in potato tubers were conducted using the Statistical Analysis System (SAS) version 9. The means separated by least significant differences ≤ 0.05 were considered significant. Correlations were also preformed between soil phosphorus and tubers dry matter contents.

4.4 RESULTS AND DISCUSSION

The specific gravity ranged from 1.067 from fresh planted Dutch Robjin seed in Pyhort to 1.092 from eight-month DLS Kenya Mpya seed in Kagema, Table 11. All the varieties from the plant localities and seed treatment had their specific gravity ≥ 0.070 being suitable for processing into French fries and crisps except Tigoni from fresh seed at Hellen, Kagema, Pyhort and Dutch Robjin from fresh seeds at Pyhort (Ooko and Kabira, 2011). The specific gravity determines the quality of potato products just like dry matter content such that the potato with specific gravity of more than 1.080 is suitable while less than 1.070 is not suitable as it tends to absorb too much oil giving a poor texture in the products (Abong' et al., 2011). Specific gravity significantly differed ($p \leq 0.05$) with plant localities, varieties and treatment of the seed potato (fresh or eight-month DLS seed. Interactions among plant locality, variety and seed treatment had significant ($p \leq 0.05$) effect on specific gravity

Dry matter content in potato tubers ranged from 19.63% from fresh planted Dutch Robjin seed in Pyhort to 27.15% from eight-month DLS Kenya Mpya seed of Kagema (Table 14).

Table 14: : Effect of plant locality and potato seed treatment on specific gravity, dry matter %, vitamin C in mg/100gFWB and total sugars % contents for four potato varieties

Locality	Variety	treatment	Specific gravity	Dry matter%	Vitamin Cmg/100gFWB	Total reducing sugars%
Hellen	Cangi	fresh	1.070±0.00i	21.50±0.60s	38.65±0.34b	0.084±0.00w
		stored	1.070±0.00i	21.50±0.60s	38.65±0.34b	0.084±0.00w
	Dutch	fresh	1.071±0.00h	23.18±0.11j	16.44±0.01q	0.22±0.01i
		stored	1.072±0.00g	24.65±0.35gh	19.60±0.05n	0.176±0.01k
	KMpya	fresh	1.070±0.00i	20.78±0.18t	22.42±2.38m	0.237±0.00g
		stored	1.077±0.00c	25.69±0.21c	30.59±0.55de	0.101±0.00t
	Tigoni	fresh	1.068±0.00j	19.65±0.18x	22.64±0.39k	0.246±0.00e
		stored	1.072±0.00g	24.22±0.06i	29.07±1.49e	0.093±0.00v
Kagema	Cangi	fresh	1.070±0.00i	23.10±0.03m	39.34±0.63a	0.051±0.00y
		stored	1.070±0.00i	23.10±0.04m	39.34±0.63a	0.051±0.01
	Dutch	fresh	1.076±0.00d	25.13±0.11e	15.29±0.09r	0.156±0.01m
		stored	1.082±0.00b	26.08±0.35b	19.82±0.21m	0.115±0.00r
	KMpya	fresh	1.071±0.00h	22.49±0.28p	24.42±0.49i	0.253±0.00c
		stored	1.092±0.00a	27.15±0.24a	39.40±0.02d	0.195±0.00j
	Tigoni	fresh	1.068±0.01j	19.75±0.19w	22.64±0.39k	0.244±0.00f
		stored	1.076±0.00d	25.63±0.03d	37.43±0.01c	0.114±0.00s
Pyhort	Cangi	fresh	1.071±0.00h	20.38±0.20v	29.02±0.11f	0.096±0.00u
		stored	1.071±0.00h	20.38±0.20v	29.02±0.11f	0.096±0.00u
	Dutch	fresh	1.067±0.00k	19.63±0.71y	11.19±0.06igg	0.432±0.00a
		stored	1.070±0.00i	20.65±1.06uv	12.42±0.05v	0.342±0.03b
	KMpya	fresh	1.070±0.00i	22.40±0.13r	11.70±0.06w	0.249±0.00d
		stored	1.075±0.00e	24.64±0.50h	19.55±0.5mn	0.184±0.00jk
	Tigoni	fresh	1.071±0.00h	23.18±0.50j	11.56±0.04x	0.237±0.00g
		stored	1.074±0.00f	24.7±0.54g	16.47±0.52p	0.147±0.00n
TigoniKARI	Cangi	fresh	1.071±0.00h	20.78±0.16u	24.27±0.37j	0.062±0.00x
		stored	1.071±0.00h	20.78±0.16u	24.27±0.37j	0.062±0.00x
	Dutch	fresh	1.071±0.01h	22.70±0.14n	14.02±0.00u	0.175±0.05km
		stored	1.072±0.01g	24.75±0.07f	14.34±0.13t	0.14±0.01p
	KMpya	fresh	1.072±0.00g	23.14±0.16k	14.92±0.95s	0.235±0.00h
		stored	1.082±0.00b	26.32±0.04ab	27.39±0.56g	0.124±0.01q
	Tigoni	fresh	1.070±0.01i	20.20±0.11bcb	25.64±0.34h	0.249±0.00d
		stored	1.071±0.00h	22.48±0.05q	32.30±0.72cd	0.154±0.01n

Results are means of two determinations with ± standard deviation. Means with the same letter in the same column are not significantly ($p \leq 0.05$) different at 5%

Dry matter content in tubers determines the quality of processed potato products (French fries and crisps) such that the potato tubers with dry matter content ≥20% are suitable for processing (Abong' et al., 2011).

Thus basing on plant localities and seed treatment, all the varieties had their dry matter content above 20% being suitable for processing into French fries and crisps except Tigoni from fresh seed at Hellen, Kagema and Dutch Robjin from fresh seed at Pyhort (Kabira and Lemaga, 2006; Ooko and Kabira, 2011) . Dry matter significantly differed ($p \leq 0.05$) with plant localities, varieties and treatment of the seed potato (fresh or eight-month DLS seed) and there were significant interactions among the plant localities, seed storage and varieties. The dry matter content basing on plant locality was lowest at Pyhort while it was highest at Hellen; it was greatest in Kenya Mpya and lowest in Cangi; tubers from DLS had higher dry matter content as tubers from fresh seeds were lower.

There was a significant ($P \leq 0.05$) correlation (r= -0.23) between soil phosphorus and tubers dry matter confirming the influence of soil P on the tubers dry matter content (Table 15) in agreement with the findings in Ekin (2011)and Woolfe (1987).

Table 15: Pearson correlation coefficient (r) between Soil P and Tubers dry matter (DM) content for the four varieties according to plant location and seed treatment

Parameters	Soil P	Tubers DM
Soil P	1.00	-0.23[a]
Tuber DM	-0.23[a]	1.00

[a]Significant correlation coefficient ($P \leq 0.05$) (N=64)

Table 16: Pearson correlation coefficient (r) between Soil pH and Tubers dry matter (DM) content for the four varieties according to plant location and seed treatment

Parameters	Soil pH	Tubers DM
Soil pH	1.00	0.20[a]
Tuber DM	0.20[a]	1.00

[a]Significant correlation coefficient (P≤0.05) (N=64)

There was a positive significant correlation (r=0.20) between soil pH and potato tubers dry matter (Table 16) implying that lower pH lowers dry matter content in tubers and vice versa in agreement with the findings in table 14.

Vitamin C content in potato tubers ranged from 11.19 mg/100g FWB from fresh planted Dutch Robjin seed in Pyhort to 39.40 mg/100g FWB from Kenya Mpya tubers from DLS seed at Kagema (Table 14). Vitamin C significantly (p≤0.05) differed with plant localities, varieties and treatment of the seed potato (fresh or eight-month DLS seed). Interactions among plant locality, variety and seed treatment had significant (p≤0.05) effect on vitamin C content. It was lowest in Pyhort, then Tigoni-KARI, Hellen and Kagema in increasing order but it was highest in tubers from DLS seeds. According to earlier investigators, vitamin C content in fresh potato tubers is in the range 3-45% content on fresh weight basis (White et al., 2009 and Burton, 1989), therefore all the varieties in all the localities had Vitamin C content within the given range. The Food and Agriculture Organization (WHO, 2004) indicated that the recommended nutrient intake of vitamin C ranges from 25 to 70 mg/day, depending on age and 6.5-10.0 mg/day of the vitamin C can prevent scurvy in people. Thus these varieties can contribute towards Vitamin C’s nutritional requirements.

There was a positive significant correlation (r=0.50) between soil pH and potato tubers vitamin C (Table 17) implying that higher pH increases vitamin C content in tubers and vice versa. This was in agreement with vitamin C results in table 14.

Table 17: Pearson correlation coefficient (r) between Soil pH and Tubers vitamin C content for the four varieties according to plant location and seed treatment

Parameters	Soil pH	Tubers vitamin C
Soil pH	1.00	0.50[a]
Tuber vitamin C	0.50[a]	1.00

[a]Significant correlation coefficient (P≤0.05) (N=64)

When tubers are fried, reducing sugars generally combine with amino acids through a non-enzymic browning reaction to form the dark color associated with “burned” food (Wiley, 2006). The reducing sugars (glucose and fructose) usually create serious problems during frying because they are chemically reactive (Visakh et al., 2013). The reducing sugars content influences the color of the final-fried potato products and hence their consumer acceptability. Therefore light colors (golden brown color) in processed potato French fries and crisps which are obtained from tubers with low reducing sugars of ≤ 0.5% FWB and ≤ 0.25% FWB respectively are desirable (Kabira and Lemaga, 2003; Abong’et al., 2009). Thus basing on these arguments all the varieties from all the plant localities and from different seed treatments had the right amounts of total sugars ≤0.5% and were therefore suitable for processing into French fries; nonetheless tubers from fresh planted and eight-month DLS Dutch Robjin seeds in Pyhort were not suitable for crisps processing since they had >0.25% total reducing sugars, Table 14. Generally all the tubers from DLS seed had lower total reducing sugars content as compared to those from fresh seeds.

There was a positive significant correlation (r=-0.30) between soil pH and potato tubers reducing sugars (Table 18) implying that higher pH lowers reducing sugars content in tubers and vice versa. This was in agreement with the results which showed that Kagema soil with pH 5.2 had lower reducing sugars in tubers at 0.05% while Pyhort soil with pH 4.0 had reducing sugars in tubers at 0.43% (Table 14).

Table 18: Pearson correlation coefficient (r) between Soil pH and Tubers reducing sugars content for the four varieties according to plant location and seed treatment

Parameters	Soil pH	Tubers reducing sugars
Soil pH	1.00	-0.30[a]
Tuber reducing sugars	-0.30[a]	1.00

[a]Significant correlation coefficient (P≤0.05) (N=64)

4.5 CONCLUSION AND RECOMMENDATION

Potato varieties, plant localities and potato seed treatment do affect specific gravity, dry matter content, vitamin C and reducing sugars in ware potatoes. DLS seed treatment produces tubers of better physico-chemical properties (having the recommendable higher dry matter, specific gravity, vitamin C and lower total reducing sugars) compared to those from fresh potato tuber seeds. Negative significant correlations between potato tubers dry matter content and soil pH and phosphorus; positive significant correlation between soil pH and potato tubers dry matter/vitamin C content show that plant locality affects the quality of ware potatoes. Basing on physico-chemical properties for ware potatoes, DLS seed potato treatment should be adopted by farmers so as to produce better quality ware potatoes for potato processing industry. Further research is recommendable for determination of post harvest quality of ware potatoes from DLS seed treatment on storage.

CHAPTER FIVE

5.0 INFLUENCE OF DIFFUSED LIGHT SEED STORAGE AND PRODUCTION LOCATION ON THE QUALITY OF FRENCH FRIES AND CRISPS FROM SELECTED KENYAN WARE POTATO VARIETIES

5.1 Abstract

Frech fries and crisps quality can be affected by potato production locality, potato varieties and seed treatment. The study was conducted to assess the influence of diffused light seed potato storage (DLS) and production location on the quality of processed French fries and crisps from four selected Kenyan varieties (Kenya Mpya, Dutch Robjin, Tigoni and Cangi). The statistical design used was completely randomised block design (CRBD) where four growth localities (National Potato Research Centre KARI-Tigoni and three farmers in Nyandarua County: Pyhort, Kagema and Hellen) were considered as blocks. The independent factors considered were: plant localities, potato seed treatment (seeds from diffused light storage and freshly harvested tubers) and potato varieties (Kenya Mpya, Dutch Robjin, Tigoni and Cangi) while dependent factors were: Moisture and oil contents in French fries and crisps and their sensory parameters. All the independent factors were analyzed using standard methods of analysis and the obtained data was analyzed using statistical analysis system (version 9).

Tubers dry matter contents showed significant correlations with oil contents of the corresponding French fries (r=-0.63) and crisps (r=-0.93) depicting inverse relationship showed that physico-chemical properties affect quality of French fries and crisps. All the sensory attributes of freshly processed French fries and crisps, differed significantly ($p \leq 0.05$) with plant localities, varieties and potato seed storage. There were significant interactions among plant locality, variety and seed treatment. The freshly processed crisps on overall acceptability aspect

were all ideal excluding those from Tigoni fresh seed in all plant localities and Dutch Robjin from fresh seed in Pyhort whose scores were below sensory threshold of 4.0. The crisps preference basing on plant locality was highest at Tigoni-KARI and lowest at Pyhort. Kenya Mpya's crisps were the best but Tigoni's were worst and those from DLS were superior as compared to those from fresh seeds.

The potato plant localities, varieties and seed treatment do influence the quality and hence acceptability of French fries and crisps. Crisps and French fries from the DLS seed being lower in moisture and oil contents coupled with their higher consumer acceptability scores, DLS seed storage should be adopted so as to process good quality French fries and crisps.

5.2 INTRODUCTION

Potato crisps have become popular as a snack food product while potato French fries have become an important food in urban areas in Kenya just as they are in the rest of the world (Kabira and Lemaga, 2006; Abong' et al., 2010). French fries are also known as *pommes de frites* or *pommes frites* in France and are called chips in the United Kingdom (Jong et al., 2011). These are fried products (French fries and crisps) which should be of high yield, fluffy, with less oil content and of light colors being determined by dry matter and reducing sugars content in the potato tubers. Potato crisps can be defined as thin potato slices that are dehydrated by deep-fat frying to a moisture content of ≥2% (Ooko and Kabira, 2011).Potato crisps can have oil content ranging from 24% to 45% (wet weight basis) thus giving the product the unique and desirable texture-flavor combination (Abong' et al., 2011).

Potato’s importance in Kenya continues to rise due to high population in Kenya (40 million people), increased urbanization and uptake of processed potato products (French fries and crisps), potatoes high contribution to food security; need for poverty eradication and economic development, its high nutritional value, high market demand for ware potatoes and need for increased income generation by small scale potato farmers (Ooko and Kabira, 2011;Muthoni and Nyamongo, 2009; Scott et al, 2013; Obado, 2009; Abong’ et al., 2009).

Lack of affordable clean potato seed following the collapse of certified seed potato multiplication and distribution system by the early 1990’s; the limited quantity of certified and disease free seed tubers which account for <5% of the whole potato seed market in Kenya; coupled with large quantity of seed tubers needed for planting (two to three tonnes per hectare is the typical seed requirement); have forced farmers to plant own-saved tubers (from pit or dark room) from previous harvests or sourced from markets or even from neighbours which are usually of poor status, often resulting in loss of seed quality through weight loss, excessive sprouting and pests and disease attacks leading to low yields and hence low quality ware potatoes (Muthoni et al., 2014). This prompted the National Potato Center KARI- Tigoni to introduce cheap on-farm storage structures for potato seeds, exposed to diffused light with good ventilation for 8 months, to be planted by selected farmers in Nyandarua County which led to early crop establishment, and consequently to higher yields (Kabira et al., 2013; Kipkoech et al., 2012; Muthoni et al., 2014).

Frying of French fries and crisps imparts favorable flavors, colors, texture and acquisition of oil which improve overall palatability and consequently consumer acceptability (Abong’ et al., 2011). All these can be controlled by potato tuber’s physico-chemical properties which in turn could be determined by genetic make-up, plant locality and seed treatment (Ooko and Kabira, 2011). Potato tubers with specific gravity of ≥1.07 and dry matter content of ≥20% result into crisps and French fries of acceptable low oil content, higher yield and good texture. Conversely their color (influenced by maillard reaction and also caramelization) depends on reducing sugars content such that tubers with higher levels of ≥0.5% and ≥0.25% respectively result into dark colored French fries and crisps which are unacceptable by consumers who expect them to be of lighter colors (Abong'et al., 2010; Kabira and Lemaga, 2003).

The harvested potatoes from DLS seed treatment have not been evaluated for their processing suitability into French fries and crisps. This study was undertaken to determine the effect of diffused light storage (DLS) seed potato treatment and production location on the quality of fresh processed French fries and crisps.

5.3 MATERIALS AND METHODS

5.3.1 Experimental design

The experimental design used was completely randomised block design (CRBD), where four growth localities: National Potato Research Centre (KARI) – Tigoni of Kiambu County, Pyhort-a farmers'group in Ol-joro-ok of Nyandarua County, Kagema-a farmers'group in Ol-joro-ok of Nyandarua County and Hellen-an individual farmer in Kipipiri Githioro of Nyandarua County) were considered as blocks. The independent factors considered were: varieties, seed treatment and production localition while dependent factors were: moisture content, oil content and sensory attributes of fresh processed French fries and crisps.

5.3.2 Potatoes for processing

Diffused light stored (DLS) potato seeds having been stored in farmers own stores for eight months at ambient temperatures under natural ventilation and freshly harvested seed belonging to four potato varieties (Kenya Mpya, Tigoni, Cangi and Dutch Robjin), known to be suitable for processing into potato crisps and French fries, were grown under standard cultural conditions (Lung'hao and Kabira, 1999) at the National Potato Research Centre-Tigoni (KARI) which served as the control and at three farms in Nyandarua County (Hellen, Kagema and Pyhort) between March and April 2013. Harvesting of the tubers was done two weeks after dehaulming the mature potatoes in July/August 2013 (allowing the tubers' skin to suberize) followed by sorting right sizes (≥40mm) for ware (Kabira and Lemaga, 2006) (Table 19). They were then packed in net bags then transported to KARI-Tigoni for curing.

Table 19: Physical characteristics for raw materials used in the study

Cultivar	Shape	Skin color	Flesh color	Eye depth
Tigoni	Round(Oval)	Cream	Cream	Shallow
Dutch Robjin	Round	Red	Cream-yellow	Medium
Cangi	Round	Cream	Cream-yellow	Medium
Kenya Mpya	Round/Oval	Cream	Cream	Shallow

Source: Abong et al., 2011 and Potato Seed Catalogue Kenya, 2013.

They were then cured for two weeks under ambient air conditions of 15-19^{o}C at 84-92% RH in a naturally ventilated ware potato store at the National Potato Research Centre (KARI), Tigoni. Curing was carried out in order to allow healing of the potato tubers' wounds and bruises that might have occurred during potato harvesting and handling. This relative humidity ensured minimal water loss from tubers. There was adequate natural ventilation around tubers for providing oxygen for respiration and to dissipate field and respiration heat.

After curing, potato tubers were processed into French fries and crisps that were then evaluated for sensory attributes, oil and moisture contents (Kabira and Lemaga, 2006). The processing and sensory evaluations were carried out in the Food Science Laboratories at the Kenya Agricultural Research Station (KARI) in Tigoni. The chemical analysis for fresh processed French fries and crisps' moisture and oil contents was conducted at the College of Agriculture and Veterinary Sciences of the University of Nairobi.

The effects of DLS seed potato treatment and production location on the quality of fresh processed French fries and crisps were thus determined as follows:

5.3.3 Crisps and French fries processing

The potato tubers were processed into French fries and crisps according to Kabira and Lemaga (2003). Ten potato tubers from each variety, according to plant locality and seed storage were used. They were fried in a batch type-deep oil fryer (E 6 ARO S.A., La Neuveville- Switzerland) containing 10 litres of Top Fry oil at 170^{o}C for 3-5minutes.

5.3.4 Determination of moisture content

Moisture content of processed French fries and crisps was determined by oven drying as outlined in AOAC (1980).

5.3.5 Sensory evaluation

Coded samples both freshly processed French fries and crisps were presented to 10 panelists (being familiar with French fries and crisps) who scored for colour, oiliness, texture, flavour and overall acceptability on a 7-point hedonic rating scale which ranged from 1 (dislike very much) to 7 (like very much) as outlined by Larmond (1977) in appendix A.

5.3.6 Objective color measurement

French fries and crisps colors were determined according to PC/SFA (1987) color chart ranging from a score of 1 to a score of 5. Where 1 was the best acceptable color (golden yellow), 5 was the worst unacceptable color (dark brown) and 3 represented the maximum acceptability score.

5.3.7 Determination of oil content

The freshly processed potato crisps and French fries were finely ground in a mortar and pestle after which duplicate 5 g samples were accurately weighed and placed into thimbles. They were extracted in Soxhlet apparatus using analytical grade petroleum ether (boiling point 40-60^{o}C) for 8 hours and the oil content determined according to AOAC (1980).

5.3.8 Data analysis

Analysis of variance (ANOVA) and least significant difference test for moisture content, oil content, sensory scores and PC/SFA colour scores for French fries and crisps were conducted using the Statistical Analysis System (SAS) version 9. The means separated by least significant differences $p \leq 0.05$ were considered significant. Correlations were also preformed between PC/SFA and sensory colours for French fries and crisps; between French fries and crisps PC/SFA colours and tubers reducing sugars.

5.4 RESULTS AND DISCUSSION

5.4.1 Moisture and oil contents in French fries and crisps

The moisture and oil contents in French fries ranged from 37.05% and 7.55% respectively in tubers from Kenya Mpya DLS seed in Kagema to 48.45% and 14.83% respectively from Dutch

Robjin fresh seed in Pyhort, Table 20. Conversely moisture and oil contents in crisps ranged from 3.15% and 30.66% respectively arising from tuber from Kenya Mpya DLS seed in Kagema to 4.69% and 42.61% respectively from Dutch Robjin fresh seed in Pyhort. French fries and crisps from potato tubers at Pyhort, Hellen, Tigoni-KARI and Kagema had moisture and oil contents sequentially in a decreasing order. Moisture and oil contents in French fries and crisps significantly differed ($p \leq 0.05$) with plant localities, varieties and treatment of the seed potato (fresh or eight-month DLS seed).There were significant interactions among plant locality, variety and seed treatment.

Table 20: Effect of potato production locality, Kenyan potato varieties and potato seed treatment on moisture and oil contents of freshly processed French fries and crisps

Locality	Variety	Treat	French fries mc	French fries oil	Crisps mc	Crisps oil
Hellen	Cangi	Fresh	43.80±0.06np	11.98±0.01k	3.74±0.15q	35.74±0.07h
		Stored	43.80±0.06np	11.98±0.01k	3.74±0.15q	35.74±0.07h
	Dutch	Fresh	44.60±0.07g	12.29±0.10g	4.21±0.09h	33.56±0.08k
		Stored	41.93±0.02u	10.15±0.07w	3.91±0.08np	33.34±0.29mn
	KMpya	Fresh	44.00±0.19mn	12.09±0.03j	4.26±0.14g	37.34±0.13g
		Stored	40.28±0.02w	9.52±0.59y	3.20±0.06u	32.78±0.21p
	Tigoni	Fresh	45.60±0.00f	13.03±0.03d	4.19±0.01i	41.48±0.08b
		Stored	44.33±0.12k	11.75±0.34m	3.87±0.10pqr	33.66±0.44jb
Kagema	Cangi	Fresh	42.04±0.05t	10.05±0.06wx	3.37±0.06t	33.84±0.74j
		Stored	42.04±0.46t	10.05±0.06wx	3.37±0.06t	33.84±0.74j
	Dutch	Fresh	44.21±0.28m	11.22±0.14p	4.97±0.02a	32.69±0.06q
		Stored	39.68±0.68x	8.91±0.12z	3.09±0.07va	31.69±0.26qa
	KMpya	Fresh	42.64±0.09s	10.97±0.04t	4.43±0.34f	34.26±0.08i
		Stored	37.05±0.02z	7.55±0.63za	3.15±0.09v	30.66±0.23s
	Tigoni	Fresh	44.38±0.34i	12.28±0.09h	4.72±0.05bc	41.18±0.28c
		Stored	43.37±0.16q	11.08±0.05s	4.13±0.08j	32.55±0.06qb
Pyhort	Cangi	Fresh	43.96±0.03n	10.47±0.07v	3.77±0.09pq	39.32±0.10e
		Stored	43.96±0.03n	10.47±0.07v	3.77±0.09pq	39.32±0.10e
	Dutch	Fresh	48.46±0.18a	14.83±0.03a	4.69±0.00c	42.61±0.07a
		Stored	44.58±0.21h	11.82±0.04km	3.84±0.09p	38.58±0.17f
	KMpya	Fresh	45.44±0.30fj	12.85±0.08e	3.96±0.02m	34.26±0.10i
		Stored	41.54±0.22v	10.79±0.01tu	3.56±0.04rs	33.35±0.02m
	Tigoni	Fresh	47.82±0.02b	12.44±0.01f	4.81±0.00b	33.66±0.01jk
		Stored	45.78±0.24e	11.45±0.07n	4.50±0.00e	33.34±0.60mb
TigoniKARI	Cangi	Fresh	43.35±0.36r	10.66±0.72u	3.79±0.14q	37.36±0.52g
		Stored	43.35±0.36r	10.66±0.72u	3.79±0.14q	37.36±0.52g
	Dutch	Fresh	46.88±0.12c	13.17±0.10c	4.61±0.53d	34.63±0.33hi
		Stored	42.51±0.54st	11.16±0.07q	3.55±0.19s	33.34±0.02ma
	KMpya	Fresh	44.36±0.42j	12.10±0.12i	3.94±0.01n	33.69±0.49ja
		Stored	39.34±0.38y	9.26±0.12x	3.37±0.11tu	31.41±0.55r
	Tigoni	Fresh	46.42±0.33d	13.37±0.07b	4.60±0.43de	39.41±0.26d
		Stored	43.51±0.67p	11.15±0.01r	4.07±0.03k	34.78±0.11ha

Results are means of two determinations with ± standard deviation. Means with the same letters in the same column are not significantly ($p>0.05$) different. All the values were expressed as % on FWB.

Table 21: Pearson correlation coefficient (r) between tubers dry matter and French fries oil contents from four varieties according to plant location and seed treatment

Parameters	Tuber dry matter content	French fries oil content
Tuber dry matter content	1.00	-0.63[a]
French fries oil content	-0.63[a]	1.00

[a]Significant correlation coefficient (P≤0.0001) (N=32)

Amount of oil absorbed and retained by French fries during frying is dependent on tubers dry matter content as confirmed by the negative correlation (r= -0.63) existing between tubers dry matter and French fries oil contents as depicted in Table 21. This implies that the higher the tubers dry matter content (>20%) the lower the oil content in the processed French fries and the reverse is also true, which is recommendable.

Table 22: Pearson correlation coefficient (r) between dry matter and crisps oil contents from four varieties according to plant location and seed treatment

Parameters	Tuber dry matter content	Crisps oil content
Tuber dry matter content	1.00	-0.93[a]
Crisps oil content	-0.93[a]	1.00

[a]Significant correlation coefficient (P≤0.0001) (N=32)

There was a very strong negative correlation (r= -0.93) between tuber dry matter content and oil content in crisps processed from the tubers as illustrated in table 22. This portrayed the fact that high oil contents in crisps were due to processing tubers which had low (<20%) dry matter content initially while it is contrary when tubers had high (>20%) dry matter levels.

Basing on other investigators, the crisps oil levels were within the acceptable ranges of (24-45%) on FWB according to Abong' et al., (2011) and Kenya Bureau of Standards (2007); although current East African Standards of 2010 recommend oil content in crisps to be at 35% maximum limit and so when basing on this then it implies that all crisps were acceptable except those from Kenya Mpya and Tigoni at Hellen from fresh seed, Cangi at Pyhort and KARI-Tigoni,Tigoni at KARI-Tigoni and Kagema from fresh seed, Dutch Robjin at Pyhort from both DLS and fresh seeds. Potato varieties played a key role in influencing French fries and crisps moisture and oil contents such that Tigoni's French fries and crisps had the highest moisture and oil contents while Kenya Mpya had the lowest levels in agreement with the findings in Abong' et al., (2011). All processed French fries and crisps originating from DLS seed had lower moisture and oil contents being superior contrasting with those from fresh seeds.

5.4.2 Sensory characteristics of the freshly processed French fries

Varieties Dutch Robjin from both fresh and eight-month DLS planted seed at Pyhort and Kenya Mpya from fresh seed planted at Hellen were the only ones not suitable for processing into French fries since their French fries color failed the sensory threshold of 4.0 of color acceptance basing on a 7-hedonic scale as shown in Table 23. The French fries color scored by panelists was in agreement with the objective color measurement due to the strong negative correlation (r= -0.59) which existed between PC/SFA and panelists color scores as reflected in Table 18. This indicated that when panelist's color score was above 4.0, then the objective color was below 3.0 illustrating high acceptability.

Table 23: Effect of plant locality and potato seed treatment on sensory and PC/SFA color scores of French fries processed from four Kenyan potato varieties

Locality	Variety	Treat	Color	Flavor	Texture	Oiliness	Acceptability	PC/SFA color
Hellen	Cangi	Fresh	5.4±0.19e	5.6±0.19d	5.8±0.16b	5.4±0.19f	5.6±0.19d	1±0d
		Stored	5.4±0.19e	5.6±0.19d	5.8±0.16b	5.4±0.19f	5.6±0.19d	1±0d
	Dutch	Fresh	5.4±0.19e	5.2±0.04h	5.6±0.74c	5.4±0.19f	5.2±0.04f	2±0c
		Stored	6.0±0.76a	5.9±0.83c	5.9±0.64a	5.0±0.76i	5.9±0.83c	2±0c
	KMpya	Fresh	3.9±0.55q	3.1±0.36v	3.4±0.51p	4.9±0.55j	4.0±0.36r	3±0b
		Stored	4.4±0.41k	4.0±0.69s	4.0±0.81n	4.4±0.41mn	4.2±0.69p	3±0b
	Tigoni	Fresh	4.1±0.36n	4.4±0.74p	4.9±0.64h	5.1±0.36h	4.4±0.74m	2.5cb
		Stored	5.4±0.06e	4.5±0.31n	5.1±0.36f	5.4±0.06f	4.5±0.31k	2±0c
Kagema	Cangi	Fresh	6.0±1.07a	6.1±0.64a	5.8±0.89b	6.0±0.07b	6.1±0.64a	1±0d
		Stored	6.0±1.07a	6.1±0.64a	5.8±0.89b	6.0±0.07b	6.1±0.64a	1±0d
	Dutch	Fresh	4.5±0.07j	5.0±0.76j	5.1±0.99f	4.5±0.07m	5.0±0.76h	2±0c
		Stored	5.2±0.16f	5.5±0.92e	5.6±0.52c	5.2±0.16g	5.5±0.92e	1±0d
	KMpya	Fresh	4.1±0.46n	4.1±0.25r	4.0±0.36n	3.9±0.46r	4.1±0.25q	4±0a
		Stored	4.4±0.60k	4.4±0.19p	4.2±0.16bm	3.4±0.6s	4.4±0.19m	3±0b
	Tigoni	Fresh	5.8±0.46b	5.2±0.16h	5.5±0.2d	5.8±0.46c	5.2±0.16f	3±0b
		Stored	5.8±0.04b	5.25±0.89g	5.2±0.89e	5.8±0.04c	5.2±0.88f	3±0b
Pyhort	Cangi	Fresh	5.2±0.04f	5.2±0.71h	5.2±0.165e	5.2±0.04g	5.2±0.71f	2±0c
		Stored	5.2±0.04f	5.4±0.92f	5.2±0.16e	5.2±0.04g	5.4±0.92e	2±0b
	Dutch	Fresh	3.1±0.25s	3.4±0.06u	4.1±1.0mn	6.2±0.25a	3.4±0.06t	4±0a
		Stored	3.4±0.41r	3.8±0.16t	4.2±0.71m	5.8±0.41c	3.8±0.16s	4±0a
	KMpya	Fresh	4.0±0.31p	4.0±0.07s	4.0±0.69n	4.0±0.31q	4.0±0.07r	3±0b
		Stored	4.9±0.81g	4.0±0.41s	4.4±0.3k	4.1±0.81p	4.3±0.41n	3±0b
	Tigoni	Fresh	4.9±0.64g	4.2±0.04q	4.7±0.28j	5.4±0.64f	4.2±0.04p	3±0b
		Stored	4.5±0.20j	4.5±0.92n	4.8±0.25i	5.5±0.2e	4.5±0.92k	2±0c
TigoniKARI	Cangi	Fresh	5.5±0.76d	6.0±0.76b	5.8±0.89b	5.5±0.76e	6.0±0.76b	1±0d
		Stored	5.5±0.76d	6.0±0.76b	5.8±0.89b	5.5±0.76e	6.0±0.76b	1±0d
	Dutch	Fresh	5.8±0.86b	5.2±0.71h	5.6±0.92c	5.9±0.46bc	5.2±0.71f	2±0c
		Stored	5.6±0.52c	5.1±0.12i	5.2±0.04e	5.6±0.52d	5.1±0.13g	2±0c
	KMpya	Fresh	4.2±0.71m	4.5±0.31n	4.8±0.39i	4.2±0.71n	4.5±0.31k	2.5±0cb
		Stored	4.7±0.28i	5.9±1.0c	5.5±0.07d	5.8±0.28c	5.9±0.99c	2±0c
	Tigoni	Fresh	4.8±0.49h	4.8±0.28m	5.0±0.07g	4.8±0.49k	4.7±0.28j	3±0b
		Stored	4.9±0.36g	4.9±0.12k	5.1±0.36f	4.9±0.36j	4.9±0.13i	3±0b

Results are means of scores from ten panelists and PC/SFA color with ± standard deviation. Means with the same letters in the same column are not significantly ($p>0.05$) different at 5%. A score of 4.0 was the acceptable lower limit for sensory evaluation on a 7-point hedonic scale while scores ≤3 were acceptable on a PC/SFA scale of 1-5.

Table 24: Pearson correlation coefficient (r) between PC/SFA and sensory color scores for French fries made from four varieties according to plant location and seed treatment

Parameters	PC/SFA color score	Sensory color score
PC/SFA color score	1.00	-0.59[a]
Sensory color score	-0.59[a]	1.00

[a]Significant correlation coefficient (P≤0.0004) (N=32)

Table 25: Pearson correlation coefficient (r) between PC/SFA color for French fries and reducing sugars from four varieties based on plant location and seed treatment

Parameters	PC/SFA color score	Reducing sugars
PC/SFA color score	1.00	0.93[a]
Reducing sugars	0.93[a]	1.00

[a]Significant correlation coefficient (P≤0.000) (N=32)

There was a very strong but positive correlation (r= 0.93) existing between French fries PC/SFA color scores and the reducing sugars from four potato varieties demonstrate that sugars can also influence French fries color, (Table 25). This shows that lower sugar levels (<0.4%) in tubers lead to lower PC/SFA color scores <3.0 attributed to lighter colors which are acceptable by consumers but when the levels are higher (>0.5%) cause unacceptable higher PC/SFA color scores >3 (dark colors).

All the sensory attributes of freshly processed French fries significantly (p≤0.05) differed with plant localities, varieties, and treatment of the seed potato (fresh or eight-month DLS seed) and also with interactions among plant locality, variety and seed treatment as shown in.

The flavor in French fries processed from tubers which had been planted from both fresh and eight-month DLS Dutch Robjin seed in Pyhort and from Kenya Mpya fresh seed at Hellen having been scored at <4.0 were not acceptable on flavor basis but the rest were acceptable since their scores were above the sensory threshold of 4.0 on a 7-hedonic scale as shown in Table 23.

The texture in the processed French fries from potato varieties in all plant locations was scored ≥4.0 and hence was acceptable. Order of preference in a decreasing manner in terms of plant locality, variety and seed treatment respectively was as follows: Tigoni-KARI, Kagema, Hellen followed by Pyhort; Cangi, Dutch Robjin, Tigoni then Kenya Mpya; eight-month DLS seed finally from fresh seed.

The oiliness was scored lowest at 3.4 in French fries processed from tubers which had been planted from DLS Kenya Mpya seed in Kagema while the highest score was at 6.2 from planted fresh Dutch Robjin seed at Pyhort, Table 23. French fries from Kagema's Kenya Mpya both fresh and DLS seeds were the only unacceptable ones since they were below the threshold level of acceptability (<4.0).

French fries on the basis of overall acceptability were all preferred having scored ≥4.0 from all the potato varieties in all the locations except those from tubers which had been planted from both fresh and DLS Dutch Robjin seeds in Pyhort. Order of preference in a decreasing manner in terms of plant locality, variety and seed treatment respectively was as follows: Tigoni-KARI, Kagema, Hellen and Pyhort; Cangi, Dutch Robjin, Tigoni and Kenya Mpya; eight-month DLS seed and lastly fresh seed.

5.4.3 Sensory characteristics of the freshly processed crisps

The crisps color scores ranged from the lowest 2.9 having been processed from tubers arising from the planted fresh Dutch Robjin seed in Pyhort to the highest 6.4 being from Cangi in Kagema (Table 26). The sensory color of freshly processed crisps statistically differed significantly ($p \leq 0.05$) with plant localities, varieties, and treatment of the seed potato (fresh or eight-month DLS seed). There were significant interactions among plant locality, variety and seed treatment.

Crisps color was acceptable from all the processed varieties in all the locations except crisps from Tigoni from planted fresh seed in all the locations (except at Tigoni-KARI) and from Dutch Robjin coming from both fresh and DLS seeds in Pyhort since they were scored <4.0, Table 26 . The color usually has strong influence on crisps acceptability and it occurs due to maillard and caramelisation reactions which depend on reducing sugars content in tuber slices during frying such that tubers with higher levels (≥0.25%) result into dark colored crisps which tend to be rejected. Since there was a high correlation (r= -0.68) between PC/SFA and sensory color scores for the potato crisp processed from four varieties, in the four locations according to the seed treatments, it shows that panelists were in agreement with the objective color measurements (Table 27). There was positive correlation (r=0.82) between PC/SFA crisps color and total reducing sugars in Table 28, implying that the higher sugar levels cause darker colors and vice versa.

Table 26: Effect of plant locality and potato seed treatment on sensory and PC/SFA color scores of crisps processed from four Kenyan potato varieties

Locality	Variety	treat	Color	Flavor	Texture	Oiliness	Acceptance	PC/SFA color
Hellen	Cangi	fresh	5.8±0.9f	5.7±0.5f	5.4±1.3j	5.6±1.06f	5.1±0.64k	1±0d
		stored	5.8±0.9f	5.7±0.5f	5.4±1.3j	5.6±1.06f	5.1±0.64k	1±0d
	Dutch	fresh	5.6±1.2g	5.4±0.7h	5.5±0.92i	5.5±0.76g	4.6±1.06m	2±0c
		stored	6.2±1.0c	6.0±0.5c	6.2±0.52c	6.5±0.53a	5.4±0.52h	2±0c
	KMpya	fresh	4.2±1.0p	4.5±0.9j	5.75±1.03f	4.6±0.92k	5.6±0.71f	3±0b
		stored	6.0±0.8e	6.0±0.8c	6.0±0.76e	6.0±0.76d	5.7±1.19e	2±0c
	Tigoni	fresh	3.9±1.1s	3.0±0.9q	3.1±0.83u	3.2±0.53t	3.9±1.06r	3±0b
		stored	4.0±1.7r	4.0±1.4k	4.2±1.16q	4.4±1.5m	4.4±1.06n	3±0b
Kagema	Cangi	fresh	6.4±0.5a	6.1±0.6b	5.4±0.74j	6.1±0.83c	5.6±0.74f	2±0c
		stored	6.4±0.5a	6.1±0.6b	5.4±0.74j	6.1±0.83c	5.6±0.74f	1±0d
	Dutch	fresh	4.4±1.3n	5.9±1.1d	5.6±0.52h	4.9±0.64j	5.2±1.49j	2±0c
		stored	5.5±1.5h	6.0±0.7c	6.3±0.71b	6.0±0.53d	5.7±0.84e	2±0c
	KMpya	fresh	5.4±1.2i	5.8±0.5e	6.1±0.52d	5.6±0.52f	6.2±1.28b	3±0b
		stored	6.2±0.7b	6.2±0.7a	6.4±0.71a	6.2±0.71b	6.4±1.06a	2±0c
	Tigoni	fresh	3.5±0.9t	3.6±1.2m	3.8±1.28t	3.9±1.12q	3.8±0.89s	3±0b
		stored	4.7±0.5k	4.6±0.7i	4.4±0.74p	4.4±0.92m	4.4±0.52n	2±0c
Pyhort	Cangi	fresh	6.1±0.3d	5.4±0.7h	5.7±0.71g	5.8±0.46e	5.9±0.64d	2±0c
		stored	6.1±0.3d	5.4±0.7h	5.7±0.71g	5.8±0.46e	5.9±0.64d	2±0c
	Dutch	fresh	2.7±0.7v	2.6±1.2r	4.0±0.83rs	3.5±0.89s	3.8±0.64s	4±0a
		stored	3.1±0.6u	3.2±0.5p	4.1±0.53r	4.0±0.64n	4.0±0.35q	4±0a
	KMpya	fresh	4.1±1.9q	4.6±0.9i	5.2±1.16k	4.6±1.1k	5.3±0.92i	3±0b
		stored	5.4±0.5i	5.5±0.5g	5.5±0.71i	5.4±0.52h	5.4±0.52h	3±0b
	Tigoni	fresh	3.5±1.2t	3.4±0.9n	3.0±0.99v	3.8±0.71r	3.6±0.74t	4±0a
		stored	4.0±1.2r	4.0±0.8k	3.9±1.07s	4.0±1.19p	4.2±1.03p	2.5±0.7cb
TigoniKARI	Cangi	fresh	6.3±0.5b	6.0±1.0c	6.1±0.83d	5.6±1.06f	6.0±0.42c	1±0d
		stored	6.3±0.5b	6.0±1.0c	6.1±0.83d	5.6±1.06f	6.0±0.42c	1±0d
	Dutch	fresh	5.2±0.7ij	5.5±0.8g	5.1±1.12m	5.6±0.74f	5.5±0.92g	2±0c
		stored	5.2±1.3j	5.5±0.9g	5.5±1.07i	5.6±1.3f	5.6±1.3f	2±0c
	KMpya	fresh	4.0±1.8r	5.0±1.1hi	5.5±0.76i	5.2±1.49i	5.5±0.76g	3±0b
		stored	5.5±1.2h	5.6±1.2fg	6.0±0.76e	5.8±1.04e	6.0±0.76c	1.5±0.7dc
	Tigoni	fresh	4.6±1.6m	4.5±1.5j	4.4±1.51p	3.8±1.3r	3.9±1.41r	3±0b
		stored	4.4±1.1n	4.6±1.3i	4.8±1.16n	4.4±1.06m	4.6±1.3m	3±0b

Results are means of scores from eight panelists and PC/SFA with ± standard deviation. Means with the same letters in the same column are not significantly different (p>0.05). A score of 4.0 was the acceptable lower limit on a 7-point hedonic scale and scores of ≤3 were acceptable on a PC/SFA color scale of 1-5.

Table 27: Pearson correlation coefficient (r) between PC/SFA and sensory color scores for crisps made from four varieties based on plant location and seed treatment

Parameters	PC/SFA color score	Sensory color score
PC/SFA color score	1.00	-0.68[a]
Sensory color score	-0.68[a]	1.00

[a]Significant correlation coefficient (P≤0.0001) (N=32)

Table 28: Pearson correlation coefficient (r) between PC/SFA crisps color scores and reducing sugars four varieties based on plant location and seed treatment

Parameters	PC/SFA color score	Reducing sugars
PC/SFA color score	1.00	0.82[a]
Reducing sugars	0.82[a]	1.00

[a]Significant correlation coefficient (P≤0.0000) (N=32)

Flavor in freshly processed crisps scores varied from 2.7 being the least score got from the planted fresh Dutch Robjin seed in Pyhort to 6.2 from DLS Kenya Mpya seed of Pyhort (Table 26). The sensory flavor of freshly processed crisps statistically differed significantly ($p \leq 0.05$) with plant localities, varieties, and treatment of the seed potato (fresh or eight-month DLS seed) and also with interactions among plant locality, variety and seed treatment.The order of fondness for crisps flavor according to plant locality, variety and seed treatment in increasing manner was as follows: Pyhort, Hellen, Tigoni-KARI and Kagema; Tigoni, Kenya Mpya/ Dutch Robjin and Cangi; fresh and then the DLS seed treatment.

The crisps texture was rated highest at 6.4 for crisps processed from Kenya Mpya tubers obtained from DLS seed in Kagema and the least score was at 3.0 for Tigoni crisps from fresh seed in Pyhort. The sensory texture of freshly processed crisps statistically differed significantly ($p \leq 0.05$) with plant localities, varieties, and treatment of the seed potato (fresh or eight-month DLS seed) and with interactions among plant locality, variety and seed treatment. Considering plant locality, potato variety and seed treatment influenced crisps level of textural acceptability from highest descending as indicated: Tigoni-KARI, Kagema, Hellen then Pyhort; Kenya Mpya/Dutch Robjin, Cangi next Tigoni; DLS seed then fresh seed.

Crisps oiliness is habitually due to the total oil absorbed/adsorbed during frying and it influenced the crisps consumer acceptability in Table 26. All the processed crisps were scored above 4.0 hence acceptable apart from crisps from Tigoni variety coming from fresh seed in all plant localities and Dutch Robjin fresh seed in Pyhort. The sensory oiliness of freshly processed crisps statistically differed significantly ($p \leq 0.05$) with plant localities, varieties, and seed potato storage (fresh or eight-month DLS seed) and with interactions among plant locality, variety and seed storage. The freshly processed crisps on overall acceptability aspect were all preferred excluding those from Tigoni variety fresh seed in all plant localities and Dutch Robjin from fresh seed in Pyhort whose scores were below sensory threshold 4.0. The overall crisps acceptability basing on plant locality, variety and seed treatment respectively ranging sequentially in a descending order was as follows: Tigoni-KARI, Kagema, Hellen next Pyhort; Kenya Mpya/Dutch Robjin, Cangi subsequently Tigoni; DLS seed after that fresh seed. Thus consumer preference for crisps was influenced by potato plant, variety and seed storage.

Generally Pyhort's French fries and crisps appeared inferior as compared to those from other localities due to its highest soil acidity as observed in an earlier study.

5.4 CONCLUSION AND RECOMMENDATION

Potato plant localities influence the quality of French fries and crisps and hence consumer acceptability. French fries and crisps processed from different potato varieties differ in quality and also in their level of consumer satisfactoriness. The DLS potato seed influence the quality and hence acceptability of the processed French fries and crisps. Crisps and French fries processed from the DLS seed contain the required lower oil contents, moisture contents and of higher levels of consumer acceptability in comparison with those from fresh seeds. DLS seed technology should be adopted by more farmers in Nyandarua County and the rest of the Country so as to yield better quality ware potatoes for the French fries and crisps processing industry.

CHAPTER SIX

6.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

6.1 GENERAL CONCLUSIONS

Soils from all the locations significantly differ in minerals and pH levels. Higher soil minerals contents lead to higher potato tubers minerals contents except for Ca, Mn and Zn which show reverse relationships.

The negative significant correlations between potato tubers dry matter content and soil pH and phosphorus; positive significant correlation between soil pH and potato tubers dry matter and vitamin C content show that production locality affects the quality of ware potatoes. DLS seed treatment causes production of potato tubers with higher specific gravity, dry matter content, vitamin C contents, and minerals contents but with lower reducing sugars content. Crisps and French fries processed from the DLS seed have the required lower oil contents, moisture contents with higher levels of consumer acceptability in comparison with those from fresh seeds.

Diffused light seed potato storage and production location do influence physico-chemical characteristics of Kenyan varieties and their processing suitability into French fries and crisps.

6.2 GENERAL RECOMMENDATIONS

The Ministry of Agriculture, Livestock and Fisheries should ensure diffused light seed potato storage is adopted by more farmers in Nyandarua County and the rest of the Kenyan Counties so as to yield more and better quality ware potatoes for the potato industry.

Further research is recommendable for determination of the effect of DLS seed treatment on post harvest quality of ware potatoes on storage and their suitability for French fries and crisps processing.

Soil and potato tuber analyses should be extended to other potato growing areas in Nyandarua County and in Kenya as a whole and this evaluation should be conducted regularly after every two years.

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APPENDIX A:

SENSORY EVALUATION SCORE SHEET

Date of evaluation.……………………..…….
Product evaluated.……………………………
Name of evaluator.…………….…………..

Please evaluate the food samples provided and indicate the degree of your liking for color, flavor, texture, oiliness and overall acceptability. Please do not communicate or consult with anyone while scoring.

Use the numerical scores from the scoring card provided. Enter your score under the sample in the scoring sheet.

7-point Hedonic scale

Quality	**Score**
Dislike very much	1
Dislike	2
Dislike slightly	3
Fair	4
Like slightly	5
Like	6
Like very much	7

The scoring card

Sample code	1	2	3	4	5	6	7	8	9	10	11	12
Color												
Flavor												
Texture												
Oiliness												
Overall acceptability												