EVALUATION OF THE PHYSICO-CHEMICAL PROPERTIES OF SELECTED POTATO VARIETIES AND CLONES AND THEIR POTENTIAL FOR PROCESSING INTO FROZEN FRENCH FRIES

By

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DECLARATION

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

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DEDICATION

This work is dedicated to my parents, Andrew and Dorfina, for their love and care, and to my uncle, Omolo, for being a wonderful guardian.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The most important processed potato products in Kenya are French fries (chips), followed by crisps and frozen French fries (chips). The demands for these products have increased over the years and therefore require that more effort is made to develop varieties with appropriate qualities for the rapidly developing Industry. Ten advanced potato clones developed by the national breeding programme in collaboration with the International Potato Centre (CIP) and eight established varieties were evaluated for frozen French fry quality. The clones were coded 393385.47, 393385.39, 393380.57, 393380.58, 385524.9, 399746.2, 392657.8, 392617.54, 391691.96 and 392637.10. The potato varieties were Tigoni, Roslin Tana, Desiree, Kerr's Pink, Dutch Robyjn, Kenya Karibu, Kenya Sifa and Asante. Tubers were harvested at full maturity and cured under ambient air conditions for three weeks before evaluation. The tubers selected from a preliminary trial were harvested at maturity and subjected to further treatments and analysis after Each cultivar was divided into three whereby one third was processed immediately after curing, a third was stored for 12 weeks at prevailing air conditions (15-19 °C/86-92 % rh) in a dark naturally ventilated store, and the other third was stored for 3 months in cold store (4 °C) before evaluation. Parameters evaluated include; physical and chemical characteristics for raw tubers processed fresh and frozen fries, and sensory quality characteristics for the fries.

Fries for the study were prepared by frying 12 mm X 12 mm potato sticks in vegetable oil at 170 °C for 2 min (par-fries) and finish fryied at 170 °C for 5 min. Blanched, partly fried or fully fried fries were frozen stored at -18 °C in a laboratory chest freezer one month in a preliminary evaluation trial and up to three months to test French fry quality of selected cultivars. Proximate and mineral compositions of raw tubers and fries were evaluated using AOAC methods.

Based on the preliminary trial, all the varieties and advanced clones except Asante, Kerr's Pink and 393380.57 were found to be suitable for processing into freshly prepared fries. Frozen French fries from all the varieties except Asante and clones 393380.57, 393380.58, 385524.9, 399746.2, 392657.8, 392617.54 and 392637.10 were acceptable following one month of freeze storage at -18 °C. Eight cultivars were selected thereafter for further evaluation including five varieties (Tigoni, Desiree, Dutch Robyjn, Kenya Karibu, and Kenya Sifa) and three advanced clones (393385.47, 391696.96 and 393385.39).

Results indicated that all the 8 cultivars had acceptable physical tuber characteristics with acceptable levels of dry matter content (≥ 20 %) and specific gravity (≥ 1.070). Reducing sugar content differed significantly (P≤0.05) with variety and storage condition. In freshly harevested tubers, reducing sugar levels ranged from 0.15 % to 0.37 %. No significant change (P>0.05) was found in the reducing sugar content when tubers were stored at ambient air conditions (15-19 °C/86-92 % rh) for 12 weeks. In cold storage (4 °C/95 % rh), tubers of all the varieties and advanced clones accumulated high amounts of reducing sugars and none was suitable for processing even after reconditioning for 3 weeks at ≥15 °C.

Ambient air storage had no significant (P>0.05) effect on proximate composition. Frying did not significantly (P>0.05) reduce any chemical constituent while freezing fries significantly (P≤0.05) reduced total ash, crude protein and total carbohydrate contents. The retention levels were, however, substantial. Fat content increased on finish frying due to absorption of oil. The 'finish frying method' influenced significantly (P≤0.05) the fat content in the fries, being higher in deep fat frying and lower in oven-fried samples.

Ambient air storage had no significant (P>0.05) effect on any of the sensory attributes evaluated. Freezing significantly (P≤0.05) reduced flavour and texture scores of the tubers while the rest of attributes like colour, oiliness and overall acceptability were not affected. Frozen French fries made from the selected cultivars were acceptable even after 3 months of frozen storage at -18 °C.

The study established that five varieties (Tigoni, Desiree, Dutch Robyjn, Kenya Karibu, and Kenya Sifa) and three advanced clones (393385.47, 391696.96 and 393385.39) were the most suitable for processing into freshly prepared and frozen French fries.

CHAPTER 1

1.0 INTRODUCTION

Potatoes are plants of the Solanaceae family commonly grown for starchy tubers. They are the world's most widely grown tuber crop and the fourth largest crop in terms of fresh produce after rice, wheat and maize (Lemaga and Kabira, 2003; Wikipedia, 2004; MoA, 2005). According to the National Policy on Potato Industry (MoA, 2005), the potato in Kenya is an important food and cash crop that plays a major role in food security and is only second to maize in terms of utilization. Production is mainly confined to the highlands (1500-3000 m above sea level) where the crop has higher yields than most of the food crops. These areas are in Central (Muranga, Nyeri, Kiambu, Kirinyaga, Maragua, Thika, and Nyandarua), Rift valley (Molo, Nakuru, Bomet, Uasin Gishu, Koibatek and Mau Narok), Eastern (Meru), with small quantities in the high altitudes of Western and Coast provinces. The production of potatoes is increasing due to economic decline of competing cash crops such as maize, pyrethrum and barley, and increasing demand from consumers and processors. By 2003, the number of growers was estimated to be 500,000 in an area of 108,000 hectares with total production of 1 million metric tonnes in two growing seasons (MoA, 2005).

Many potato varieties including Roslin Eburu, Roslin Tana, Nyayo, Kenya Sifa, Kenya Baraka, Desiree, Asante, Tigoni, Annet, Dutch Robyjn and Kerr's Pink are currently grown and marketed in Kenya (KAIC, 2004). But most of these varieties are faced with the challenge of susceptibility to diseases and poor processing qualities (MoA, 2007). Furthermore, the nutritional information on these potatoes is not well documented. Although the National Potato Research Center (KARI-Tigoni) continues to develop new varieties presumed to be superior to existing ones in terms of disease tolerance (mainly late blight and viruses), the processing qualities of new releases have never been adequately established. Among the existing varieties, the long oval white (Nyayo and Roslin Tana) and the red-skinned Desiree are the most popular for French fries (chips) while the round red-skinned types Kerr's Pink and Dutch Robyjn are commonly used for crisps (Kabira, 2000). The French fry processing characteristics of Asante, Tigoni and Furaha have also been evaluated but this was limited to sensory evaluation.

The most important products in the Kenyan potato processing industry are potato chips (French fries), followed by crisps and frozen chips whose demands have rapidly increased due to rapid growth of fast food restaurants and snack bars in the urban areas (Walingo et al., 2004). The processing industry requires potatoes with well-defined characteristics including high consumer and processing qualities that can only be established through appropriate evaluation.

Storage is important both at family level and nationally as the crop becomes an important dietary constituent (Kabira, 1983; Walingo et al., 2004). In order to supply potatoes throughout the year, storage should be in low-cost stores and not rely on electric and mechanical power that is unaffordable to many farmers and processors. High storage temperatures affect processing quality of potatoes by accelerating metabolic activities which lead to deterioration. It would therefore be important to know the effect of storage conditions on processing and nutritional qualities of different potato cultivars. Potatoes for storage should be fully mature to permit ease of handling and transportation. Time of harvest affects yields, storage and processing quality (Kabira, 1983; Burton, 1989). The potato is a living organism with high water content subject to weight loss and loss of quality due to respiration, water evaporation and chemical changes. In low temperature regimes (below 14 ^{o}C) in the highlands, potatoes keep for one to two months before sprouting depending on variety, growing and weather conditions. On the average, most varieties can be stored for up to 12 weeks before excessive losses can begin to occur (Kabira, 1983). Many farmers lack storage facilities and are forced to sell crops soon after harvesting, often fetching low prices. Improvement in post-harvest storage using natural cool air for ventilation is becoming increasingly necessary because the supply of potatoes at harvest normally exceeds prevailing market demand and those not sold immediately must be stored in sufficient amounts to meet demands until the next harvest, 4 to 5 months later. Past investigations have shown considerable losses during storage under farm-level conditions in Kenya. However, no information is available on effects of storage on processing and nutritional quality characteristics of major potato varieties during storage at prevalent ambient air conditions under which most of potatoes are held before they are sold or eaten. Results of studies on frozen French fries showed that the product can store for 3 to 6 months depending on variety and still be acceptable for consumption (Kabira, 2000; Talburt and smith, 1967). Reports from the United States showed an increased trend towards potato utilization in form of frozen chips due to convenience and longer shelf life which ensures steady supply on all growing seasons (USAID, 2001). In Kenya, the technology is new to many and only one or two companies have ventured into the business with most of the product being imported (Walingo et al., 2004). In order to supplement efforts made at the National Potato Research Centre, Tigoni, 18 potato cultivars including 8 varieties and 10 advanced potato clones were screened and the physico-chemical properties and potential for processing into frozen French fries of selected potato cultivars were evaluated.

1.1 Justification

Kenyan potato breeders are challenged by the rapidly growing potato industry to develop new varieties with improved processing qualities besides resistance to major pests and diseases. In an attempt to meet these challenges, researchers have come up with many varieties that are available in the market. New ones are also being developed at the KARI's National Potato Research Center, Tigoni and need to be evaluated for processing qualities before release as varieties. On the other hand, inadequate information on the physico-chemical characteristics and lack of adequate evaluation of processing suitability of Kenyan potato cultivars has contributed to underutilization of local potato tubers due to importation tubers for frozen French fry industry. These factors cause low profits to the producers, price fluctuation to consumers and underdevelopment of frozen French fry industry.

The potato industry in Kenya has undergone rapid expansion over the last decade with an estimated 500,000 growers, in 2003. The land under potato farming was estimated at 108,000 hectares with an output of 1 million tonnes per year in the two growing seasons (MoA, 2003). The annual production was worth KSh.5 billion when valued at farm gate, while at consumer prices the crop was valued at more than KSh.10 billion per year. At the international level, potato is the most important source of food among the non-cereal crops, fourth after wheat, rice and maize. In Kenya, the crop is second to maize due to its high production per unit time and land and is suitable for rotation with barley, maize and wheat and hence important to the economy (Kabira, 1990; Lemaga and Kabira, 2003).

The potato is consumed fresh as boiled or processed into chips (French fries), crisps, frozen chips and other potato-based snacks (Walingo et al., 2004). Processing adds value, provides a means to carry over surpluses from one season to another as it contributes to better shelf life, easy handling and helps reduce transport costs.

Furthermore, processing reduces over-reliance on consumption of maize as staple food adding to the available food supply besides forging links between agriculture and industry and creating employment. The most important potato products in Kenya are chips, followed by crisps, potato based snack foods and frozen chips. The demand for these products has rapidly increased over the years (Walingo et al., 1997) yet little effort has been made to develop potato varieties with appropriate qualities for this rapidly developing Industry. The long oval white varieties, Nyayo, Roslin Tana and Desiree are the most popular for chips while the red-skinned types-Kerr's Pink and Dutch Robyjn are used for crisps. Although past investigations have shown considerable losses during potato storage, no information is, however, available on effects of storage on processing and nutritional quality characteristics of major potato varieties during storage at prevailing ambient air conditions under which most of potatoes are held before they are sold or eaten. Many cultivars resistant to diseases are available but can only be recommended for release after their processing qualities have been elucidated. Results of previous studies on frozen French fries show that potato chips from local cultivars can be stored for 3-6 months and still be acceptable for consumption (Kabira, 2000). Recent reports from the United States give an increased trend towards potato utilization in form of frozen French fries due to convenience and longer shelf life and hence ensure steady supply of processed potatoes (USAID, 2001). In Kenya the frozen French fry technology is new to many and only one or two companies have ventured into the business with most of the product being imported from South Africa (Walingo et al., 2004). In order to supplement efforts made at the National Potato Research Centre, Tigoni, there was need to evaluate and come up with suitable varieties for processing into frozen chips to support local industry, and ensure steady supply of the products all year round without relying on importation.

1.2 Objectives

Main objective: To evaluate the physico-chemical properties of selected potato varieties and clones and their potential for processing into frozen French fries.

1.2.1 Specific objectives

The specific objectives were:

1. To investigate suitability of commercial potato varieties and advanced clones for processing into frozen French fries.
2. To evaluate the physical and chemical characteristics of selected potato cultivars.
3. To evaluate processing quality of selected potato cultivars.
4. To evaluate the processing properties and nutritional value of stored raw tubers and frozen French fries from selected cultivars.

1.3 Hypotheses

1. Commercial potato varieties and advanced clones are suitable for processing into frozen French fries.
2. Physical and chemical characteristics are not different in the selected potato cultivars.
3. All the selected potato varieties and advanced clones are suitable for processing into fries.
4. Some potato cultivars, fresh or stored can produce acceptable French fries whose quality does not change appreciably when stored frozen up to 3 months.

CHAPTER 2

2.0 LITERATURE REVIEW

Potato (*Solanum tuberosum*) is globally the most widely grown food crop after rice, wheat and maize (Burton, 1989). The crop has its origins in the Andes Mountains of Peru and Bolivia from where it spread throughout the whole world. In Kenya, potato is the second most valuable staple food crop after the cereal grains (MoA, 2003).

The potato tuber is an enlarged portion of an underground stem, rhizome or stolon of the potato plant. Most tubers are found at the end of the stolon. Botanically, the tuber is a stem with the "eye", as true leaf scar. It is a storage organ for nutrients manufactured during the growth cycle of the plant. The proximate composition and nutrient composition depends on growing season-temperature, rainfall, soil and nutrient elements, area grown, cultural practices, maturity, method of harvesting and genetic make-up (Burton, 1966; Smith, 1977). The periderm is usually removed on peeling and losses as much as 20% may be realized varying with age, eye depth, shape and extent of periderm removal (Gould, 1977).

2.1 Distribution of potato in Kenya

Potato production is confined to the high altitude areas (1500-3000 m above sea level) where it has higher production potential than maize and other cereals (Hunt 1980; Kabira 1990; MoA, 2006). Most growing areas are in Central Province (Kiambu, Muran'ga and Nyeri), Eastern (Meru), Rift valley (Molo, Mau Narok and Kinangop) and small quantities in the high altitudes of Coast and Western provinces (Kabira, 1990). Most of the production is on small family farms of two hectares on average.

Seed propagation is best above 2300 m as below this the potatoes very are susceptible to degenerative virus diseases. Potatoes require regular rainfall of about 25 mm per week and the yield is governed by rain duration with 3 month period as minimum (Hunt, 1980). The potatoes do well in free draining, fertile, medium-loam soils. Heavy soils restrict tuber growth.

2.2 Nutritional contribution of potato

The potato has been regarded as a crop for the industrialized nations and hence of minor economic and nutritional importance to the less developed countries (Horton, 1987). Ironically, a third of the world's production is from the developing countries and economically, potato is very important after rice, wheat and maize. There has been increased production due to the use of modern technology and science in plant breeding, pest management, and post-harvest technology (Horton, 1987). In Kenya, production has increased tremendously over the years. By 2003, the average annual production was estimated at 1 million metric tonnes per year (MoA, 2003). Potato produces more energy and protein per hectare than the other staples. Table 1 shows average contents of major constituents of the potato tuber. The total solid content (dry matter content) is important for quality and should be high for processed products yields and less oil absorption (Kirkpatrick et al., 1956). It is genetically determined and significant difference exists between varieties and is influenced by cultural factors (Burton, 1966).

Table 1: Average content of major constituents of the potato tuber.

Constituent	Average weight (% of total tuber)	Range
Water	80.00	66.30-86.70
Dry matter content	20.00	13.70-34.80
Carbohydrates	16.90	15.4-26.80
Protein	2.00	1.00-2.00
Lipid	0.10	0.10-1.00
Ash	1.00	1.00-4.00

Source: Woolfe, (1987)

Dry matter content varies with tuber size (more in small tubers and less in larger tubers) and is determined indirectly by measuring the specific gravity since the relationship is well documented (Burton, 1966; Ludwig, 1972).

Potato protein content is the same as that of wheat but higher than that of rice and corn. The protein has a high proportion of essential amino acids especially lysine which is limiting in most cereals. It is, however, less in sulphur containing amino acid (methionine) and hence can form a complementary base with the cereal staples. The complementary relationship is historical since it has been used with other foods to sustain many lives in the past. Potato bread was a principal diet in the First and Second World Wars and in the Andes, it was well consumed with foods like milk to meet daily requirements (Burton, 1989). The potato can supply up to 7%, 6% and 5 % daily protein needs for children aged 1-2 years, 2-3 years, 3-5 years, respectively from 100 g and up to 3-6 % for adults depending on the body weight according to the United Nations Food and Agricultural Organization (FAO, 1989).

In Britain, potato was considered a better source of protein than energy and potentially by far the most important source of vitamin C (Burton, 1989). About 2 kg of boiled potatoes can provide 6.4 g N that is enough to meet daily requirements. Cooking and processing by any method does not lead to appreciable loss of the dietary N from the potato (Burton, 1989). The protein content ranges 1.6-2.1 g/100 g on fresh weight basis and has a high biological value (70%) equaling that of soybean protein but varies slightly with varieties (Harris, 1978).

The potato was considered as fattening but the truth is that it is a poor source of energy and can only fatten at excessive levels of consumption (Burton, 1989). The energy requirement for an adult is about 17,000 KJ, puberty (boy-17,000 KJ and girl-14,000 KJ) and children 4,000 KJ. But 100 g potato can only supply 290 KJ, meaning that one would require about 4.5-5.5 kg to supply 13000-16000 KJ to meet the requirements and more than 6 kg to have surplus which would fatten. The energy increases, however, by 20% due to fat in processing. Chips would, therefore, supply about 600 KJ/100 g fresh weight basis meaning one would require to have eaten about 3.5 kg to meet energy demands (Harris, 1978).

The major vitamin contributions include vitamin C, thiamine, riboflavin and niacin. Vitamin C concentration ranges from 3-40 mg/100 g fresh weight and is found as reduced and oxidized forms (Harris, 1978). According to WHO/UK, its requirement is 20 mg per day; to alleviate scurvy one requires 10 mg per day (Burton, 1989). The vitamin is susceptible to loss on cooking and processing especially when the potato is cooked and kept hot. The loss is also aggravated by subsequent storage, but refrigeration slows down its break down. The UK supply of vitamin C from potatoes was estimated to be 19.4-30 % (Kwiatkowska et al., 1989). The potato compares well with other vegetables with 100 g supplying 10 % thiamine and niacin, 5-10 % vitamin B6 and 50 % vitamin C (Horton, 1987).

Important minerals found in the potato tuber are given in Table 2.

Table 2: Mineral composition[1] of the potato tuber

Element	Maximum range	Approximate normal range
Calcium	10-130	30-90
Copper	0.06-2.83	0.4-1
Iron	1.4-71.5	2.5-10
Magnesium	45.9-216.5	60-140
Manganese	0.0-51.1	0.5-9
Phosphorus	119-605	150-300
Potassium	1020-4500	2820
Sodium	0.0-332	20-300
Zinc	0.8-2.9	1.8

[1] On a dry matter basis (mg/100 g)
Source: Burton, (1989)

According to Horton, (1989), the potato is a moderately good source of iron (2.5-10 mg), phosphorus and magnesium (60-140 mg), iodine (0.002-0.6 mg), copper (0.06-2.83 mg), calcium (30-90 mg) and an excellent source of potassium in 100 g of potato. About 200 g of potatoes would provide 10 % of phosphorus and magnesium, up to 20 % copper, iron and iodine (Burton, 1989). The dietary fiber supply is mainly of peptic nature. Approximately 200 g will supply 2-4 g dietary fiber which is equivalent to about half that supplied by other commonly eaten vegetables. Fiber is good due to its bulk, water absorption and provision of substrate for gut micro-flora.

Although the potato is important in nutrient provision, it is important to note its antinutritive factors. Protease inhibitors are in the range of 15-25 % of the soluble proteins but are largely denatured by heat. Steroid alkaloid (solanine) is present at a concentration of 2-10mg/100g and is heat stable. Tubers with glycoalkaloid concentration of 20 mg/100 g and above are considered toxic and unfit for human consumption (Burton, 1989). Care is then needed on selecting potatoes and the green ones that have more of these antinutrients should be avoided (Kabira and Lemaga, 2003). No poisoning arising from these antinutrients has, however, been reported in Kenya. But care is needed in breeding programmes to avoid release of cultivars with high toxicity levels.

2.3 Potato processing in Kenya

Potato processing technologies were originally developed in the Andean mountains over 2000 years ago. Potato processing in the developed countries started during the 1st World War. Research on processing and construction of low cost facilities during the 2nd World War set the stage for great expansion of potato processing in the United States of America (Horton, 1987). In processing, potatoes are converted into products that are less bulky, perishable and less expensive to store and transport (Kabira, 1990). In Western Europe, the potato processing industry was started in the 1950s, initially using American technology. However, the specific European requirements concerning raw materials as well as consumer specifications for the final products created a need for research into appropriate potato processing techniques.

Over the years, the market for processed potato products in the whole of Africa seemed highly limited due to high cost of raw materials. Since 1990's, there has been increase in the number of small processing industries mainly producing snack foods such as crisps for sale to tourists and specific groups of consumers. In hotels and many restaurants, French fries are prepared mainly from freshly harvested potatoes, and a few hotels emulate the concept of frozen French fries that are mainly imported (Walingo et al., 2004). In Kenya, potatoes have been utilized mainly as fresh products for incorporation into local foods. In 1979, Durr and Lorenzl (1980) recorded five small-scale crisp processing plants processing about 10 tonnes of fresh potatoes per week out of the national production of 400,000-500,000 tonnes per year. The major consumers of the crisps were largely schools, kiosks and retail shops (Kabira, 1990). In the seventies, there was slow improvement in the processing due to slow expanding market mainly in the urban areas (Hunt, 1987).

Research on potato processing in Kenya was initiated in the late 1970's to service function to the National Potato Breeding and Development program (Kabira, 1987). Research conducted so far has, however, dealt mainly with suitability of the various cultivars for conventional processed products such as crisps, flakes and dehydrated potato products (Kabira and Njoroge, 1984; Kabira, 1990). More comprehensive national policy drafted on processing recognizes the need for simple technologies such as solar dehydration and frozen French fries, in order to promote greater utilization and preservation of potatoes (MoA, 2005).

2.4 Processing of Frozen French fries

Frozen potato products processing began in 1945 in America by commercial freezing of French fries using snowflakes to cover the products. The production increased in America from 3.5 million to 750 million kg by 1964. Rapid growth of institutional market accounted for most of the growth in the industry (Talburt and Smith, 1967). Other by-products such as patties, puffs, hush brown, and mashed potatoes are closely associated with frozen French fries production. These utilize slivers and short pieces or nubbins of potatoes that would otherwise be wasted in cutting operations.

Frozen French fries have gained popularity due to convenience to the consumer; needs only to remove the pack, heat in oven or finish fry before serving. Figure 1 shows the general process for frozen French fries.

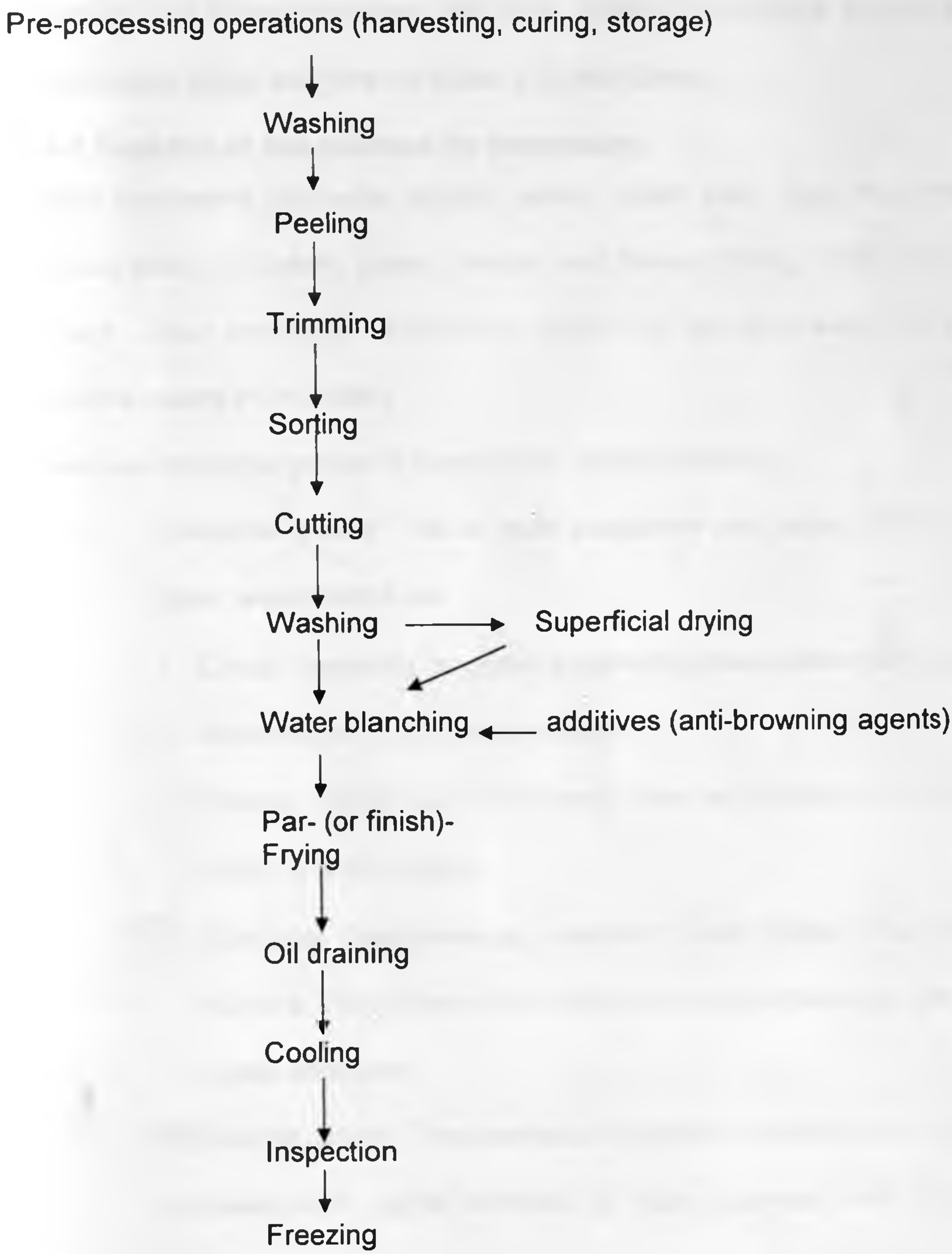

Figure 1: General flow sheet for processing of frozen French fries

The most common frying procedure is the double frying stage that involves par-frying which prepares the fries so that they take less time to finish-fry for consumption. The finish-frying can also be done in a conventional oven or microwave oven. A single fry can also be done at temperatures of 180 ˙ 200 °C for 4 min (Burton, 1989). Many advantages have been associated with frozen French fries including reduction in cost of shipping potatoes to consumer centers, greater flexibility in meal preparation, reception with minimum kitchen disruption, uniformity in quality through out the year and reduced labour and time for hotels and institutions.

2.4.1 Selection of raw potatoes for processing

Potato processing attributes include variety, tuber yield, high dry matter, finished product yield, oil content, colour, texture and flavour (Wong, 1992; Smith, 1975). In storage, colour and sugar reduction in addition to sprouting, weight loss and rotting influence quality (Hunt, 1980).

There are distinctive groups to consider for quality including:

i) *Consumer quality:* This is quite subjective and varies with the consumer. Basic requirements are:

- Colour: Important for quality judgment; golden yellow for French fries
- Amount of oil in the fried products.
- Texture and flavour: The French fries are crunchy on the out side but tender or mealy inside.
- Nutritional quality-energy, vitamin C and protein, few minerals and vitamins. These have little influence on consumers, as they are hidden quality attributes.

ii) *Processing quality:* The processor transforms potatoes into sellable product to make profit. He is interested in yield (turnover) with need to satisfy consumer demands. Requires potatoes that use less labour and are easy to process.

iii) *Producer quality:* The producer requires crops adapted to his environment that give good yields and are sold at good prices either immediately or after some period of storage.

To satisfy consumer quality demands, the processor must operate in a suitable environment and utilize the best available raw materials. The requirements include equipment, methods, and raw materials that are potatoes and oil.

The major problem in frozen potato products processing is the selection and procurement of suitable raw tuber stock. Raw potato tuber should be carefully selected to avoid high peeling and trimming losses and subsequent low yields (Wong, 1992). Though standards may differ from region to region, the tubers for French fries should have appropriate size and shape with reasonable dry matter content, with low levels of glycoalkaloids and low tendency to browning (Burton, 1989). For French fries, the following characteristics are considered when selecting potatoes for processing.

2.4.1.1 External tuber characteristics

a) Skin and flesh colour

Flesh colour, a result of anthocyanins (pink) and carotenoids (yellow/white) influences the colour of finished product and depends on variety (Harris, 1978). Pale yellow or cream white potatoes have been shown to produce slight golden coloured products good for chips. Colour is genetically determined and varieties should thus be carefully selected (Kabira and Lemaga, 2003).

b) Shape and size

These are very important attributes that must be considered when selecting raw tubers for French fry processing. There are four distinct shapes: round, oval, kidney shaped and pointed (Harris, 1978). For French fries, large size and long tubers (50 mm and above) are preferred for elongated strips. It is more of varietal influence as well as cultural. Shape and size influence the peeling losses or recovery (high losses for small tubers). Use of large tubers results in lower peeling losses and provides greater yield of long-cut fries especially desirable for restaurants (Smith, 1967).

c) Eye depth

Depth of tuber eyes is important when abrasive peeling is used. Deep eyes take longer to peel with excessive losses. Trimming time increases if the peeler has not removed eyes sufficiently resulting in increased costs. These are varietal characteristics and therefore one ought to choose potatoes with shallow eyes.

d) Greening

According to Kenyan potato standards, greening should not constitute more than 4 % of the total weight of the tuber (MoA, 2005). Greening occurs due to exposure of tubers to light where they develop chlorophyll and change from normal appearance. Greening is high in immature tubers stored at high temperatures and such tubers are high in glycoalkaloids beneath the skin (Harris, 1978).

e) Sprout growth: These should be very little or none at all (Smith, 1975).

2.4.1.2 Internal tuber characteristics

a) Dry matter content and specific gravity

The total solids content determines greatly the processing quality. Dry matter content influences the yield, oil content of the fried products and texture of the finished products. It also influences textural characteristics for French fries associated with palatability and mealiness. Tuber of high dry matter content is known to produce fries of high yield that absorb less oil and have good nutritive value (Burton, 1966; Smith, 1975). But too high dry matter content result into too hard and dry fries. High dry matter content (specific gravity of 1.080) also shortens the time of cooking since the tubers have less water and permits high frying turnover thus increasing profitability.

Dry matter varies from 13.1% to 36.8% and is influenced by the potato variety and harvest maturity (Smith, 1975). For French fries, the dry matter content should be 20-24% (Kabira and Lemaga, 2003).

b) Reducing sugars

The reducing sugar content influences the colour of the finish-fried products. Tubers with high reducing sugars result in darker and bitter products. For French fries, potatoes should have 0.5 % reducing sugars or less on fresh weight basis (Kabira and Lemaga, 2003). The major sugars in potatoes are sucrose, fructose and glucose. The reducing sugar content is low in fully mature tubers but may accumulate with cold storage. Immature tubers have high sucrose (Kabira, 1990). Apart from maturity, reducing sugars are also influenced by storage conditions. At temperatures below 10°C, starch is converted to reducing sugars that then accumulates in the tubers (Talburt and Smith, 1967). Due to the need to prolong storage life (minimize sprout, shriveling and spoilage), tubers can be stored to as low as 5 °C and then reconditioned at 15 °C and above prior to use in order to reduce the levels of reducing sugars to acceptable levels (Nielsen and Wickel, 1967).

c) After cooking blackening

This form of darkening occurs in pre-peeled, oil blanched, boiled tubers, steamed, frozen, canned or dehydrated potato products and greatly depends on variety (Kabira and Lemaga, 2003, 2003). The discoloration normally occurs at stem ends of the tubers. It is due to black coloured complex compounds produced by reaction of ferric iron and orthodihydric phenol (chlorogenic acid). Cultivars that with tubers that darken 24 hours after boiling are not suitable for processing into frozen French fries (Kabira and Lemaga, 2003).

2.4.2 Peeling potatoes for processing

Peeling is the second most important step in processing frozen French fries after selection of raw tubers. Peeling efficiency and effectiveness determine yield of the finished products to a great extent, even more so than percent solids, labour costs of inspections, wastes and disposals (Harrington and Shaw, 1967).

Ideal conditions a remove thin layer and leave no peel, eyes or other material to be removed by trimming. But in practice, this condition is not achieved and inspection coupled with trimming (labour) amounts to half of the total peeling cost. Sometimes peel losses run as high as 25-30 %. Depending on the peeling procedure, certain changes such surface damage and cooked layer on surface may occur on the surface of the potato. No single peeling method is, however, applicable universally or is there any that is satisfactory for every situation. The method used depends on the type of plant (Talburt and Smith, 1967). For small plants compact, inexpensive equipment will be suitable but peel and trim losses are always high except they are flexible in operation. Large processing companies require continuous peeling equipment rather than batch-type peelers for smoother running and efficiency. Whichever method is chosen, it should minimize hand trimming and inspection. Methods employed include hand peeling, abrasion-peeling, lye-peeling (immersion in sodium hydroxide at low or high temperature), steam peeling (use of steam under high pressure) or a combination of steam and lye peeling. Common peeling methods include hand peeling using knives, abrasive peeling by machine, and peeling by lye or steam (Martz, 1984, Kabira and Lemaga, 2006).

2.4.3 Blanching

This is a term used to refer to heat treatment (60-100 °C for 5 to 20 min) of vegetables in order to, among other things, prevent enzymatic browning. The strips are blanched prior to frying. The major benefits of this operation include:

- Uniform colour of fried products.
- Decreased fat absorption through gelatinization of the surface starch.
- Decreased frying time as potato is partially cooked.

- Improved texture of the final product.

The leaching of sugars that result from this operation serves to even out variations of sugar concentrations at or near the surface of French fries. It gives lighter and more uniform colour, but does not eliminate the need for reconditioning. The process may, however, lead to loss of desirable flavour, vitamins, minerals and nitrogen component (Woolfe, 1987). Two blanchers may be operated in series including one with diluted sugar concentration to control surface sugar for required colour. After blanching, the fries have to be dried to reduce water load on the fryer and minimize rate of hydrolytic break -down of fat (Benes et al., 1941). The lower the moisture, the less frying time is taken and fat absorbed and hence less soggy fries are produced.

2.4.4 Deep fat frying

From the dryer, the potato strips are conveyed directly to the fryer. The capacity of the equipment generally is limiting in the process line. Most manufacturers use continuous fryers but some use batch type equipment. Modern continuous fryers process from 2-4 tonnes of raw potatoes per hour. The essential elements of the unit include:

- A tank of hot oil where fries are cooked.
- Means of heating and circulating oil.
- Filter for removing particles from the oil.
- Conveyer to carry fries into and out of the tank
- Reservoir with heated oil for adding to the circulating oil.
- Vapour collecting hoods above the tank.

The batch equipment has an oil tank and heating element only; perforated wire baskets are used to hold the French fries. The thermostatically controlled temperatures used range from 160-200 °C.

The oil used should be highly refined to give finished products of good flavour, texture and appearance. There should be constant replenishment of oil to compensate for that absorbed by the chips. Chips fried at high temperatures have lower oil content than those fried at lower temperatures since the low viscosity of the hotter oil favours more complete drainage of oil from cooked chips. After cooking, the high temperatures should be maintained on the chips for 1-2 min to reduce significant amount of oil that adheres on the cooked fries. Chips may be sorted in size at this point if sorting was not done at selection of raw materials. Addition of spices if desired is done immediately when fat is still liquid to cause maximum adherence. Fat absorbed enhances flavour but if in excess, an oily product is obtained. Oil content varies with dry matter content of the raw potato, strip sizes and retention time in heating oil (Talburt and Smith, 1967).

Two modes of frying can be used, single stage or two stages where the strips pass first fryer for a half of the cooking time before being finished in the second fryer. Double stage frying increases through-put rate and permits even colour development. Frying reduces the moisture content and hence loss in yield. Some fat is, however, absorbed and hence the yield finally may fall to 30-45 % (Talburt and Smith, 1967).

The quality of oil used is affected by different factors. It should be the highest quality possible since the oil is part of the finished product and will be subjected to prolonged storage. The recommended fat turnover period (time taken to replace fresh oil) is 10-16 hr. Metals such as copper should be avoided to prevent break down of free fatty acids. Volatilized contents should not be allowed to drip back from the exhaust, to prevent them carrying off-odors and off-flavours and fat deterioration. Particles of potatoes are removed periodically to avoid being charred and lowering oil quality. The equipment should be periodically cleaned to avoid accumulation of gums that will not only decrease rate of heat transfer, but also increase chances of strips sticking together.

2.4.5 Freezing and packaging

Loose pieces of French fries may be frozen on perforated continuous belt in a tunnel freezer before being packed in poly bags of different sizes ready for storage or distribution to hotels and catering institutions. For batch processors, the fries are left to cool under ambient air temperatures before packaging and deep-freezing at -18 °C (Talburt and Smith, 1967).

2.5 Nutritive value of frozen French fries

Frozen French fries are the most important frozen potato products that include patties, mashed potatoes, puffs and hash brown. They may be either par-fried or finished fried by the processor; in the former case they are finish-fried later in deep fat, and the latter, oven heated before consumption. The various unit operations in their production affect the nitrogenous constituents, vitamins and minerals (Woolfe, 1987).

Commercial brands of frozen fries were found to have only 66 % of the total protein of the home made fries (Augustin et al., 1979). Exposure of potatoes to water or high temperature during processing reduced total N to 85 % and 81 %, respectively of its original value in large and small-sized French fries with main point of loss being the blanching water (Augustin et al., 1979). Significant ($P \leq 0.05$) losses of glutamic and aspartic acids, valine, phenylalanine, arginine, methionine and tryptophan occurred during hot water (77°C) blanching of 0.95 cm-thick French fries (Kozempel et al., 1982). More losses of the amino acids occur through the maillard browning reaction between sugars and amino acids during frying, although to a small extent (Woolfe, 1987).

Commercial production of French fries can lead to considerable losses in vitamins with great losses being caused by peeling, slicing and blanching operations (Augustin et al., 1979). Frying was found to cause loss in vitamins except ascorbic acid and thiamine. Other factors influencing the extent of losses are: previous storage of raw materials, size of French fry cut, type of blanching and finishing operations (frying or oven-heating). Overall loss when freshly harvested potatoes were used was 44 % for ascorbic acid and thiamine, 39% riboflavin and 24 % niacin (Gorun, 1978). The losses increased to 72 %, 54 %, 45 % and 35 %, respectively when the potatoes were stored in a cold store for six months prior to use. Generally, significant amounts of all vitamins are lost during the preparation of frozen French fries.

No information is available on mineral losses during frozen French fries production. Woolfe (1987) assumed that losses would occur through removal of outer tuber layers during peeling and leaching on slicing, boiling and blanching. Up to 30 % of the ash was demonstrated to have been lost in frozen French fries attributed to processing and finishing operations other than deep-frying (Woolfe, 1987).

2.6 Storage stability of frozen French fries

Home frozen French fries stored at -18 °C maintained good quality for two months and thereafter became less acceptable with respect to flavour and texture. Kirkpatrick and others in 1956 made detailed study on effect of stored par-fried fries stored up to 9 months at -18 °C. French fries made from potatoes immediately after harvesting and frozen stored for 9 months were found to be acceptable when evaluated after finish-frying. There was decrease in colour and flavour scores but high scores were recorded on lack of oiliness and crispiness. All the potato fries made acceptable frozen fries. Losses after one year were not significant. When oil blanched frozen fries were held at ordinary refrigeration temperatures, (5 °C) taste panel gave low scores on flavour, texture and colour than at -18 °C and microbial counts were higher at the former temperature (Boyle et al., 1964). No varietal effect in storage stability has been reported in the past studies.

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 MATERIALS

Eight established potato varieties (released and marketed) and ten advanced potato clones (new potato cultivars developed and not yet named or released as varieties) from the national potato breeding program at the National Potato Research Center, Tigoni, were grown under the same standard cultural conditions for this study (Lung'aho and Kabira, 1999). On maturity, tubers were dehaulmed two weeks before harvesting prior to evaluation. Evaluations were done at the National Potato Research Center, Tigoni (processing, storage and sensory evaluation), Jomo Kenyatta University of Agriculture and Technology (chemical analysis) and University Of Nairobi's College of Agriculture and Veterinary Sciences (chemical analysis and validation).

3.2 METHODS

3.2.1 Preparation of potato tubers for processing

After harvesting, potatoes 50 mm diameter and above were selected and packed in plastic net bags in lots of approximately 18 kg weight. They were then left to cure at ambient air conditions (Appendix I) for three weeks in naturally ventilated dark store at the National Potato Research Station, Tigoni (Kenya Agricultural Research Institute). The potatoes were then ready for processing and storage evaluations.

3.2.2 Methods of screening trial for processing suitability

The tubers of the 18 cultivars were evaluated for processing using physical tuber characteristics of shape, size, eye depth, skin and tuber flesh colours, specific gravity and dry matter contents. The schematic diagram shown in Figure 2 was used to screen the materials with regard to colour of the processed and stored French fries. Sensory evaluation was also employed.

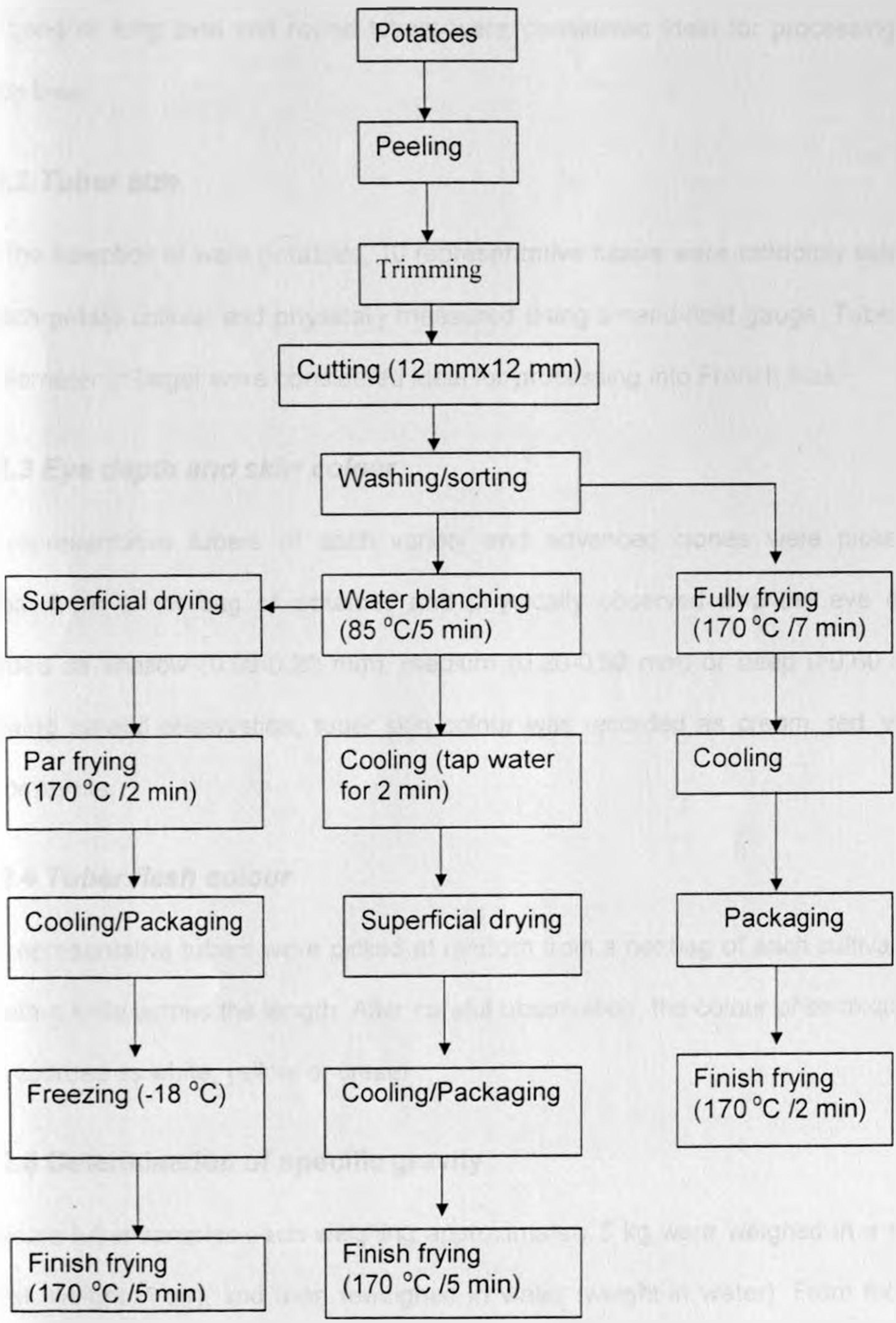

Figure 2: Laboratory processing scheme for chilled/frozen French fries.

3.2.2.1 Tuber shape

By observation, tuber shapes were recorded as round, elongated, long, oblong or oval. Long or long oval and round tubers were considered ideal for processing into French fries.

3.2.2.2 Tuber size

After the selection of ware potatoes, 10 representative tubers were randomly selected for each potato cultivar and physically measured using a hand-held gauge. Tubers 50 mm diameter or larger were considered ideal for processing into French fries.

3.2.2.3 Eye depth and skin colour

Ten representative tubers of each variety and advanced clones were picked at random from a net bag of potatoes and physically observed and the eye depth recorded as shallow (0.00-0.20 mm), medium (0.20-0.50 mm) or deep (>0.60 mm). Following careful observation, tuber skin colour was recorded as cream, red, white, pink or purple.

3.2.2.4 Tuber flesh colour

Five representative tubers were picked at random from a net bag of each cultivar and cut with a knife across the length. After careful observation, the colour of each cultivar was recorded as white, yellow or cream.

3.2.2.5 Determination of specific gravity

Duplicate tuber samples each weighing approximately 5 kg were weighed in a metal basket (weight in air), and then reweighed in water (weight in water). From the two measurements, specific gravity (SG) was calculated as follows:

$$SG = [\text{Weight in air (g)}] / [\text{Weight in air (g)} - \text{Weight in water (g)}]$$

Tubers with values greater than 1.075 were considered to be of good quality for processing. Tubers with specific gravity values less than 1.070 were generally unacceptable (Lulai and Orr, 1980).

3.2.2.6 Moisture and dry matter determination

Five tubers were chopped into approximately 1-2 cm pieces and mixed thoroughly. Triplicate samples of approximately 20 g were placed in tared open aluminium dishes and each weighed accurately. They were dried in a thermostatically controlled air-oven at 80 °C for 72 hr, cooled in a desiccator and weighed. The weight of the residue was calculated as percent dry matter. Potatoes with dry matter contents greater than 20% were considered acceptable for processing.

% dry matter = (Weight of residue/Sample weight) X 100

3.2.3 Processing methods

3.2.3.1 Abrasive peeling

Representative tubers (4 kg) from each variety or clone were weighed before peeling was accomplished using an electrical-driven abrasive peeler (EP 05/5171/CO, Metcalfe Equipment Ltd., North Wales) for 2-3 min. The peeled potato tubers were washed and sorted to remove the low-grade tubers and trimmed with kitchen knife to remove decayed portions, greened parts and the remains of the eyes and skin.

3.2.3.2 Cutting and sorting

The tubers were cut lengthwise using a hand-operated cutter to produce 12x12 mm fries. They were sorted to remove the short or broken pieces less than 30 mm in length. The fries were washed under running tap water to remove surface starch which could cause the fries to stick together during frying. Excess water was removed from the surface of the fries by mopping with cloth towel.

3.2.3.3 Blanching and cooling

Potato strips (12x12 mm) from each cultivar were immersed into hot water at 85 °C for 5 min in a water immersion batch blancher and then drained on a wire-mesh screen. Water blanched fries were cooled under running tap water (18 °C) for 2 min before being dried and packaged, or par-fried, cooled and packaged before frozen stored in laboratory chest freezer at -18 °C.

3.2.3.4 French fries preparation

The fries were prepared by frying in an institution size, batch type deep oil fryer (E 6 ARO S.A., La Neuveville, Switzerland) containing about 7 litres of "Elianto" corn oil maintained at a fixed temperature of 170 °C. Frying was accomplished in two stages, par-frying (2 min), and finish frying (5 min). The fries were drained off oil (1 min), placed on plates and left to cool at room temperature before sensory evaluation, or being packaged into polyvinyl chloride bags (gauge 125), sealed, and taken to the laboratory for chemical evaluation, or for frozen storage for up to 3 month at -18 °C

3.2.3.5 Assessment of post frying darkening

Post frying darkening was assessed on scale of 1 (very low) to 5 (very high) according to French fry colour chart (NIVAA, 1984). For comparison purpose, colour of the fries was also measured using colour spectrophotometer (Model NF 333, Nippon Denshoku, Japan) and interpreted on the CIE L*a*b colour space. A standard white surface was used for calibration (Melton et al., 2001). The colour difference between the standard white surface and the sample was calculated from the following formula:

$$\Delta E^*_{ab} = \{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2\}^{1/2}$$

Where, ΔL^*, Δa^* and Δb^* are the respective differences in L^*, a^* and b^* values between the sample colour and the standard white surface.

3.2.3.6 Post-cooking discoloration

Representative tuber samples (2-5), free of diseases, undamaged and clean, were selected and placed in boiling water for 20-30 min. Tubers were considered ready when a fork penetrated them. The tubers were then placed on a white surface, cut longitudinally into halves and left to cool overnight. Colour of the samples were recorded on a scale of 1 (intense black discoloration) to 9 (no discoloration) (Kabira and Lemaga, 2003).

3.2.3.7 Sensory evaluation and colour of French fries

To asses acceptability of the potato fries to potential consumers, sensory analysis was performed by a panel of 10 members of the Kenya National Potato Research Station, Tigoni. Coded samples were presented to the panellists and scored for colour, texture, flavour, oiliness and overall acceptability on a 9-point hedonic scale (Larmond, 1977) with 1= extremely poor and 9= extremely good as shown in the score sheet (Appendix II). A score of 5 was the lower limit of acceptability. Analysis of variance was done to compare the difference in chips quality as affected by variety.

3.2.4 Analytical methods on potato and potato products

3.2.4.1 Determination of moisture content

The moisture content of fresh tubers and processed products was obtained by standard analytical method No. 14.003 (AOAC, 1980). Triplicate samples (5 g) were weighed in aluminum dishes and oven dried at 105 °C to constant weight. The dried samples were cooled in a dessicator to room temperature and weighed. Loss of weight due to drying was converted to percent moisture content as follows:

Moisture % = (weight of moisture evaporated/weight of sample) x 100

3.2.4.2 Determination of reducing sugars

Reducing sugars were determined by the Luff-Schoorl method number 4 of the International Federation of Fruit Juice Producers (1985). Potato cubes (100 g) were blended in a Waring blender with 100 ml water to obtain the juice. The juice was then clarified: 5 ml of Carrez I solution was added to 10 ml of the juice and mixed in 100 ml volumetric flask. This was followed by 5 ml Carrez II solution. The solution was then made to 100 ml using distilled water before being filtered.

The clarified sugar solution (25 ml) was put into a 100 ml volumetric flask, made up to the mark and well mixed. Duplicate samples (25 ml) of Luff's solution was put into a 300 ml conical flask and 10 ml of the diluted sugar solution added followed by distilled water to bring the volume to about 50 ml. The mixture was then heated under reflux condenser so that boiling started within 2 min and solution kept boiling for exactly 8 min. The mixture was immediately cooled and 9 ml of potassium iodide solution (166 g/l) added. Thereafter, 20 ml of 25 % sulphuric acid was added and the mixture swirled. The precipitated iodide was titrated with 0.1N sodium thiosulphate solution with 1% starch solution as indicator, from the blue colour to cream yellow. The titre volume was used to obtain reducing sugar levels (Appendix III) and the value multiplied with a factor (f) considering dilutions as follows.

Reducing sugar (mg/100 g) = X mg x factor

Where X = mg of reducing sugar obtained from the table

Factor = (100 x 100 x 200)/ (10 x 25 x 10)

3.2.4.3 Determination of total ash

Total ash was determined by standard analytical method No. 31.012 (AOAC, 1980). Two grams of the dried samples (section 3.2.4.1) were weighed in duplicate into porcelain ashing dishes previously cleaned and dried in an air oven at 105 °C, cooled in a dessicator and tared. The dishes were then held in a muffle furnace at 550 °C overnight before being removed and cooled in a dessicator to room temperature and weighed. The residue weight represented total ash. Percent ash was calculated as follows:

Ash % = (weight of ash remained/weight of sample) x 100

3.2.4.4 Determination of crude fibre

Crude fibre content was determined following standard analytical method No. 7.065 (AOAC, 1980). Two grams of dried samples were weighed in duplicate into 500 ml conical flasks and boiled with 200 ml of 1.25% sulphuric acid for exactly 30 min under reflux condenser. The digest was then filtered with Pyrex glass filter (crucible type) and the residue completely washed with boiling water until free of acid. The residue was then boiled with 200 ml of 1.25 % sodium hydroxide solution for exactly 30 min under reflux condenser and filtered, and washed with boiling water before washing with 1 % HCL. It was then washed twice with alcohol and three times with ether before drying at 100 °C for 1 hr. The residue was cooled in a dessicator and weighed (W_1) before incineration at 500 °C for 1 hr before cooling and weighing to get constant weight (W_2). Crude fibre was calculated as a percentage as follows:

Fibre % = {($W_1 - W_2$) /sample weight} x 100

3.2.4.5 Determination of crude fat

Crude lipid (ether extract) was determined by standard analytical method No. 7.056 (AOAC, 1980). Five grams (5 g) samples were weighed in duplicate in tared cellulose extraction thimbles (Whatman, 22x80 mm) and extracted with analytical grade petroleum ether (boiling point 40-60 °C) in Soxhlet extraction unit for 16 hr. The ether extract was transferred to 300 ml flat-bottomed flasks that had been previously washed, dried in an oven at 105 °C, cooled in a dessicator and weighed. Excess petroleum ether was evaporated and residual extract dried in an oven at 105 °C to constant weight and expressed as a percentage of the original dry weight as follows:

Fat % = (Weight of fat extracted/Sample weight) x 100

3.2.4.6 Determination of crude protein

Crude protein was determined as total nitrogen using the semi-micro Kjeldahl method No. 2.057 (AOAC, 1980). Total nitrogen was converted to protein using a factor of 6.25. Duplicate samples (1 g) were weighed in 100 ml Kjeldahl flasks followed by 5.5 g Kjeldahl catalyst ($CuSO_4$ K_2SO_4= 1:10). Sulphuric acid at the rate of 15 ml per sample was added. A blank analysis was carried out without sample at the same time. The flasks were heated on Kjeldahl heating assembly until all frothing stopped and a clear blue solution obtained. After cooling to room temperature, the digest was dissolved in 100 ml distilled water. The diluted digest (10 ml) was then mixed with 15 ml 40 % sodium hydroxide then steam distilled. About 60 ml distillate was collected from each sample in a 125 ml Erlenmeyer flask containing 25 ml of 4 % boric acid and two drops of mixed indicator (prepared by dissolving 0.2 % methyl red and 0.2 % methylene blue in methanol). The quantity of ammonia in the distillate was determined by titration with 0.02 N hydrochloric acid until colour changed from blue to dirty green. Percent crude proteins were calculated as:

Nitrogen % = (V_1-V_2) x N x f x 0.014 x 100/S, where,

V_1 = titre for the sample (ml), V_2 = titre for the blank (ml), S = weight of sample taken (g)

N = normality of standard HCL solution (0.02), f = factor of standard HCL solution.

Protein % = Nitrogen % x Protein factor (6.25).

3.2.4.7 Determination of total carbohydrates

Total carbohydrates were determined by difference: 100- (crude fibre + crude fat + crude protein + total ash + moisture content).

3.2.4.8 Determination of minerals

Minerals were determined in both raw and processed products by AOAC method of analysis No. 3.006-3.023 (AOAC, 1980). Triplicate samples (1g) were ashed in a muffle furnace at 500 °C for 2 hr and cooled. After cooling, 2 ml of 50 % nitric acid was added and evaporated on hot plate to dryness and ashed again for 1 hr. The ash cooled and dissolved in 10 ml of 50 % of hydrochloric acid and transferred to a 50 ml volumetric flask. 1 % HCL was used to top up to the mark. Shimadzu model AA Atomic Absorption Spectrophotometer (Shimadzu Corp., Kyoto, Japan Model AA-6200) was used to determine total calcium, sodium, potassium, zinc, iron, and magnesium using respective cathode lamps. Standard concentrations of these minerals were prepared (0.5, 1, 1.5, 2, 2.5 ppm), their absorbance taken and standard curves generated. Readings from the Atomic Absorption Spectrophotometer were used to calculate levels of the respective minerals.

Phosphorus was determined by methods of analysis No. 4500-P E. (AOAC, 1996). Triplicate samples (50 ml) prepared as for the other minerals were pipetted into clean conical flasks followed by 0.05 ml phenolphthalein indicator. A combined reagent (8 ml) was then added and mixed thoroughly. After at least 10 min and not more than 30 min, the absorbance of the samples was measured at 880 nm using reagent blank as the reference solution. The levels of phosphorus were then calculated from the standard curve.

3.2.4.9 Data analysis

Analysis of variance (ANOVA) and least significant difference test for the variables was conducted using the Statistical Analysis System (SAS version 9). Pearson correlation analysis was also performed to determine linear relationships where necessary.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 Trial 1: Screening of commercial varieties and advanced clones

4.1.1 Physical tuber characteristics

Physical tuber characteristics of the 8 potato varieties and 10 advanced clones used in the preliminary studies are given in Table 3.

Table 3: Physical tuber quality characteristics of 18 potato cultivars

Cultivar	Tuber shape[1]	Tuber size[2] (mm)	Eye depth[1]	Skin colour[1]	Flesh colour[1]
Tigoni	Round oval	50-70	Shallow	Cream	Cream
Roslin Tana	Long oval	50-65	Shallow	Cream	Cream
Desiree	Long oval	50-65	Medium	Red-purple	White
Kerr's Pink	Round	30-45	Medium	Pale-purple	White
Dutch Robyjn	Round	50-60	Medium	Red-purple	White-yellow
Kenya Karibu	Round	50-60	Medium	Deep-Red	Yellow
Kenya Sifa	Flat/round	60-80	Medium	Pink	Cream
Asante	Round	50-65	Medium	Red	White
393385.47	Round	55-70	Shallow	Cream	Yellow
392637.10	Round	50-65	Shallow	White-pink eyes	White
392617.54	Round	50-70	Medium	White	White
393385.39	Round	50-60	Medium	Red-purple	White
393280.57	Round	50-65	Medium	Red	White
393371.58	Round	50-75	Shallow	White	White
385524.9	Round	50-60	Shallow	White	White
399746.2	Oblong	60-85	Shallow	White-pink eyes	White
392657.8	Round	50-60	Shallow	White	White
391691.96	Round	50-65	Shallow	Dark-purple	Cream/white

[1]Determined visually

[2]Determined using a hand-held sizer gauge

Most cultivars, with exception of varieties Roslin Tana and Desiree, and clone 399746.2 that were either long oval or oblong, had tubers that were round in shape. All the cultivars except Kerr's Pink had tuber sizes of 50 mm and above in diameter.

Variety Kenya Sifa and clone 399746.2 had the largest tuber sizes (60 mm and above) while variety Kerr's Pink had the smallest tubers (below 50 mm).

Tuber shape and size are important characteristics with respect to external quality and greatly influence peeling and trimming losses during processing. The potatoes should therefore have good appearance in order to limit these losses (Talburt and Smith, 1967; Kabira, 2000). According to Kabira and Lemaga (2003), potatoes for French fries should be 50 mm and above in diameter. Furthermore, tuber shape influences the length of French fries; the tubers preferred by processors are long oval, oblong or elongated to give long-shaped finished products. Roslin Tana and Desiree that are elongated are well suited for the shapes of French fry strips. Tigoni, Kenya Sifa and clones 393371.58, 393385.47, 399746.2 and 391697.96 that are round or oblong also meet the shape criteria required for French fries given that their sizes meet the requirement. Kerr's Pink, Dutch Robyjn, Kenya Karibu, Asante and clones 392637.10, 392617.54, 393385.39, 393280.57, 385524.9 and 392657.8 have round shapes but they all, except Kerr's Pink, have tuber sizes (50 mm and above in diameter) in the range applicable for processing French fries especially where the short fries are a delicacy.

All the cultivars had either shallow or medium eye depths. None had deep eye depths that would lead to adverse losses during peeling and trimming. The cultivars can therefore be suitable for processing French fries without major losses (Smith, 1975; Kabira and Lemaga, 2003).

Most cultivars had white/cream or red skin colours with exception of clone 391691.96 that had dark-purple skin. White/cream colour was dominant in the flesh of tubers. White or red skin colours are associated with good quality by many Kenyan consumers (Kabira, 2000). The clone 391691.96 is an exception; dark purple skin colour is a rare appearance and may not be popular with the consumers at the initial stages of introduction but may trigger curiosity (but does not affect process suitability).

4.1.2 Specific gravity and dry matter content

Variation in specific gravity and dry matter of the potato varieties and clones used in the preliminary evaluation work are given in Table 4.

Table 4: Specific gravity and dry matter content of 8 potato varieties and 10 advanced clones

Cultivar	Specific gravity[1] ± sd	Dry matter content[2] (%) ± sd
Asante	1.075 ± 0.002	19.06 ± 0.398
Desiree	1.087 ± 0.004	22.53 ± 0.627
Dutch Robyjn	1.096 ± 0.002	24.33 ± 0.711
Kerr's Pink	1.091 ± 0.002	23.15 ± 0.344
Kenya Karibu	1.090 ± 0.001	24.03 ± 0.202
Kenya Sifa	1.076 ± 0.004	20.29 ± 0.471
Tigoni	1.084 ± 0.002	22.28 ± 0.375
Roslin Tana	1.090 ± 0.002	23.01 ± 0.186
392637.1	1.074 ± 0.001	20.10 ± 0.203
399746.2	1.067 ± 0.003	20.10 ± 0.427
393385.39	1.074 ± 0.002	20.35 ± 0.304
393385.47	1.090 ± 0.004	24.25 ± 0.141
392617.54	1.068 ± 0.003	18.59 ± 0.202
393280.57	1.058 ± 0.001	16.63 ± 0.092
393371.58	1.078 ± 0.001	21.02 ± 0.695
392657.8	1.066 ± 0.002	16.41 ± 0.185
385524.9	1.074 ± 0.002	19.40 ± 0.231
391691.96	1.086 ± 0.004	22.95 ± 0.064

[1]Determined by the-under water weight method.
[2]Determined by oven drying.
Results are means of three determinations.

The specific gravity of cultivars varied from 1.058 in clone 393280.57 to 1.096 in variety Dutch Robyjn. All the cultivars except clones 393280.57, 392657.8, 399746.2 and 392617.54 had specific gravity more than 1.070. Dry matter content ranged from 16.41 % in clone 393280.57 to 24.33 % in Dutch Robyjn. Most cultivars except variety Asante, and clones 393280.57, 392657.8, 385524.9 and 392617.54 had dry matter contents above 20 %.

There were significant ($P \leq 0.05$) differences in the dry matter contents of the cultivars. The highest dry matter content was observed in Dutch Robyjn (24.25 %) followed by

Kenya Karibu (24.03 %). These tubers also had higher specific gravities showing linear relationship between dry matter content and specific gravity (Ludwig, 1972; Smith, 1975). The average dry matter content of 20.94 % is in agreement with results reported by Woolfe (1987). Tubers with higher dry matter and specific gravity generally have higher yields, lower oil absorption, better texture and flavour and are more economical to process (Lulai and Orr, 1979; Burton, 1989). French fries processing requires tubers with dry matter content of above 20% and specific gravity of 1.070 and above (Kabira and Lemaga, 2003). Therefore, using specific gravity and dry matter content as quality selection criteria, clones 393280.57, 392657.8, 399746.2 and 392617.54, and variety Asante would not be suitable for processing into French fries.

4.1.3 Colour changes after processing

Different modes of processing were employed in order to screen the selected varieties and clones for processing into frozen French fries. Table 5 shows the average NIVAA colour scores for French fries in frozen storage after a month of observation. Scores for after-cooking blackening of boiled tubers following 24 hr exposure at ambient air conditions are also presented.

Deep-frozen samples that had been subjected to 4 different treatments (water blanching, oil blanching, and water blanching and par-frying, and fully frying) showed mixed colour changes following a month of frozen storage. Samples from varieties Tigoni, Roslin Tana, Desiree, Dutch Robyjn, Kerr's Pink, Kenya Sifa and Kenya Karibu, and clones 393385.47, 393385.39 and 391691.96 had colour scores below 2.5 that is the acceptable limit. They maintained acceptable colours (score below 2.5) and could be acceptable by consumers following a month of storage at -18 ^{o}C. The rest of the cultivars had scores above 2.5 and were therefore considered unsuitable for processing into frozen French fries. Colour scores for blackening after boiling were, however, slightly different. Variety Asante and clones 392617.54, 392637.10, 393280.57, 392657.8, 399746.2, 385524.9 and 393380.58 had lower colour scores of 5 and below. This means, they had blackened within 24 hr of observation. After-cooking blackening is a simple test performed to gauge suitability of potato cultivars for processing into frozen French fries. Any tuber that shows sufficient discoloration (score of 5 and below) shows that the potato cultivar is unsuitable for processing into frozen French fries. This indicates the tubers' susceptibility to browning or blackening under frozen storage (Kabira and Lemaga, 2003).

Table 5: Average colour scores for boiled tubers and frozen French fries processed from 8 potato varieties and 10 advanced clones after 1 month frozen storage

Cultivar	Water blanched[1]	Oil blanched[1]	Water blanched and par-fried[1]	Fully fried[1]	Boiled Tubers[2]
Tigoni	1	1	1	1	9
Roslin Tana	1	1	1	1	9
Desiree	1	1	2	1	9
Kerr's Pink	1	1	2	1	9
Dutch Robyjn	1	1	2	1	9
Kenya Karibu	1	1	2	2	9
Kenya Sifa	1	1	1	1	7
Asante	4	2	2	3	5
393385.47	2	1	2	2	9
392637.1	3	2	5	5	7
393385.39	1.5	2	1	1	7
392617.54	3	3	5	4	7
393280.57	4	5	5	4	5
393371.58	3	5	5	4	1
385524.9	5	5	5	4	1
399746.2	5	5	5	4	5
391691.96	1	1	1	1	9
392657.8	4	5	3	3	5

[1]Scores of 2.5 and below are acceptable on a scale of 1 to 5.

[2]Colour of the boiled samples were recorded on a scale of 1 (intense black discoloration), 5 (sufficient discoloration to make the potatoes unacceptable) to 9 (no discoloration).

4.1.4 Sensory evaluation

Table 6 shows average sensory and NIVAA colour scores for French fries processed from 8 potato varieties and 10 advanced clones.

Table 6: Average sensory and NIVAA colour scores for French fries processed from 8 potato varieties and 10 advanced clones.

Cultivar	Overall acceptability[1]	Flavour[1]	Colour[1]	Texture[1]	Oiliness[1]	NIVAA colour scores[2]
Tigoni	6.20a	6.10a	6.20b	5.90a	5.20a-b	1.00d
Roslin Tana	6.00a	6.10a	6.10b	5.90a	5.30a-b	1.00d
Desiree	6.70a	6.20a	6.60a	5.90a	5.70a	1.00d
Kerr's Pink	5.30d	4.80c	4.70e	5.60a	4.80a-b	1.00d
Dutch Robyjn	5.70b	5.70b	5.70c	5.60a	5.40a-b	1.50c
Kenya Karibu	5.80b	5.60b	6.10b	5.60a	5.30a-b	1.50c
Kenya Sifa	5.60b	5.50b	5.80c	5.00b	5.40a-b	2.50bc
Asante	4.6d	4.80c	4.30f	4.20c	4.70a-b	3.00b
393385.47	5.9b	6.10a	5.60c	5.90a	5.20a-b	1.50c
392637.10	5.5c	5.20b	5.50c	4.90b	4.80a-b	1.50c
392617.54	5.40c	5.30b	5.40c	5.30b	5.20a-b	1.00d
393385.39	5.50c	5.00b	5.30c	5.00b	5.10a-b	2.50bc
393280.57	4.60d	4.40c	5.30c	4.20c	4.80a-b	4.00a
393371.58	5.20c	4.90c	4.20f	5.40a	4.80a-b	2.50bc
385524.9	5.50c	5.00b	5.00d	5.50a	4.90a-b	1.50c
399746.2	5.60c	5.30b	5.50c	5.60a	5.20a-b	1.00d
392657.8	5.40c	4.90c	4.60e	4.30c	4.30c	2.50bc
391696.96	5.90b	5.30b	5.00d	5.80a	5.30a-b	1.00d
CV (%)	2.22	3.89	1.85	1.22	2.26	2.20
LSD (P≤0.05)	0.73	0.50	0.40	0.56	0.51	0.52

[1]Evaluation was done on 9-point hedonic scale. A score of 5 was the acceptable lower limit.
[2]Scores of 2.5 and below are acceptable on a scale of 1 to 5.
Means with the same letter in the same column are not significantly different.

The NIVAA colour scores and sensory data (Table 6) had a significant (P≤0.05) correlation coefficients (r=-0.759) indicating the agreement between sensory and objective colour measurement. The results showed that all the potato varieties and advanced clones tested, except Asante and 393280.57 were suitable for processing into fresh French fries. The varieties, Desiree, Tigoni and Roslin Tana had in general higher French fry quality compared to other cultivars. Colour perception was significantly (P≤0.05) different among the cultivars. The sensory colour quality of Desiree (6.6) was the highest, while those of Tigoni and Roslin Tana were comparable. Variety Kerr's Pink and Asante, and clones 393280.57, 393371.58 and 392657.8 were unacceptable.

Flavour perception was significantly ($P \leq 0.05$) different among the cultivars. All the tubers except those of Asante, Kerr's Pink, 393280.57, 393371.58 and 392657.8 gave acceptable flavour. Oil and browning products represent the primary flavouring sources in French fries (Lloyd, et al., 2004). Textural scores were statistically ($P \leq 0.05$) different among the cultivars. For texture liking, Asante, 392637.10, 393280.57 and 392657.8 had scores below acceptable limit of 5. The rest of the tubers were acceptable (scores above 5).

Scores for oiliness were generally lower compared to other attributes. Oily mouth feel liking was not statistically ($P > 0.05$) different. Tubers of Kerr's Pink, Asante, 392637.10, 393371.58, 393371.58, 385524.9 and 392657.8 had scores below the acceptable limit. This shows that the fries from these cultivars retained more oil giving high oily mouth feel not preferred by consumers (Lloyd, et al., 2004). Overall acceptability of the fries from the cultivars was statistically ($P \leq 0.05$) different. Apart from Asante and clone 393380.57 that had significantly unacceptable lower scores (below 5), the rest of the tubers were acceptable to the panelists. The sensory results for fresh fries show that the panelists generally rejected only two cultivars, Asante and clone 393280.57.

4.1.5 Preliminary conclusion

In short, preliminary processing and screening of the 8 potato varieties and 10 advanced clones showed that all the cultivars except Asante and clone 393380.57 could be processed into fresh French fries. Seven varieties (Tigoni, Roslin Tana, Desiree, Kenya Karibu, Kenya Sifa, Kerr's Pink and Dutch Robyjn) and three advanced clones (391691.96, 393385.47 and 393385.39) could be used to process frozen French fries and warranted further evaluation. Tubers of Kerr's Pink and Roslin

Tana were, however, not available for further study since they had undergone degeneration due to susceptibility to viral diseases and other infections including late blight. Therefore, this left only five varieties (Tigoni, Desiree, Kenya Karibu, Kenya Sifa, and Dutch Robyjn) and three advanced clones (391691.96, 393385.47 and 393385.39) for further studies on processing into frozen French fries.

4.2 Trial 2: Evaluation of selected 5 potato varieties and 3 advanced clones (8 cultivars) for processing into frozen French fries

4.2.1 The physical tuber quality characteristics

Details of physical tuber quality characteristics of the eight cultivars are given in table 3. All the 8 cultivars had acceptable sizes (50 mm and above in diameter) as recommended for fries (Kabira and Lemaga, 2003) and the lengths (30 mm and above) that is appreciated by most consumers (Walingo et al., 2004; Oreldo, 2004). For proper conceptualisation of the 8 cultivars, photographs of the tubers showing external and internal characteristics are given in figures 3-10.

Figure 3: Tuber characteristics of variety Kenya Karibu.

Kenya Karibu tubers are round in shape. Tuber sizes range from 65-75 mm in diameter and 70-90 mm in length. They are reddish pink in skin and yellow in flesh. They have medium eye-depths. The characteristics suit them for processing into French fries.

Figure 4: Tuber characteristics of advanced clone 393385.47.

The advanced clone 393385.47 is oblong and elongated in shape with tuber size of 60-70 mm in diameter and 70-80 mm in length. The tubers have shallow eyes, cream/yellow skin colour and yellow flesh. These qualities make the cultivar suitable for processing into French fries.

Figure 5: Tuber characteristics of variety Dutch Robyjn.

Dutch Robyjn tubers are round in shape with medium/deep eye-depth. Tubers have light purple skin colour and the flesh is cream yellow. The size ranges 55-65 mm in diameter and 65-80 mm in length. The variety has been known to be suitable for processing crisps and also famous for mashing (mukimo). Its qualities are suitable for processing into French fries.

Figure 6: Tuber characteristics of advanced clone 391691.96.

Clone 391691.96 is dark purple in skin colour and cream/white in flesh. The tubers are round in shape with shallow eye-depths. The size ranges 45-65 mm diameter and 50-60 mm long. They may be used to process French fries of medium length.

Figure 7: Tuber characteristics of variety Tigoni.

Tigoni tubers are round with shallow eyes. The skin and flesh are cream/yellow in colour. Size ranges from 65-75 mm in diameter and 60-80 mm in length. The qualities make it suitable for processing into French fries.

Figure 8: Tuber characteristics of variety Desiree.

Tubers of Desiree are elongated oval in shape with medium eye-depths. They are reddish pink and cream yellow in flesh colour. Tubers range from 55-70 mm in diameter and 80-140 mm in length. These tubers have been used to process long fresh French fries.

Figure 9: Tuber characteristics of variety Kenya Sifa.

Kenya Sifa tubers are large (70-80 mm in diameter, 70-90 mm long). They are round in shape with shallow eyes. Tubers are reddish pink in skin and cream yellow in flesh. These qualities appropriate for processing into French fries.

Figure 10: Tuber characteristics of advanced clone 393385.39.

The clone 393385.39 has light red skin colour with cream flesh. The tubers are round in shape and sizes range from 55-65 mm in diameter and 45-60 mm in length. They have medium/deep eye depth. They may be used to process French fries of medium length.

4.2.2 Specific gravity and dry matter content

Table 7 shows variation in specific gravity and dry matter content of the 8 potato cultivars immediately after harvesting and after 12 weeks storage at ambient conditions.

Table 7: Specific gravity and dry matter contents of 8 potato cultivars immediately after harvesting and after 12 weeks storage at ambient conditions

	Fresh tubers immediately after harvesting		Tubers after 12 weeks storage at ambient conditions	
Cultivar	**Specific gravity[1] ± sd**	**Dry matter content[2] ± sd**	**Specific gravity[1] ± Sd**	**Dry matter Content[2] ± sd**
393385.39	1.075 ± 0.003	20.556 ± 0.092	1.080 ± 0.001	21.276 ± 0.344
393385.47	1.083 ± 0.003	22.836 ± 0.250	1.089 ± 0.004	24.053 ± 0.129
391691.96	1.076 ± 0.002	20.973 ± 0.421	1.085 ± 0.004	22.953 ± 0.064
Desiree	1.087 ± 0.003	22.213 ± 0.163	1.088 ± 0.002	22.460 ± 0.512
Dutch Robyjn	1.092 ± 0.003	24.660 ± 0.178	1.095 ± 0.002	25.013 ± 0.220
Kenya Karibu	1.081 ± 0.001	21.136 ± 0.239	1.090 ± 0.001	22.966 ± 0.104
Kenya Sifa	1.082 ± 0.002	20.880 ± 0.191	1.076 ± 0.004	21.180 ± 0.123
Tigoni	1.084 ± 0.002	22.283 ± 0.375	1.083 ± 0.001	23.736 ± 0.382

[1]Determined by the-under water weight method
[2]Determined by oven drying
At ambient conditions (15-19 °C/86-92 % rh)
Results are means of three determinations.

The specific gravity of the cultivars varied from 1.075 in clone 393385.39 to 1.092 in variety Dutch Robyjin when evaluated immediately after harvesting. With specific gravity of 1.075 and above, all the tubers were suitable for processing French fries (Kabira and Lemaga, 2003; Smith, 1975). In all the fresh and stored tubers, Dutch Robyjn consistently had high specific gravity followed by clone 393385.47 while clone 393385.39 had low levels. Storage at ambient air conditions had no significant (P>0.05) effect on the specific gravity.

High dry matter content was recorded in all the cultivars. There were significant (P≤0.05) differences in the dry matter contents of the cultivars with values ranging from 20.56 % in clone 393385.39 to 24.66 % in Dutch Robyjn. This range of dry matter content falls within recommended levels as far as French fries processing is concerned. After 12 weeks of ambient storage, dry matter content significantly (P≤0.05) increased in all the cultivars. Such increase can be attributed to water evaporation from the tubers over time period of storage (Smith, 1975; Woolfe, 1987; Burton, 1989).

Variety Dutch Robyjn had the highest dry matter content followed by Tigoni while the rest of the cultivars had almost the same values. Whereas the results of dry matter content in Dutch Robyjn are lower than that of an earlier study, the levels in variety Disiree were comparable to those quoted by Imungi (1987).

Relationship between weight under water, specific gravity and dry matter

The relationships were described by linear regression equations. The relationship between the weight under water and dry matter content for 105 samples from 8 varieties and 10 advanced clones is illustrated in Figure 11. Relating the weight under water to dry matter of the potato cultivars in the results of investigation by von Scheele the relation was:

$$\% \text{ d.m} = 0.0493 \times \text{w.w.} + 1.95$$

But Lundun (1956) while doing almost similar investigation on different cultivars had different equation altogether:

$$\% \text{ d.m} = 0.05 \times \text{w.w.} + 2.55$$

In this investigation using the regression line from Figure 11 the relation that resulted was:

$$\% \text{d.m} = 0.0472 \times \text{w.w.} + 3.3708$$

There was high significant (P≤0.05) correlation coefficients (r=0.8366) between dry matter and weight under water, thus dry matter linearly increased with weight under water. The correlation coefficient exceeded 0.80 that is the required minimum for use in prediction. This means that with great level of confidence, weight under water of potatoes could be used to estimate percent dry matter contents as quick measure of quality.

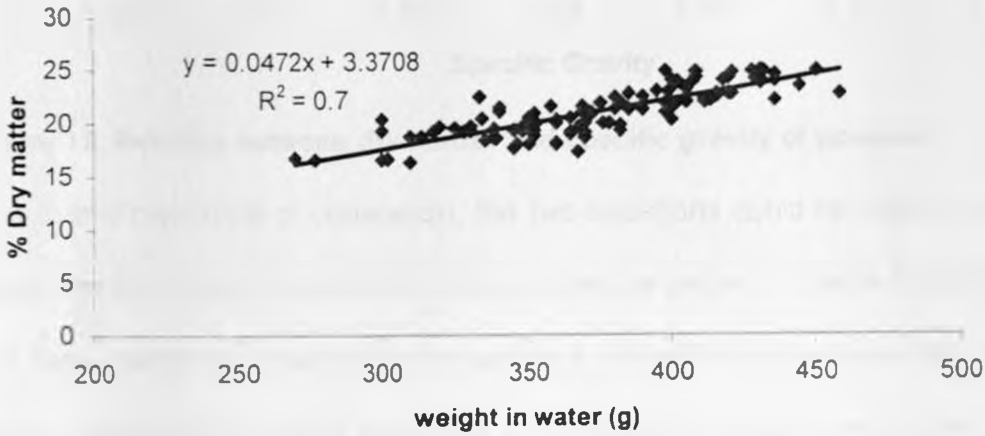

Figure 11: Relation between weight in water and dry matter content of potatoes

In his publication, Ludwig (1972) observed that the investigation done by Lundun (1956) could give the following relation between specific gravity and dry matter content:

%d.m. =215.73 (S.G. - 0.98.25)

In this investigation, there was significant (P≤0.05) correlation coefficient (r=0.81) between dry matter and specific gravity indicating linear relationship between the two parameters. This correlation coefficient exceeded the minimum 0.80 used for prediction (Figure 12). The regression line gives the following relation:

%d.m. = 195.52 x S.G. – 190.42

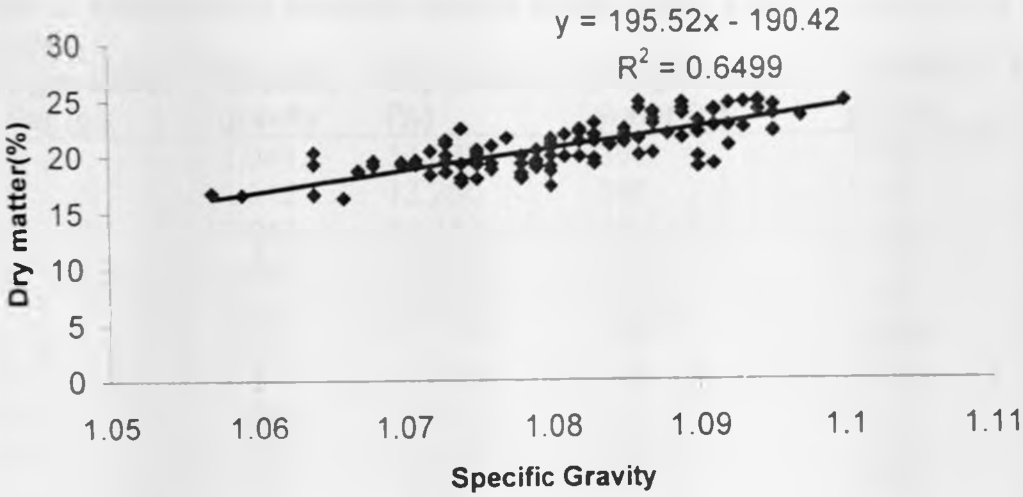

Figure 12: Relation between dry matter and specific gravity of potatoes

Due to this high level of correlation, the two equations could be used to calculate specific gravity and dry matter content of the potatoes as shown in Table 8. For quick estimation this table could be appropriate to estimate these two parameters by simply using the weight under water method especially in the potato processing industries.

Table 8: Relationship between weight under water, specific gravity and percent dry matter

Weight under water (g)	Specific gravity	Dry matter (%)	Weight under water (g)	Specific gravity	Dry matter (%)
200	1.041	13.023	380	1.082	21.201
205	1.042	13.250	385	1.084	21.428
210	1.043	13.477	390	1.085	21.655
215	1.044	13.705	395	1.086	21.882
220	1.045	13.932	400	1.087	22.109
225	1.046	14.159	405	1.088	22.336
230	1.047	14.386	410	1.089	22.564
235	1.049	14.613	415	1.090	22.791
240	1.050	14.840	420	1.092	23.018
245	1.051	15.067	425	1.093	23.245
250	1.052	15.295	430	1.094	23.472
255	1.053	15.522	435	1.095	23.699
260	1.054	15.749	440	1.096	23.926
265	1.056	15.976	445	1.097	24.154
270	1.057	16.203	450	1.099	24.381
275	1.058	16.430	455	1.100	24.608
280	1.059	16.658	460	1.101	24.835
285	1.060	16.885	465	1.102	25.062
290	1.061	17.112	470	1.103	25.289
300	1.064	17.566	475	1.104	25.517
305	1.065	17.793	480	1.106	25.744
310	1.066	18.020	485	1.107	25.971
315	1.067	18.248	490	1.108	26.198
320	1.068	18.475	495	1.109	26.425
325	1.070	18.702	500	1.110	26.652
330	1.071	18.929	505	1.111	26.879
335	1.072	19.156	510	1.113	27.107
340	1.073	19.383	515	1.114	27.334
345	1.074	19.611	520	1.115	27.561
350	1.075	19.838	525	1.116	27.788
355	1.077	20.065	530	1.117	28.015
360	1.078	20.292	535	1.118	28.242
365	1.079	20.519	540	1.120	28.470
370	1.080	20.746	545	1.121	28.697
375	1.081	20.973	550	1.122	28.924

4.3 Chemical composition of raw and processed potato tubers

4.3.1 Reducing sugar content

Figure 13 shows the reducing sugar levels in 8 potato cultivars at harvest and after 12 weeks of storage at ambient conditions.

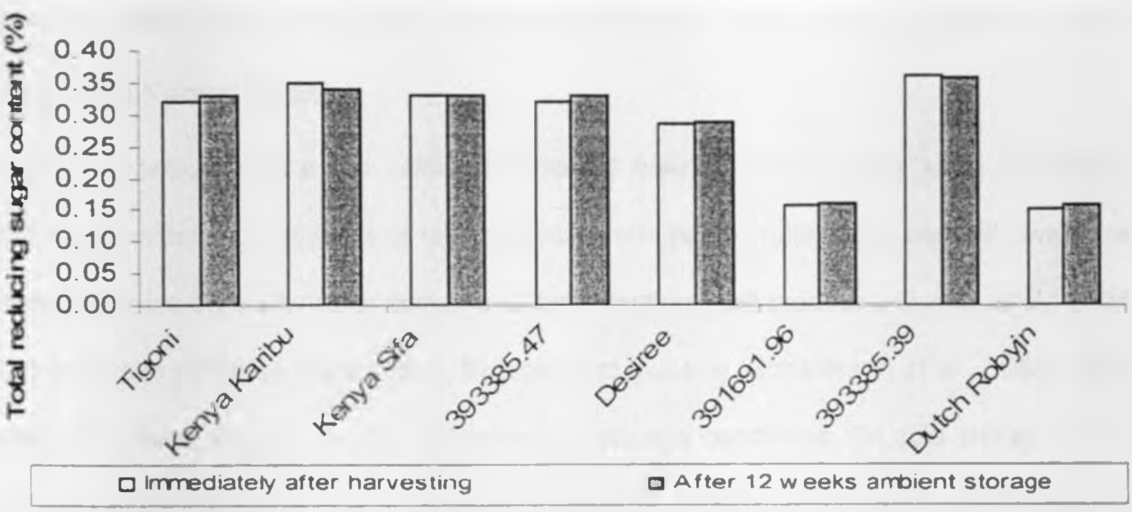

Figure 13: Percent total reducing sugars of 8 potato cultivars at harvest and following 12 weeks storage at ambient air conditions

There were significantly (P≤0.05) different levels of reducing sugar contents between cultivars. All the cultivars had low levels of reducing sugars with the highest recorded being 0.37 % in clone 393385.39 while Dutch Robyjn had the lowest level of 0.15 %. Potatoes for French fry processing should have total reducing sugars of 0.5 % and below (Nielson and Wickel, 1967). Besides factors such as environmental and cultural practices including temperature, mineral nutrition, harvesting and storage conditions, genetic component have a strong influence on initial reducing sugar levels in a mature tuber as well as during storage (van Es and Hartmans, 1987). The tendency to contain high or low content of sugars is a heritable trait (Kumar et al., 2004). As a result, cultivars have been bred particularly for chipping having in mind the levels of reducing sugars (Hamernik and Hanneman, 1998; Guar et al., 1999). In the present study, all the 8 cultivars could be used for chipping based on levels of sugars.

In all the cultivars, there was no significant (P>0.05) difference in total reducing sugar content between freshly harvested tubers and after 12 weeks of storage at ambient conditions (15-19 °C/86-92 % rh). This means that the ambient air conditions did not trigger any sugar accumulation or reduction in either of the two harvests and could be appropriate for storage so long as other components of potatoes are not adversely changed. Such results were also reported by Kabira (1983) using varieties Kerr's Pink, Desiree and Kenya Baraka.

Reducing sugars influence the colour of finished fried potato products such as French fries. Presence of excessive amounts of reducing sugars in potato tubers has been shown to result in unacceptably brown coloured or darker and bitter tasting fried products (Kumar et al., 2004). The major sugars in potatoes are sucrose, fructose and glucose (Schwimmer et al., 1954). Apart from maturity, reducing sugars are also influenced by storage conditions. On cold storage (4 °C), total reducing sugars increased in all cultivars (Figure 14). After one month of cold storage, there was a sharp increase in reducing sugars in variety Dutch Robyjn and clone 391691.96 that had low initial reducing sugars than the other cultivars. In the second and third month, reducing sugar levels were almost at par for all the cultivars and there were no significant (P>0.05) differences noted.

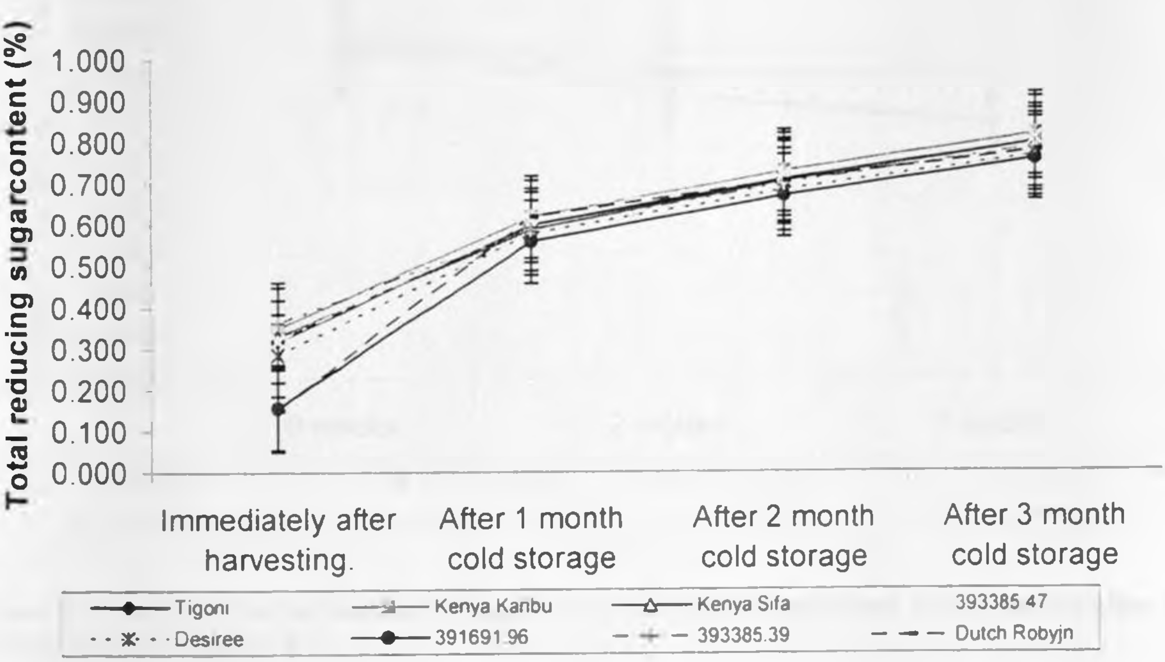

Figure 14: Variation of total reducing sugars for cultivars at harvest and following 3 months cold storage at 4 °C

At temperatures below 10 °C starch is converted to reducing sugars that then accumulate (Talburt and Smith, 1967; Hertog et al., 1997). Due to the need to prolong storage life (minimize sprout, withering and spoilage), however, tubers can be stored to as low as 4°C and then reconditioned at 15 °C and above prior to use (Nielsen and Wickel, 1967). The only challenge is that not all varieties behave this way (Kumar et al., 2004). In this study, reconditioning for 3 weeks (maximum recommended period) following 3 months of cold storage (minimum period aimed to be achieved in cold storage) did not reduce total reducing sugars to safe levels (below 0.5%) in all the cultivars (Figure 15). The fries produced from cold stored tubers from all the cultivars were dark brown and had burnt flavours that were unacceptable to the taste panel. This means that none of the varieties can be stored in cold stores and later be used for processing French fries. Research can, however, be carried out to come up with varieties that can either chip directly from cold storage or after reconditioning to reap the benefits of potato cold storage (Sowokinos, 1996). Breeding programs that can yield such cultivars should be encouraged.

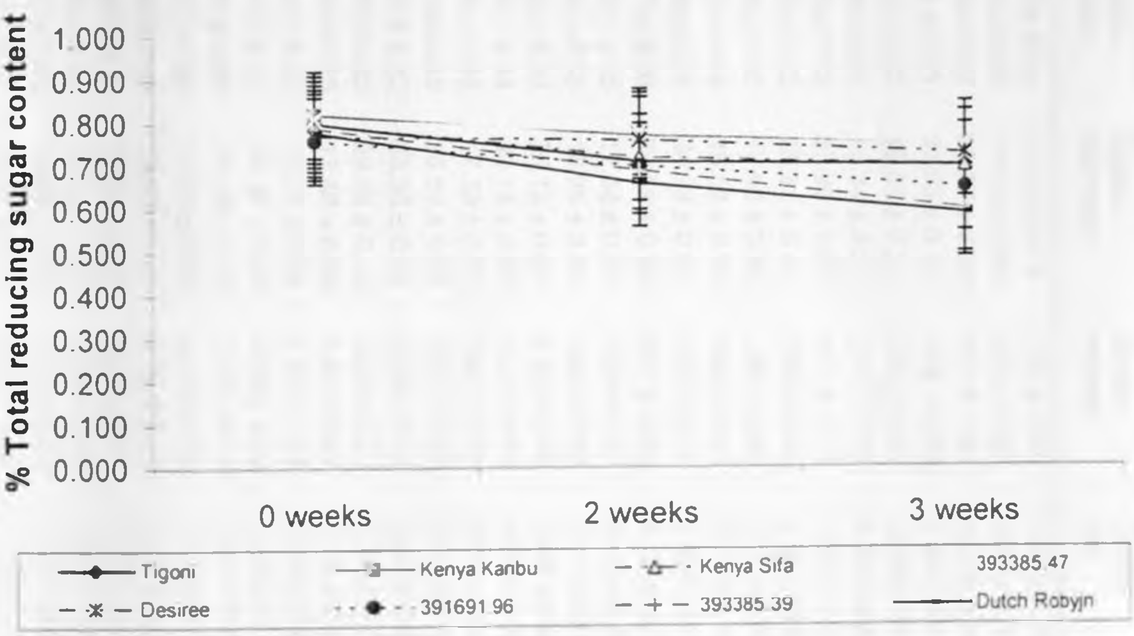

Figure 15: Variation in total reducing sugars on reconditioning tubers of 8 cultivars after 3 months cold storage at 4°C

4.3.2 Proximate Composition of potato cultivars and their products

Proximate composition of 8 different cultivars and processed products is given in Table 9. Raw and boiled potato tubers had lower average energy content than French fries. The energy content averaged 334 KJ per 100 g in cultivars.

Table 9: Proximate composition of 8 potato cultivars and their processed products (g/100 g)-FWB

Cultivar	Potato product	Energy KJ	Moisture Content	Carbo-hydrates	Crude Protein	Crude Fat	Crude Fibre	Total ash
Tigoni	Raw	358 ± 0.33	76.90 ± 0.36	19.28 ± 0.15	1.91 ± 0.07	0.09 ± 0.18	1.22 ± 0.05	0.95 ± 0.16
	Boiled	340 ± 0.32	78.20 ± 0.35	17.78 ± 0.03	2.33 ± 0.25	0.08 ± 0.25	1.15 ± 0.07	0.80 ± 0.04
	Fresh fries	792 ± 0.20	53.96 ± 0.22	35.37 ± 0.29	3.77 ± 0.08	3.62 ± 0.78	1.47 ± 0.25	1.81 ± 0.08
	Frozen fries	776 ± 0.30	57.36 ± 0.21	31.85 ± 0.10	3.23 ± 0.10	4.99 ± 0.85	1.21 ± 0.08	1.36 ± 0.06
Kenya Karibu	Raw	320 ± 0.22	79.10 ± 0.29	16.85 ± 0.23	2.08 ± 0.45	0.09 ± 0.10	1.06 ± 0.35	1.09 ± 0.04
	Boiled	313 ± 0.25	79.78 ± 0.30	16.34 ± 0.21	2.16 ± 0.16	0.08 ± 0.09	1.05 ± 0.11	0.89 ± 0.16
	Fresh fries	879 ± 0.11	49.45 ± 0.13	37.20 ± 0.04	4.75 ± 0.15	4.68 ± 0.73	1.64 ± 0.21	2.28 ± 0.13
	Frozen fries	766 ± 0.13	58.45 ± 0.12	29.31 ± 0.41	3.63 ± 0.14	5.69 ± 0.84	1.27 ± 0.04	1.65 ± 0.18
Kenya Sifa	Raw	322 ± 0.30	79.50 ± 0.40	17.63 ± 0.17	1.32 ± 0.63	0.12 ± 0.08	1.06 ± 0.19	0.76 ± 0.44
	Boiled	312 ± 0.32	80.15 ± 0.44	16.59 ± 0.03	1.81 ± 0.16	0.11 ± 0.14	1.07 ± 0.21	0.69 ± 0.16
	Fresh fries	813 ± 0.20	54.15 ± 0.25	34.93 ± 0.44	3.69 ± 0.04	4.42 ± 0.90	1.36 ± 0.23	1.45 ± 0.05
	Frozen fries	775 ± 0.23	58.77 ± 0.26	30.59 ± 0.56	2.77 ± 0.18	5.75 ± 0.76	1.13 ± 0.10	0.99 ± 0.28
393385.47	Raw	334 ± 0.32	78.59 ± 0.58	17.80 ± 0.21	1.89 ± 0.23	0.12 ± 0.06	1.00 ± 0.13	0.89 ± 0.33
	Boiled	321 ± 0.30	79.56 ± 0.58	16.95 ± 0.34	1.95 ± 0.28	0.11 ± 0.04	1.07 ± 0.16	0.76 ± 0.01
	Fresh fries	785 ± 0.52	54.52 ± 0.30	35.13 ± 0.63	3.92 ± 0.45	3.48 ± 0.62	1.26 ± 0.14	1.69 ± 0.18
	Frozen fries	776 ± 0.52	57.56 ± 0.34	32.14 ± 0.20	3.29 ± 0.16	4.84 ± 0.38	1.13 ± 0.08	1.04 ± 0.28
Desiree	Raw	327 ± 0.20	78.88 ± 0.46	17.33 ± 0.62	1.92 ± 0.72	0.13 ± 0.02	1.11 ± 0.02	1.07 ± 0.12
	Boiled	315 ± 0.21	79.78 ± 0.46	16.51 ± 0.04	2.03 ± 0.32	0.13 ± 0.21	1.13 ± 0.04	0.91 ± 0.12
	Fresh fries	823 ± 0.42	53.78 ± 0.22	33.96 ± 0.59	4.00 ± 0.02	4.97 ± 0.92	1.22 ± 0.21	2.07 ± 0.22
	Frozen fries	810 ± 0.44	57.67 ± 0.30	29.46 ± 0.13	3.29 ± 0.29	6.93 ± 0.62	1.33 ± 0.07	1.55 ± 0.35
391691.96	Raw	320 ± 0.50	79.40 ± 0.25	17.40 ± 0.04	1.61 ± 0.39	0.05 ± 0.18	1.14 ± 0.04	0.76 ± 0.40
	Boiled	312 ± 0.51	80.02 ± 0.26	16.74 ± 0.34	1.76 ± 0.78	0.06 ± 0.25	1.12 ± 0.09	0.68 ± 0.10
	Fresh fries	928 ± 0.25	46.78 ± 0.02	41.30 ± 0.58	4.38 ± 0.39	4.31 ± 0.78	1.69 ± 0.25	1.54 ± 0.01
	Frozen fries	768 ± 0.24	58.44 ± 0.04	31.18 ± 0.92	3.15 ± 0.14	5.11 ± 1.00	1.23 ± 0.16	0.89 ± 0.04
393385.39	Raw	323 ± 0.12	79.22 ± 0.50	17.03 ± 0.04	2.01 ± 0.28	0.10 ± 0.17	1.10 ± 0.18	0.95 ± 0.11
	Boiled	314 ± 0.10	79.89 ± 0.49	16.43 ± 0.34	2.09 ± 0.52	0.11 ± 0.14	1.12 ± 0.15	0.81 ± 0.53
	Fresh fries	941 ± 0.44	46.98 ± 0.11	38.87 ± 0.58	4.83 ± 0.24	5.55 ± 0.49	1.58 ± 0.45	2.19 ± 0.13
	Frozen fries	776 ± 0.36	58.33 ± 0.16	29.05 ± 0.92	3.54 ± 0.28	6.11 ± 0.49	1.45 ± 0.24	1.52 ± 0.08
Dutch Robygyn	Raw	389 ± 0.16	75.06 ± 0.35	20.64 ± 0.36	2.39 ± 0.13	0.09 ± 0.05	1.04 ± 0.05	1.01 ± 0.23
	Boiled	377 ± 0.14	76.02 ± 0.40	19.74 ± 0.61	2.55 ± 0.51	0.10 ± 0.11	1.06 ± 0.08	0.83 ± 0.10
	Fresh fries	857 ± 0.32	49.51 ± 0.20	39.45 ± 0.63	4.74 ± 0.14	3.09 ± 0.77	1.22 ± 0.18	1.99 ± 0.18
	Frozen fries	815 ± 0.44	54.94 ± 0.23	33.81 ± 0.71	3.81 ± 0.80	4.90 ± 0.10	1.20 ± 0.01	1.45 ± 0.04

Means ± sd

Carbohydrate= 100-(%moisture content + % crude fat + %crude fibre + %crude fat + % ash).

Variation in dry matter content of the cultivars contributed to a range of energy contents (312-389 KJ). Such variations were also found in North America (Toma, 1978). According to Woolfe (1987), raw potato tubers have lower average energy content (318-334 KJ/100 g) compared to other roots and tubers such as sweet potato (485 KJ/100 g), yam (444 KJ/100 g) and cassava (607 KJ/100 g). French fries, however, had higher amounts of energy ranging from 776 KJ to 941 KJ per 100 g. These values are slightly lower than those reported by Woolfe, (1987). The increase of energy in the fries has been attributed to the absorbed oil during frying (Burton, 1989; Lloyd et al., 2004).

Carbohydrate content varied in the raw tubers ranging from 16.34 % to 19.74 %. The range in the study compares well with those reported earlier by Smith (1975) and Woolfe (1987). The potato carbohydrates have been classified as starch, non-starch and sugars.

Starch is mainly found in pockets called granules in form of amylopectin and amylose, and contributes a major part of the dry matter and hence a major contributor to the energy value of the potatoes. In the tuber, it decreases from the skin towards the centre (Woolfe, 1987). Non-starch polysaccharides constitute very little portion of the dry matter (1.2 % on fresh weight basis). They are structures that form the cell wall and middle lamella material such as celluloses, lignin, hemicelluloses and pectin that are mainly insoluble. Their importance lies in the texture of the finished product.

The average crude protein of 1.89% (FWB) in the cultivars was comparable to those of most root and tuber staples. The protein composition is, however, slightly different with potato having high digestibility and more lysine, but with low levels of sulphur-containing (methionine and cystine) amino acids (Woolfe. 1987). Hence, potato can complement other staples.

The crude fibre ranging from 1.04 to 1.22 % compares with those found earlier by Woolfe (1987) and Paul and Southgate (1978) of 1-2 g/100 g on fresh weight basis. Compared to other raw items, its level is similar to that of sweet potatoes but lower than that of other roots and tubers. Potatoes cooked as French fries offers more concentrated source of crude fibre (1.21-2.12 %) than when potatoes raw or boiled.

The ash content of the potatoes averaged 0.94% per 100g in the cultivars. French fries had ash content in the range of 1.01 % to 1.14 %. This range compares well with those reported by Burton (1989) and Woolfe (1987). There exists a large range of minerals that constitute the ash content reported by many authors as attributed to soil type, application of fertilizers and potato variety.

4.3.2.1 Effect of processing and storage on the chemical composition of raw potato tubers and process products

4.3.2.1.1 Carbohydrate content

Table 10 shows variation in carbohydrate contents of the potato tubers for the different cultivars when raw and processed. Carbohydrate levels differed significantly ($P \leq 0.05$) in raw tubers and processed potatoes among cultivars. Total carbohydrates ranged from 85.31 % in Kenya Karibu to 88.72 % in Kenya Sifa for raw tubers. The potato has been reported to have lower average carbohydrate content than other roots and tubers such as sweet potato and cassava. Due to large variation in tuber dry matter content, carbohydrate content varies greatly within varieties (Woolfe, 1987).

Table 10: Carbohydrate content (% dwb) in raw and processed potato tubers

Cultivar	Raw	Boiled	Fresh fries	Frozen fries
393385.39	88.67a	88.72a	81.74a	76.65a
391691.96	85.83c	86.24bc	77.22c	73.66d
393385.47	87.08b	87.50b	80.65a	77.38a
Desiree	86.15bc	86.26bc	77.17c	72.40e
Dutch Robyjn	85.74c	86.11bc	80.67a	77.35a
Kenya Karibu	85.31c	85.50d	77.21c	75.10c
Kenya Sifa	88.72a	88.44a	79.74b	76.35a
Tigoni	87.11b	86.40	80.04a	76.21b
CV (%)	0.57	0.54	1.08	0.80
LSD ($P \leq 0.05$)	0.74	0.70	1.26	0.90

Results (dry basis) are means of two determinations
Means with the same letters within the same column are not significantly different at 5%level of significance

Boiled tubers did not have significant (P>0.05) difference in carbohydrate contents compared to raw tubers. Carbohydrate levels, however, reduced significantly (P≤0.05) in fresh and frozen fries. Similar reductions have been explained to result from reaction with amino acids during non-enzymatic (maillard) browning and damage due to crystallized water on freezing par-fried fries (Woolfe, 1987; Ramasawmy et al., 1999).

The levels of carbohydrates did not, however, differ significantly (P>0.05) when fresh tubers were compared to stored tubers in both harvests (Table 11). This was the same for the processed forms. The major change occurring in carbohydrate chemistry during storage has been attributed to conversion of starch or sucrose to reducing sugars (Woolfe, 1987; Blenkinsop et al., 2003). But the ambient storage under which these tubers were subjected did not trigger this kind of reaction as had earlier been ascertained in the study of reducing sugars in section 4.3.1. This explains lack of significant change in carbohydrate content in the cultivars in question.

Table 11: Total carbohydrate content (% dwb) in freshly harvested and ambient stored tubers with their processed products

Cultivar	Treatment	Raw	Boiled	Fresh fries
393385.39	A	85.83e	86.24c	77.22c
	B	86.00d	86.25c	76.45cd
391691.96	A	88.67ab	88.72a	81.74a
	B	89.11a	88.83a	81.78a
393385.47	A	87.08c	87.50b	80.65a
	B	87.47c	87.10b	81.28a
Desiree	A	86.15d	86.26c	77.17c
	B	86.26d	86.24c	76.73d
Dutch Robyjn	A	85.74e	86.11c	80.67a
	B	86.12d	85.95d	80.18a
Kenya Karibu	A	85.31e	85.50d	77.21c
	B	85.35e	84.98e	78.38c
Kenya Sifa	A	88.72ab	88.44a	79.74b
	B	89.02a	88.88a	80.34a
Tigoni	A	87.11c	86.40c	80.04a
	B	87.73c	86.16c	79.38b
CV (%)		0.41	0.57	0.99
LSD (P≤0.05)		n.s	n.s	n.s

Results (dry basis) are means of two determinations
Means with the same letters within the same column are not significantly different at 5%level of significance.
A=immediately after harvesting, B=after 12 weeks ambient storage

4.3.2.1.2 Crude protein

Table 12 shows the crude protein content of the potato tubers for the different cultivars when raw and processed.

Table 12: Crude protein content (% dwb) of raw and processed potato tubers

Cultivar	Raw	Boiled	Fresh fries	Frozen fries
391691.96	6.68c	7.16b	6.15d	6.94b
393385.47	8.40a	8.31b	8.20a	7.67a
393385.39	7.72b	7.03c	7.30b	6.79b
Desiree	7.94b	8.08b	7.61b	7.03b
Dutch Robyjn	8.65a	8.19b	8.17a	7.81a
Kenya Karibu	8.38a	8.26a	8.23a	7.91a
Kenya Sifa	6.74c	7.31c	6.65c	5.75d
Tigoni	7.26c	7.76b	7.08d	6.94b
CV (%)	5.14	5.32	3.2	4.26
LSD ($P\leq0.05$)	n.s	n.s	0.34	0.41

Results (dry basis) are means of two determinations
Means with the same letters within the same column are not significantly different at 5 %level of significance

The cultivar had significant ($P\leq0.05$) influence on crude protein levels with values ranging from 6.68 % to 8.65 % in clone 391691.96 and Dutch Robyjn in raw tubers, respectively. The potato protein at about 2 % (FWB) is comparable to that of most other root and staples, with the exception of cassava, which has only half of this amount (Woolfe, 1987). It is also comparable, on a dry basis (8.4 %), with that of the cereals such as corn (9.5 %) rice (6.8 %) and sorghum (10.9 %).

The levels of crude protein differed significantly ($P\leq0.05$) in boiled tubers, fresh and frozen French fries among the cultivars. There was, however, no significant ($P>0.05$) effect of boiling and frying on crude protein content when compared with raw tubers. This is in agreement with the findings of Toma et al. (1978). On the other hand, freezing significantly ($P\leq0.05$) reduced crude protein content in all the cultivars with losses ranging from 4.5 % in Tigoni to 14.7 % in Kenya Sifa. This means that retention rates were in the range of 85.3-95.5%. This range of retention level is comparable to those reported earlier by Augustin et al. (1979) of 81 % to 85 %.

The levels of crude protein content differed significantly ($P \leq 0.05$) with the cultivars when analyzed after 12 weeks of storage at ambient air conditions (Table 13).

Table 13: Crude protein content (% dwb) in fresh and stored tubers

Cultivar	Treatment	Raw	Boiled	Fresh fries
391691.96	A	6.68d	6.6c	6.15d
	B	6.43d	6.16c	6.40d
393385.47	A	8.40a	8.11a	8.20a
	B	8.21a	8.15a	7.92a
393385.39	A	7.72b	8.03a	7.30b
	B	7.42bc	7.53a	6.99c
Desiree	A	7.94b	8.08a	7.61b
	B	7.64b	7.88a	7.31bc
Dutch Robyjn	A	8.65a	8.55a	8.17a
	B	8.37a	8.20a	8.35a
Kenya Karibu	A	8.38a	8.26a	8.23a
	B	8.49a	8.38a	8.16a
Kenya Sifa	A	6.74d	6.5c	6.65d
	B	6.43d	6.1c	6.31d
Tigoni	A	7.26c	7.76ab	7.08c
	B	6.99cd	7b	6.98c
CV (%)		3.16	6.15	3.80
LSD ($P \leq 0.05$)		n.s	n.s	n.s

Results (dry basis) are means of two determinations
Means with the same letters within the same column are not significantly different at 5%level of significance.
A=immediately after harvesting, B=after 12 weeks ambient storage

There was, however, no significant ($P>0.05$) effect when values for fresh tubers were compared to stored tubers. Toma et al. (1978) and Weaver et al. (1979a) also observed that there were little changes of no nutritional significance in crude protein content of potatoes stored for between 2 to 4 months.

The insignificant reduction of protein content over the period of storage at ambient air conditions could be attributed to protein breakdown that may occur as a result of sprouting according to Burton (1978).

4.3.2.1.3 Crude fat content

Variation in crude fat content of the eight potato cultivars with processing methods is given in Table 14.

Table 14: Crude fat content (% dwb) in raw and processed potato tubers

Cultivar	Raw	Boiled	Fresh fries	Frozen fries
391691.96	0.49a	0.51a	8.77e	11.77e
393385.47	0.45a	0.48a	9.45e	13.45d
393385.39	0.44a	0.53a	7.44f	10.85f
Desiree	0.45a	0.51a	9.82e	15.33b
Dutch Robyjn	0.40a	0.38a	6.40f	10.38f
Kenya Karibu	0.38a	0.37a	8.58e	13.00d
Kenya Sifa	0.53a	0.51a	9.01e	13.11d
Tigoni	0.46a	0.34a	7.61f	11.13f
CV (%)	23.62	27.52	7.55f	4.19
LSD (P≤0.05)	n.s	n.s	1.15	0.89

Results are means of two determinations
Means with the same letters within the same column are not significantly different at 5 % level of significance.

The crude fat content ranged from 0.38 % to 0.53 % in Kenya Karibu and Kenya Sifa for raw tubers, respectively. There was no significant (P>0.05) difference in the crude fat content between raw and boiled tubers among the cultivars. These values compare well with the findings of Gilliard (1973) who found values of 0.4 % to 0.65 % (dwb) in 23 varieties. This range is too low to have any nutritional significance. It has, however, been reported to play significant rolein potato palatability, enhancing tuber cellular integrity and resistance to bruising, and plays a part in reducing enzymic darkening in tuber flesh (Woolfe, 1987). Approximately 75 % of fatty acids of the potato lipids are polyunsaturated linoleic and linolenic acids that contribute to production of both desirable flavour characteristics in cooked tubers and undesirable 'off' flavours in processed products.

Boiling did not have significant (P>0.05) effect on the fat content. Frying of potatoes, however, increased fat content significantly (P≤0.05) ranging from 6.4 % in Dutch Robyjn to 9.82 % in Desiree in tubers. Moreover, frozen fries had higher levels of fat content compared to fresh fries. These findings compare well to those reported ealier by Greenfield et al. (1984) and Melton et al. (2001). Many factors have been reported to affect fat uptake into French fries, including oil quality, frying temperature and duration, product shape, moisture content, solid content, gel strength, and proteins (Pinthus et al., 1995). The potato cultivar significantly ($P \leq 0.05$) affected fat uptake in the French fries. The different cellular structures may have affected fat uptake by influencing either the loss of moisture or damage done to original anatomy during processing.

Crude fat content as influenced by dry matter content and moisture content

Apart from inherent genetic make up, the higher fat content in the variety Desiree may have been due to the greater decrease in moisture content during frying process (Figures 16 and 17; Table 15).

Table 15: Moisture content in raw tubers, fresh and frozen French fries of 8 cultivars

		Moisture content of French fries (%)		Moisture losses (%)	
Cultivar	**Initial moisture content in tubers (%)**	**Fresh Fresh**	**Frozen Fries**	**Fresh Fries**	**Frozen Fries**
391691.96	77.56 ± 0.01	54.80 ± 0.01	31.14 ± 0.02	22.73 ± 0.04	46.38 ± 0.04
393385.37	82.04 ± 0.06	59.05 ± 0.07	36.14 ± 0.11	22.92 ± 0.08	36.07 ± 0.07
393385.47	78.56 ± 0.05	55.53 ± 0.38	46.34 ± 0.01	22.80 ± 0.01	32.23 ± 0.01
Desiree	75.16 ± 0.14	52.10 ± 0.14	42.06 ± 0.08	23.03 ± 0.04	43.24 ± 0.03
Dutch Robyjn	77.56 ± 0.09	55.42 ± 0.02	29.84 ± 0.03	22.06 ± 0.01	47.63 ± 0.01
Kenya Karibu	79.35 ± 0.06	57.40 ± 0.08	46.69 ± 0.21	21.73 ± 0.28	40.58 ± 0.03
Kenya Sifa	78.80 ± 0.02	58.51 ±0.55	41.34 ± 0.02	19.90 ± 0.02	37.43 ± 0.04
Tigoni	78.55 ± 0.02	61.05 ± 0.06	40.75 ± 0.32	17.44 ± 0.05	37.57 ± 0.03

Means ± sd

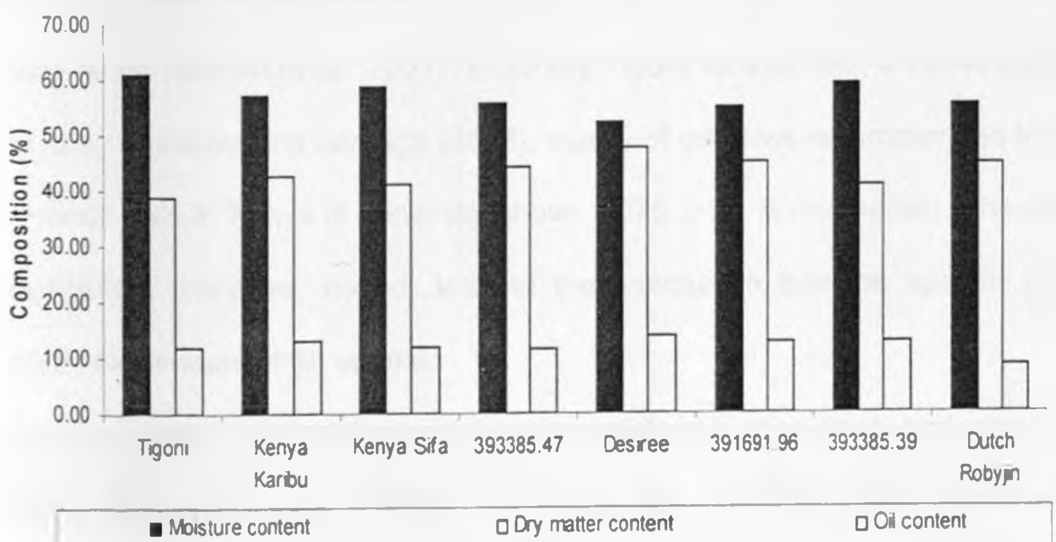

Figure 16: Compositions of freshly prepared French-fries from 8 cultivars

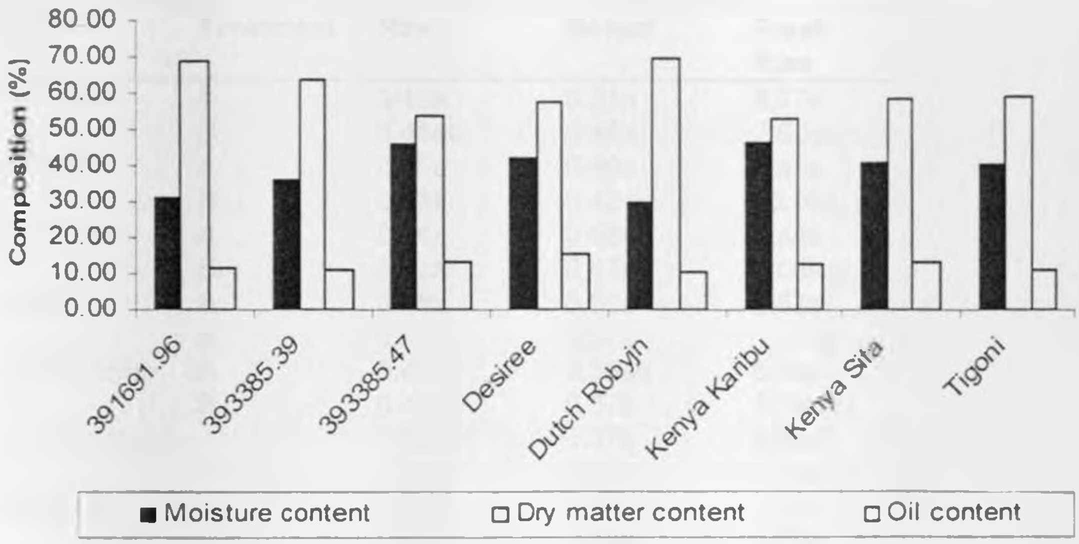

Figure 17: Compositions of frozen French-fries from 8 cultivars after finish frying.

The loss of moisture was directly related to fat uptake: that is the less moisture lost, the lower the uptake. This result is in agreement with the work of Gamble et al. (1987). The specific gravity and solids-content have also been shown to affect fat uptake by French fries. Potatoes with high dry matter (>20 %) have been shown to produce high yield of French fries with lower fat content than those of lower dry matter (Lulai and Orr, 1979). Hagenimana et al. (1998) working on sweet potatoes, found a linear relationship between dry matter content and fat uptake in thin sliced crisps, with fat decreasing with increase in dry matter. Within a single variety of potato, specific gravity has been shown to vary over a wide range (Melton et al., 2001). In variety Tigoni for example, it varies from 1.75-1.86. According to Kabira and Lemaga (2003), quality of potatoes recommended for processing as French fries in Kenya is generally above 1.075 (>20 % dry matter). The results of this investigation, therefore, do not lead to the conclusion that the specific gravity alone controls the amount of fat uptake.

Crude fat content in raw tubers and processed forms when fresh and after 12 weeks of ambient storage is given in Table 16. There was significant ($P \leq 0.05$) difference in the crude fat content among the cultivars. Ambient air storage for 12 weeks, however, had no significant ($P > 0.05$) effect on the crude fat content either in the raw, boiled or fried tubers.

Table 16: Crude fat content (% dwb) in fresh stored tubers

Cultivar	Treatment	Raw	Boiled	Fresh fries
391691.96	A	0.49a	0.51a	8.77a
	B	0.41ab	0.46a	7.60ab
393385.47	A	0.45a	0.48a	9.45a
	B	0.53a	0.42	10.00a
393385.39	A	0.44a	0.53a	7.44b
	B	0.57a	0.47a	7.08b
Desiree	A	0.45a	0.51a	9.82a
	B	0.52a	0.57a	10.63a
Dutch Robyjn	A	0.40b	0.38ab	6.40c
	B	0.40b	0.37b	6.50c
Kenya Karibu	A	0.38b	0.37b	8.58a
	B	0.38b	0.35b	7.99a
Kenya Sifa	A	0.53a	0.51a	9.01a
	B	0.53a	0.44a	9.09a
Tigoni	A	0.46a	0.34b	7.61b
	B	0.38ab	0.33b	8.39ab
CV (%)		19.68	21.99	7.35
LSD (P≤0.05)		0.13	0.13	0.92

Results are means of two determinations.
Means with the same letters within the same column are not significantly different at 5%level of significance.
A=immediately after harvesting, B=after 12 weeks ambient storage

Effect of finish frying method on oil content of French fries

Table 17 shows effect of finish frying method used on the frozen French fries on oil content.

Table 17: Crude fat content (% dwb) of 8 cultivars after deep fat frying and oven cooking

		Deep-fat-frying		Oven-cooking	
Cultivar	Fresh fries	Par-fried	Fully-fried	Par-fried	Fully-fried
Desiree	10.11a	17.22a	16.22a	11.22a	15.66a
393385.39	9.91b	16.32b	14.35b	10.40c	13.94b
Kenya Sifa	8.99c	15.12d	13.56c	10.95b	13.21c
Kenya Karibu	8.66d	15.64c	13.55c	10.30c	12.98d
391691.96	7.54e	15.11e	12.00e	8.22g	11.54e
Tigoni	7.00f	14.10f	11.25g	9.00f	11.00f
393385.47	6.99g	14.00f	11.00h	8.12g	10.69g
Dutch Robyjn	5.54h	13.56g	11.65f	8.00h	10.21h
CV (%)	2.11	3.15	2.52	4.06	4.11
LSD (P≤0.05)	0.42	0.88	0.36	0.64	0.89

Results are means of two determinations.
Means with the same letters within the same column are not significantly different at 5 %level of significance.

The fat contents differed significantly (P≤0.05) with the different methods of finish frying among the varieties with Desiree and Dutch Robyjn having consistently higher and lower levels respectively. Freshly prepared French fries had significantly (P≤0.05) lower levels of fat compared to frozen fries irrespective of the finish frying method used. Freezing French fries causes more pores on the surface due to water crystallization and coupled with more moisture loss during finish frying lead to more fat uptake (Melton et al., 2001; Aguelera and Gloria-Hernandez, 2000). Generally, oven-finished fries had lower amounts of fat than those that were finish-fried in deep fat since no more fat is absorbed in the process. The conditions of finish frying have pronounced effect on the quality of the finished product not only on fat content, but also on colour and texture (Janusz and Holt, 1973).

4.3.2.1.4 Crude fibre content

Crude fibre content of raw tubers differed significantly (P≤0.05) among the cultivars (Table 18). Variety Tigoni had the highest levels of crude fibre (2.48 %) while Desiree (2.28 %, %) had the lowest level (1.79 %) in tubers of the 8 cultivars. The reduction in crude fibre content was, however, not significant (P>0.05) after boiling, frying or freezing when compared to raw potatoes. The results compare well to the findings of Jones et al (1985) who observed little change of fibre content in flesh of baked, roasted or French fried Sebago variety potatoes on a dry weight basis.

Table 18: Crude fibre content (% dwb) in raw and processed potato tubers

Cultivar	Raw	Boiled	Fresh fries	Frozen fries
391691.96	2.01c	1.87d	2.22ab	2.01c
393385.39	2.26b	2.11c	2.01b	2.12bc
393385.47	1.98c	1.83d	1.95b	1.88de
Desiree	1.79c	1.72e	1.85c	1.85de
Dutch Robyjn	2.23b	1.98d	2.05b	1.83de
Kenya Karibu	2.29b	2.31b	2.10b	2.06c
Kenya Sifa	1.90c	1.76e	2.07b	2.06c
Tigoni	2.48b	2.29b	2.43a	2.07c
	2.48b	2.29b	2.43a	2.07c
CV (%)	7.00	5.23	13.10	5.59
LSD (P≤0.05)	0.24	0.16	0.43	0.17

Results (dry basis) are means of two determinations.
Means with the same letters within the same column are not significantly different at 5 %level of significance.

Table 19 shows average crude fibre content of fresh and ambient stored tubers.

Table 19: Crude fibre content (% dwb) in fresh and stored tubers

Cultivar	Treatment	Raw	Boiled	Fresh fries
391691.96	A	2.01b	1.87cd	2.22a
	B	1.83c	1.83cd	1.88c
393385.39	A	2.26a	2.11a	2.01b
	B	2.12b	2.12b	2.47a
393385.47	A	1.98c	1.83cd	1.95c
	B	1.90c	1.95c	1.88c
Desiree	A	1.79d	1.72d	1.85c
	B	1.75d	1.73d	1.85c
Dutch Robyjn	A	2.23b	1.98bc	2.05b
	B	2.17b	2.01b	2.16ab
Kenya Karibu	A	2.29ab	2.31a	2.10b
	B	2.07b	2.20a	2.03b
Kenya Sifa	A	1.90c	1.76d	2.07b
	B	1.86	1.89cd	1.82c
Tigoni	A	2.48a	2.29a	2.43a
	B	2.21b	2.07b	2.25ab
CV (%)		7.29	6.05	9.64
LSD (P≤0.05)		0.22	n.s	n.s

Results (dry basis) are means of two determinations
Means with the same letters within the same column are not significantly different at 5%level of significance
A=immediately after harvesting, B=after 12 weeks ambient storage

The crude fibre content differed significantly (P≤0.05) in the raw and processed tubers among the cultivars. There was, however, insignificant (P>0.05) reduction of crude fibre content after 12 weeks of ambient storage when compared to fresh tubers. Toma et al (1978) when working on several North American varieties found similar results after 8 months of storage at 3.3 °C. Woolfe (1987) in the review states that it is unlikely to have any quantitative alteration in crude fibre content.

4.3.2.1.5 Total ash content

Table 20 shows total ash content of 8 cultivars for the the raw and processed tubers Cultivar had a significant (P≤0.05) effect on the total ash content of raw tubers and thei processed forms. The ash contents differed significantly (P≤0.05) in the raw tubers with the varieties Desiree (3.69 %) and Kenya Karibu (3.65 %) having the highest levels while varieties Tigoni (2.76 %) and Kenya Sifa (2.12 %) having the least levels. The total ash content of potatoes has been reported to be about 1 % (FWB) and 3.5 % (DWB) an contains some important minerals and trace elements essential to various body structures and functions (True et al., 1978; Burton, 1989).

Table 20: Total ash content (% dwb) of raw and processed potato tubers.

Cultivar	Raw	Boiled	Fresh fries	Frozen fries
391691.96	2.36d	1.95de	2.12d	1.89d
393385.47	3.07c	2.57c	3.13b	3.11b
393385.39	2.79c	2.12d	2.68c	2.74c
Desiree	3.68b	3.14a	3.56b	3.40a
Dutch Robyjn	2.99c	2.36d	2.73c	2.65c
Kenya Karibu	3.65b	2.97b	3.89a	3.67a
Kenya Sifa	2.12d	1.99de	2.54d	1.94d
Tigoni	2.76c	2.23dc	2.84c	2.40cd
CV (%)	7.16	7.36	5.67	6.33
LSD ($P \leq 0.05$)	0.32	0.26	0.24	0.25

Results (dry basis) are means of two determinations

There exists large variation in ash content of the cultivars in the study. Such variations have been reported by True et al. (1978) and Woolfe (1987) with causes of variation being attributed to variety, soil type and fertilizer application. Among the boiled tubers the variety had significant ($P \leq 0.05$) influence on the ash content. Variety Desiree had the highest level (3.14 %) while Tigoni had the lowest level (2.23 %). Using raw tubers as the reference point, boiling significantly ($P \leq 0.05$) reduced the total ash content in all the cultivars. Such decrease has been attributed to leaching of the minerals in the cooking water (Burton, 1989).

Ash content levels varied significantly ($P \leq 0.05$) in the fresh French fries among the cultivars with Variety Kenya Karibu having the highest level (3.68 %) while clone 393385.39 had the lowest (2.70 %). There was no significant ($P > 0.05$) change in ash content of tubers when processed into fresh French fries indicating that frying alone did not cause mineral leaching. Among the tubers that were fried and frozen, there was significant ($P \leq 0.05$) difference in the ash content with the highest mean recorded by Kenya Karibu (3.67 %) while clone 391691.96 had the lowest (1.89 %). This shows that clone 391691.96 was greatly affected by freezing, within its structures, to cause leaching during frying.

Table 21 shows total ash content before and after ambient storage. The levels of total ash differed significantly (P≤0.05) with the cultivars but there was no significant (P>0.05) effect of storage on the total ash in the raw and fried tubers harvested 90 and 120 days after planting. These results are in agreement with Woolfe (1987).

Table 21: Total ash content (% dwb) of fresh and stored tubers

Cultivar	Treatment	Raw	Boiled	Fresh fries
391691.96	A	2.36cc	1.95cd	2.12cd
	B	2.44cd	1.93cd	2.35cd
393385.47	A	3.07b	2.57bc	3.13ab
	B	3.15b	2.72b	3.18ab
393385.39	A	2.79c	2.12c	2.68b
	B	2.66c	2.76b	2.78b
Desiree	A	3.68a	3.14a	3.56a
	B	3.74a	3.20a	3.50a
Dutch Robyjn	A	2.99c	2.36c	2.73b
	B	2.92c	2.58bc	2.82b
Kenya Karibu	A	3.65a	2.97b	3.89a
	B	3.72a	3.60a	3.45a
Kenya Sifa	A	2.12d	1.99cd	2.54c
	B	2.17d	1.99cd	2.45c
Tigoni	A	2.76c	2.23c	2.84b
	B	2.70c	2.64bc	2.80b
CV (%)		5.24	6.08	12.75
LSD (P≤0.05)		0.23	0.23	0.56

Results (dry basis) are means of three determinations
Means with the same letters within the same column are not significantly different at 5%level of significance
A=immediately after harvesting, B=after 12 weeks ambient storage

4.3.2.1.5.1 Effect of processing on mineral composition

There is very little literature that covers this area as few researchers have ventured into i (Woolfe, 1987). The tubers analysed had considerable amounts of calcium, potassium sodium, phosphorus, iron, magnesium and zinc. Since processing had significan (P≤0.05) effect on the total ash, variations of specific minerals with processing were assessed.

Phosphorus

Table 22 shows average phosphorus content in raw and processed potato tubers. Phosphoru levels differed significantly (P≤0.05) among cultivars in raw tubers. The levels range from 132 mg/100 g in clone 393385.47 to 207 mg/100 g in Dutch Robyjn. Values reporte for phosphorus vary with different authors. Woolfe (1987) reported range of 27-89 mg/100 g (fresh weight basis) while Burton, (1989) reported range of 150-300 mg/100 g (dry weight basis). The range in this study compares with values reported by Burton, (1989). On boiling phosphorus content significantly ($P \leq 0.05$) reduced with percent losses ranging from 9.7 % in Tigoni to 16.7 % in Dutch Robyjn. The losses due to leaching on boiling can be reduced by retaining the skin (True et al., 1979). Though there was reduction in the levels of phosphorus in the fresh and frozen fries, the reduction was not significant ($P > 0.05$). Thus freezing did not have any adverse effect on the mineral.

Table 22 Average phosphorus content (mg/100 g dwb) in raw and processed potato tubers

Cultivar	Raw	Boiled	Fresh fries	Frozen fries
Dutch Robyjn	207a	187a	206a	203a
Kenya Karibu	200a	177a	196a	196a
391691.96	174b	151b	171b	170b
Desiree	151c	128c	148c	147c
393385.39	145c	122c	142c	141c
Kenya Sifa	143c	121c	140c	139c
Tigoni	142c	120c	140c	138c
393385.47	132c	110c	130c	128c
CV (%)	7.42	8.74	7.62	7.62
LSD ($P \leq 0.05$)	18.05	18.35	18.23	18.06

Results (dry basis) are means of three determinations
Means with the same letters within the same column are not significantly different at 5%level of significance.

Potassium

The raw tubers had high amounts of potassium ranging from 697 mg to 2082 mg per 10(g of dry weight basis (Table 23). The levels of potassium differed significantly ($P \leq 0.05$ with processing among cultivars with variety Dutch Robyjn having highest level (208: mg/100 g) while clone 393385.39 had the lowest (697 mg/100 g). This level compares t(those documented by Burton (1989). Significant ($P \leq 0.05$) losses of potassium occurred ir boiled tubers (13.2-39.89 %), fresh fries (12.1-36.6 %) and frozen fries (12.92-39.3 %) The losses were more pronounced on boiled tubers and frozen fries. These losses pos(

no danger of deficiency since the retained amounts in each processing is still substantial and the mineral is also available in other foods (Woolfe, 1987; Burton, 1989).

Table 23: Potassium content (mg/100 g dwb) in raw and processed potato tubers

Cultivar	Raw	Boiled	Fresh fries	Frozen fries
Dutch Robyjn	2082a	1807a	1832a	1813a
Kenya Karibu	1802b	1529b	1552b	1534b
393385.47	1726c	1450c	1475c	1456c
Kenya Sifa	1533d	1258d	1282d	1263d
Tigoni	1009e	733e	758e	737e
391691.96	981f	705f	730f	711f
Desiree	779g	507g	529g	509g
393385.39	697h	419h	442h	423h
CV (%)	0.14	0.17	0.05	0.09
LSD (P≤0.05)	2.85	2.68	0.75	1.45

Results (dry basis) are means of three determinations
Means with the same letters within the same column are not significantly different at 5%level of significance.

Sodium

The average levels of sodium content in raw and processed potato tubers are given in Table 24.

Table 24: Average sodium content (mg/100 g dwb) in raw and processed potato tubers

Cultivar	Raw	Boiled	Fresh fries	Frozen fries
393385.47	322a	317a	318a	316a
Dutch Robyjn	315b	311b	312b	308b
Kenya Sifa	303c	300c	300c	298c
Desiree	301c	296d	299d	296d
Tigoni	290d	288e	288e	285e
391691.96	216e	212f	214f	210f
Kenya Karibu	202f	200g	201g	198g
393385.39	191g	187h	188h	186h
CV (%)	0.56	0.46	0.21	0.23
LSD (P≤0.05)	2.25	1.84	0.84	0.92

Results (dry basis) are means of three determinations.
Means with the same letters within the same column are not significantly different at 5%level of significance.

Sodium levels of raw tubers differed significantly (P≤0.05) among cultivars. The levels ranged from 191 mg/100 g in clone 393385.39 to 322 mg/100 g in clone 393385.47. This compares with the range of 20 mg to 300 mg per 100 g (dwb) that was reported by Burton

(1989). Though there was reduction in the levels of sodium in boiled, fresh and frozen fries, the reductions were not significant (P>0.05) to cause any alarm. Similar results were reported by True et al., (1979) and Woolfe (1987).

Calcium

Table 25 shows average levels of calcium in the 8 potato cultivars.

Table 25: Calcium content (mg/100 g dwb) in raw and processed potato tubers

Cultivar	Raw	Boiled	Fresh fries	Frozen fries
Kenya Karibu	92a	89a	92a	89a
391691.96	80b	75b	61b	58b
Desiree	62c	57c	61b	58b
Kenya Sifa	52d	47d	51c	48c
Tigoni	43e	39e	42d	39d
Dutch Robyjn	42f	38f	37e	34e
393385.39	37g	32g	36f	31f
393385.47	37g	32g	35f	31f
CV (%)	0.45	1.29	0.97	0.89
LSD (P≤0.05)	0.37	0.99	0.75	0.65

Results (dry basis) are means of three determinations
Means with the same letters within the same column are not significantly different at 5%level of significance

Calcium levels varied significantly (P≤0.05) with processing in all cultivars. The range o 37 mg to 92 mg per 100 g in the raw tubers (dry basis) compares to that reported by Burton (1989). The values in fresh French-fries did not significantly (P>0.05) differ wher compared to raw tubers while boiling and freezing significantly (P≤0.05) reduced levels o calcium. Boiling losses ranged from 8.27 % in clone 393385.39 to 13 % in Dutch Robyjn On freezing, there was significant (P≤0.05) reduction with losses ranging from 7.88 % ir 393385.39 to 12.43 % in Dutch Robyjn. This translate to high retention (92.22-87.57 % making it feasible to process and freeze-store chips without serious losses.

Zinc

Zinc levels in raw and processed potatoes are given in Table 26. Zinc levels differe significantly (P≤0.05) among the cultivars in raw tubers. The levels ranged from 1.7 mg/100 g in Tigoni to 2.90 mg/100 g in Dutch Robyjn. The levels of zinc in the stud compares with those reported by Woolfe (1987) and Burton (1989). Levels of zinc did not significantly (P>0.05) differ for French fries compared to the raw tubers. On boiling zinc content significantly (P≤0.05) reduced with losses ranging from 8.27 % in clone 393385.39 to 13 % in Dutch Robyjn. Likewise, the levels significantly (P≤0.05) reduced in freeze stored French fries with losses ranging from 7.85 % in 393385.39 to 12.44 % in Dutch Robyjn. Retention rate of 92.25-87.56 % allows us to take the advantages of processing without adverse losses of this mineral required by body enzymes for synthesis and metabolism (FAO/WHO, 1996).

Table 26: Zinc content (mg/100 g dwb) in raw and processed potato tubers

Cultivar	Raw	Boiled	Fresh fries	Frozen fries
Dutch Robyjn	2.90a	2.58a	2.77a	2.67a
391691.96	2.87b	2.57a	2.74b	2.58b
Kenya Sifa	2.78c	2.52ab	2.65c	2.55b
Kenya Karibu	2.76d	2.51ab	2.63d	2.54b
393385.39	2.66e	2.44b	2.55e	2.45c
393385.47	1.93f	1.70c	1.81f	1.72d
Desiree	1.78g	1.55d	1.66g	1.56e
Tigoni	1.77g	1.54d	1.65g	1.55e
CV (%)	0.4	2.8	0.61	1.55
LSD (P≤0.05)	0.01	0.09	0.02	0.05

Results (dry basis) are means of three determinations
Means with the same letters within the same column are not significantly different at 5%level of significance.

Iron

Table 27 shows variation of iron content with processing.

Table 27: Iron content (mg/100 g dwb) in raw and processed potato tubers

Cultivar	Raw	Boiled	Fresh fries	Frozen fries
Desiree	4.54a	4.32a	4.55a	3.99a
Kenya Karibu	4.31b	4.12c	4.45b	4.00a
Kenya Sifa	4.31b	4.25b	4.32c	3.95b
393385.47	3.89c	3.55d	3.88d	3.47c
Dutch Robyjn	3.77d	3.43e	3.76e	3.43d
Tigoni	3.57e	3.21f	3.64f	3.21e
391691.96	2.74f	2.66g	2.88g	2.41f
393385.39	2.65g	2.53h	2.72h	2.33g
CV (%)	4.7	8.8	2.9	4.6
LSD (P≤0.05)	0.026	0.044	0.02	0.02

Results (dry basis) are means of three determinations.
Means with the same letters within the same column are not significantly different at 5%level of significance.

Iron content differed significantly ($P \leq 0.05$) among the cultivars in raw tubers ranging from 2.65 mg/100 g in clone 393385.39 to 4.54 mg/100 g in Desiree. The range in the study compares well with values reported by Burton, (1989). Levels of iron did not significantly ($P > 0.05$) differ for fresh French fries compared to the raw tubers. Boiling significantly ($P \leq 0.05$) reduced levels of iron with losses ranging from 2.6 % in Kenya Sifa to 10.8 % in Tigoni. This translates to about 90.2-97.4 % retention in iron content among the cultivars after boiling. The loss due to leaching was described by Woolfe (1987) as nutritionally insignificant. Freezing significantly ($P \leq 0.05$) reduced iron content with losses ranging from 7.62 % in Kenya Karibu to 10.56 % in Tigoni. Freezing crystallized water in cells and resultant damage in fry structures lead to leaching of minerals in frying oil. Woolfe (1987) assumed without any reported analysis that there would be losses during peeling and slicing of chips in preparation of frozen French fries. The present study shows that losses due to frozen storage compares with those due to boiling with substantial retention level of 89.44-92.38 % that allows the technology to be embraced.

Magnesium

The amount of magnesium in the 8 cultivars ranged between 67 mg in clone 391691.96 to 153 mg in variety Kenya Karibu per 100 g (dry basis) in the raw tubers (Table 28).

Table 28: Magnesium content (mg/100 g dwb) in raw and processed potato tubers

Cultivar	Raw	Boiled	Fresh fries	Frozen fries
Kenya Karibu	153a	145a	152a	146a
Dutch Robyjn	138b	131b	137b	132b
Desiree	120c	113c	118c	114c
Kenya Sifa	116d	103d	115d	110d
393385.47	111e	104d	110e	105e
393385.39	88f	81e	88f	82f
Tigoni	85g	77e	84g	78g
391691.96	67h	60f	66h	61h
CV (%)	0.32	0.34	0.46	0.54
LSD ($P \leq 0.05$)	0.53	0.53	0.75	0.84

Results (dry basis) are means of three determinations
Means with the same letters within the same column are not significantly different at 5%level of significance.

This compares to the range of 45.9 mg to 216.5 mg per 100g (dwb) reported by Burton (1989). The levels of magnesium differed significantly (P≤0.05) with processing among the cultivars. Boiling significantly reduced (P≤0.05) magnesium content with percent losses ranging from 5.07 % in Desiree to 11.2 % in Dutch Robyjn. Similar results have been reported by True et al., (1979) and Woolfe, (1987). Likewise, freezing significantly (P≤0.05) reduced levels of magnesium with average losses ranging from 4.3 % in Dutch Robyjn to 8.95 % in clone 391691.96. The high retention rate 91.05-95.6 % means that mineral will be adequate from frozen chips.

Manganese

Table 29 shows average manganese levels in raw and processed potato tubers.

Table 29: Manganese content (mg/100 g dwb) in raw and processed potato tubers

Cultivar	Raw	Boiled	Fresh fries	Frozen fries
Kenya Karibu	3.61a	3.36a	3.59a	3.38a
Dutch Robyjn	3.25ab	2.48e	3.23ab	3.02ab
Kenya Sifa	3.22ab	3.18b	3.19ab	2.98ab
393385.47	2.98cb	2.71c	2.96cb	2.75cb
Desiree	2.80c	2.53d	2.77c	2.56c
391691.96	2.77c	2.52d	2.75c	2.54c
Tigoni	2.35d	2.11f	2.33d	2.12d
393385.39	2.16d	1.90g	2.14d	1.93d
CV (%)	9	5.2	9.9.06	9.77
LSD (P≤0.05)	0.39	0.02	0.39	0.4

Results (dry basis) are means of three determinations.
Means with the same letters within the same column are not significantly different at 5%level of significance.

Manganese levels differed significantly (P≤0.05) among the cultivars in raw tubers ranging from 2.16 mg/100 g in clone 393385.39 to 3.61 mg/100 g in Kenya Karibu. The range in the study compares well with values reported by True et al. (1978) and Burton (1989). Levels of manganese did not significantly (P>0.05) differ in fresh French fries compared to the raw tubers. Boiling, however, significantly (P≤0.05) reduced manganese content with losses ranging from 6.9 % in Tigoni to 12 % in Dutch Robyjn. This translates to about 88-93.9 % retention of manganese among the cultivars after boiling. Freezing significantly (P≤0.05) reduced manganese content with losses ranging from 6.4 % in

Tigoni to 10.65 % in Dutch Robyjn translating to 89.35-93.6 % retention that is adequate for consumption (Woolfe, 1987).

4.3.3 Sensory quality characteristics of French fries

Sensory quality characteristics of freshly prepared and frozen French fries for 8 potato cultivars are shown in Table 30.

Table 30: Sensory quality characteristics of freshly prepared and frozen French fries for 8 potato cultivars

Cultivar	Treatment	Colour	Texture	Oiliness	Flavour	Overall acceptability
Desiree	A	6.77a	6.60a	6bcd	5.80b	6.46a
	B	6.65a	6.44a	6.77a	5.66a	7.00a
Tigoni	A	6.69ab	6.53a	6.53a	6.76a	6.15a
	B	6.44bc	6.11ab	5.88bcd	5.55a	6.44abc
Kenya Sifa	A	6.53ab	6.57a	6.34ab	6.65a	6.53a
	B	6.55b	6.55a	6.77a	5.78a	6.88ab
Kenya Karibu	A	6.31bc	6.34a	6.30abc	6.69a	6.07a
	B	6.42bc	6.01ab	5.8bcd	5.50a	6.34abc
391691.96	A	6.53ab	6.57a	6.34ab	6.65a	6.53a
	B	5.77d	5.89abc	6.67a	5.88bc	6.33bcd
Dutch Robyjn	A	5.92cd	6.53a	6.53a	6.46a	6.53a
	B	6.55b	6.22ab	6.33ab	5.44ab	6.55abc
393385.47	A	5.54d	5.53cd	5.61de	5.73b	5.53b
	B	4.77ef	5.22d	5.55cde	5.00e	5.22e
393385.39	A	5.33e	5.53b	5.82cd	5.92b	5.30b
	B	4.77ef	4.66d	5.33ed	5.11e	5.00f
Golden Valley Chips		6.55b	6.11ab	6.00bc	5.77cd	6.22cd
CV (%)		2.70	2.93	4.43	3.70	2.95
LSD (P≤0.05)		0.41	0.43	0.45	0.42	0.42

Means with the same letters within the same column are not significantly different at 5%level of significance
Evaluation was done on 9-point hedonic scale. 5 was the acceptable lower limit.
A=fresh fries. B=frozen French fries

All the attributes evaluated differed significantly (P≤0.05) among the cultivars. In freshly prepared fries, variety Desiree had the highest colour score (6.77) while clone 393385.39 had the least score (5.33) as confirmed by the objective colour measurements (Figure 18). The same trend was also noticed in texture. Variety Tigoni had highest scores in flavour (6.76) while clone 393385.47 had the lowest (5.73). In oiliness variety Desiree scored poorly compared to Tigoni, the objective fat measurements did indicate earlier that the variety has tendency to absorb more oil. When processed into fresh fries, all the varieties and clones were generally acceptable with varieties Kenya Sifa (6.53), and Dutch Robyjn (6.46) having higher scores while clone 393385.39 had the lowest score (5.30).

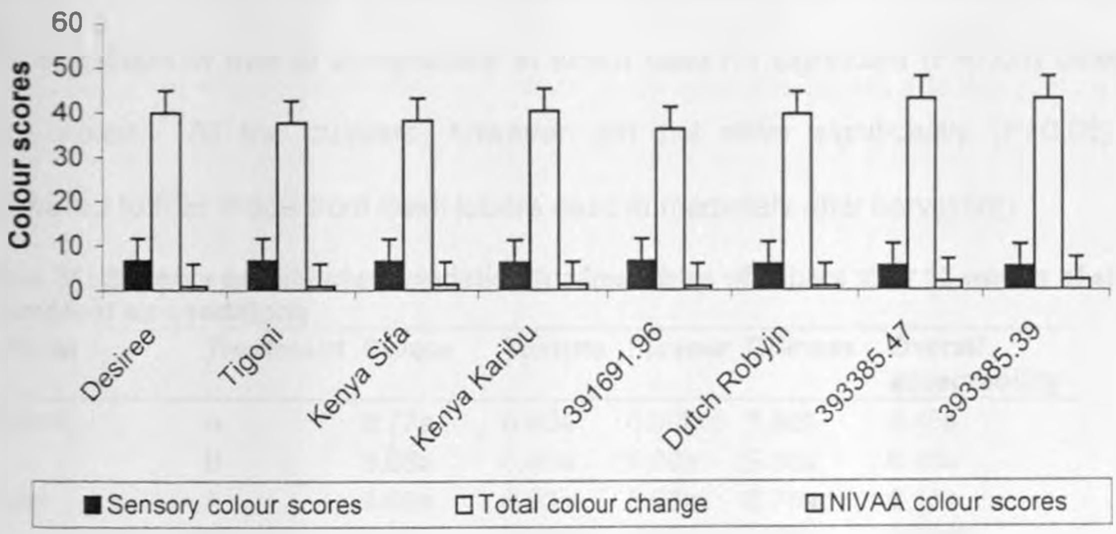

Figure 18: Comparison between colour meter readings, NIVAA and sensory colour scores

The sensory attributes significantly (P≤0.05) differed among the cultivars when the fries were frozen for 3 months. Variety Desiree scored highly in colour (6.65) compared to clones 393385.39 and 393385.47 that had lowest scores (4.77) below acceptable limit. Frozen fries from varieties Kenya Sifa, Dutch Robyjn, Tigoni and Kenya Karibu were comparable in colour to the commercial chips, golden valley and had no significant (P>0.05) reduction. Colour and flavour scores in the 3 clones, however, significantly (P≤0.05) reduced. Kenya Sifa and Desiree scored highly in texture and oiliness compared to clones 393385.39 and 393385.47 that had lowest scores. Freezing did not, however have significant (P>0.05) effect on the two attributes in the 5 varieties as opposed to significant (P≤0.05) reduction in the three clones. Flavour scores were significantly (P≤0.05) lower in all cultivars, but clone 391691.96 had the highest score (5.88) while clone 393385.47 had the least score (5.00). In general, all the varieties and clones made acceptable frozen fries with clone 393385.39 and 393385.47 being just acceptable (scores of 5.00 and 5.22, respectively). Fries from Desiree (7.00) were highly acceptable followed by Kenya Sifa (6.88), Dutch Robyjn (6.55), Tigoni (6.44), Kenya Karibu (6.34), clone 391691.96 (6.33), Golden Valley (6.22).

After 12 weeks storage at ambient conditions, the tubers made acceptable French fries (Table 31). The evaluated attributes differed significantly (P≤0.05) among the cultivars with exception of overall acceptability in which case no significant (P>0.05) differences were noted. All the cultivars, however, did not differ significantly (P>0.05) when compared to fries made from fresh tubers used immediately after harvesting.

Table 31: Sensory quality characteristics for fresh fries of tubers after 12 weeks of storage at ambient air conditions

Cultivar	Treatment	Colour	Texture	Flavour	Oiliness	Overall acceptability
Desiree	A	6.77a	6.60a	6.00bcd	5.80b	6.46a
	B	6.66a	6.40a	5.80a	5.55a	6.45a
Tigoni	A	6.69a	6.53a	6.53a	6.76a	6.15a
	B	5.42b	5.14bc	5.00c	5.92b	5.85ab
Kenya Sifa	A	6.53a	6.57a	6.34ab	6.65a	6.53a
	B	6.57a	5.85ab	6.00a	6.14b	6.42a
Kenya Karibu	A	6.31b	6.34a	6.30abc	6.69a	6.07a
	B	6.22b	6.20a	6.00a	5.85b	6.00b
391691.96	A	6.53ab	6.57a	6.34ab	6.65a	6.53a
	B	4.50e	4.42c	5.28bc	5.14a	5.10c
Dutch Robyjn	A	5.92bc	6.53a	6.53a	6.46a	6.53a
	B	5.80bc	6.28a	6.28a	5.57a	6.14ab
393385.47	A	5.54d	5.53b	5.61de	5.73b	5.53b
	B	5.52d	5.50b	5.80a	5.80a	5.50b
393385.39	A	5.33e	5.53b	5.82cd	5.92b	5.30b
	B	6.00ab	5.14bc	5.71ab	5.85b	6.28a
CV (%)		2.70	2.93	4.43	3.7	2.95
LSD (P≤0.05)		0.43	0.42	0.47	0.46	0.45

Means with the same letters within the same column are not significantly different at 5%level of significance
Evaluation was done on 9-point hedonic scale. 5 was the acceptable lower limit.
A=immediately after harvesting, B=after 12 weeks ambient storage

CHAPTER 5

5.0 CONCLUSION AND RECOMMENDATIONS

CONCLUSION

The study succeeded in identifying specific cultivars for processing into acceptable frozen French fries in Kenya. Out of 18 cultivars, 5 varieties (Tigoni, Desiree, Dutch Robyjn, Kenya Karibu, and Kenya Sifa) and 3 advanced potato clones (393385.47, 391696.96 and 393385.39) were found to have good physical tuber qualities and were suitable for processing into French fries. The specific gravity and dry matter contents were above the lower acceptability limits of 1.070 and 20 %, respectively.

The proximate and mineral composition of the varieties Tigoni, Desiree, Kenya Karibu Kenya Sifa and Dutch Robyjn, and the clones 391691.96, 393385.47 and 393385.39 were found to be comparable to those reported in literature.

Storage of potato tubers at ambient air conditions (15-19 °C/86-92% rh) for 12 weeks in the dark store did not have any deleterious effect on proximate and mineral composition of the tubers. Cold stored tubers could not be used in processing French fries due to accumulation of reducing sugars to higher levels that did not reduce to safe levels even on reconditioning for up to 3 weeks.

Frying alone did not have any adverse effect on proximate chemical and mineral composition of the potatoes. Even though boiling and frozen storage significantly ($P \leq 0.05$) decreased total ash content, carbohydrates and minerals; iron, manganese, zinc potassium, calcium and magnesium, the rate of retentions were considerably higher to making processing of frozen French fry technology in Kenya worth consideration.

RECOMMENDATIONS AND FUTURE WORK

Since the five varieties (Tigoni, Desiree, Dutch Robyjn, Kenya Karibu, and Kenya Sifa) and three advanced clones (393385.47, 391696.96 and 393385.39) were suitable for processing into French fries, Seed multiplication program at KARI should ensure adequate production and distribution of these cultivars to farmers. They should also be promoted for commercial use by the potato industry. Research on other processed products such as crisps should be carried out to ascertain suitability of particular varieties and to diversify the use of these cultivars.

The study was carried out in one location, National Potato Research centre with optimum conditions of potato growth. Similar study should be carried out with the same cultivars in different locations of Kenya to ascertain any existing differences.

There is need to conduct research geared to wards breeding varieties that can either chip directly from cold storage or after reconditioning.

6.0 REFERENCES

Afzal, T.M. and Abe, T. (1999). Some fundamental attributes of infrared radiation drying o potato. Dry. Technol. *17* (2), 137–155.

Aguelera, J.M. and Gloria-Hernandez, H. (2000). Oil absorption during frying of frozer par-fried potatoes. J.Food Sci. 65 (3), 477-479).

AOAC, (1980). Official methods of analysis, 13th ed., Ass. Off. Anal. Chem., Washington DC, USA.

AOAC, (1996). Official Methods of Analysis, 16th Ed., Ass. Off. Anal. Chem. Gaithersburg, MD.

Augustin, J., Swanson, B.G., Teitzel, C., Johnson, S.R., Pometto, S.F., Artz, W.E., anc Huang, C.P. (1979). Changes in the nutrient composition during commercia processing of frozen potato products. J.Food Sci.44: 807-9.

Blenkinsop, R.W., Copp, L.J., Marangoni, A.G. and Yada R.Y. (2000). Effects of lov temperature storage on carbohydrate metabolism in potato tubers. Hortscience (USA). 34 (3): 526.

Blenkinsop, R.W., Copp, L.J., Yada R.Y. and Marangoni, A.G. (2003). A proposed role fo the anerobic pathway during low-temperature sweetening in tubers of Solanum tuberosum. Physiologia plantarum 118 (2), 206-212 doi: 10.1034/j.1399 3054.2003.00079.x

Boyed, I.M. and Duncan, H.J. (1981). The effect of maturity on potato components preliminary findings on sugar levels. 8th Trienn. Conf. EAPR, 13th April, Munich 218-219.

Burton, W.G. (1966). The Potato. 2nd ed.H. Veenman en Zonen N.V., Wageningen Holland.

Burton, W.G. (1978). Post-harvest behavior and storage of potatoes. Potato Res. 17:374 409.

Burton, W.G. (1989). The potato.3rd ed. Longman Group UK, Ltd. pp. 286-360.

Buttery, R.G. and Teranishi, R. (1963). Measurements of fat auto-oxidation and browning aldehydes in food. J. Agric. Food. 11: 504-507.

Buzby, J.C. and Hodan, A.F. (2006). Americans switch from fresh to frozen potatoes. United States Department of Agriculture, Washington DC.

Dagerskog, M. and Osterström, L. (1979). Infrared radiation for food processing I. A study of the fundamental properties of infrared radiation. Lebensm-Wiss. u.-Technol. *12* (4), 237–242.

Daniels,L., Barbara. J. Prange, R.K., Nowak, J., Asiedu., S.K., Walsh, J.R. (2005) Sprout development and processing quality changes in potato tubers stored under ethylene: 1. Effects of ethylene concentration. American Journal of potato Research, 10 (9) 155-160.

Durr, G. and Lorenzl, G. 1980. Potato production and utilization in Kenya. International Potato Center.

Es A van, Hartmans K.J. (1987). Sugars and starch during tuberisation, storage and sprouting. In storage of potatoes, Eds Rastovski and A van Es. Wageningen.

FAO, (1989). Utilization of tropical foods: Roots and tubers, Rome, Italy. pp. 43-46.

FAO/WHO, (1996). Expert consultation on human vitamins and minerals, Rome, Italy. pp 43-46.

Farkas, B.E. and Hubbard, L.J. (2000). Analysis of convective heat transfer during immersion frying. Dry. Technol. *18*(6), 1269–1285.

Farkas, B.E., Lloyd, B.J. and Keener, K.M. (2004). Development of a radiant heating process to mimic immersion frying. In *Refereed Proceedings of the 9th International Congress on Engineering and Food*, 6th May, Montpellier, France.6-5 04.

Gaon, D. and Wiedersatz, J. (1993). Process for preparing fat free snack chips, U.S. Patent No. 5,202,139.

Gamble, M.H., Rice, P., Selman, J.D. (1987). Relationship between oil uptake and moisture loss during frying of potato slices. J.Food Sci. Technol. 22:233-241.

Gilliard, T. (1973). Lipids and fatty acid composition of tubers from different varieties of potato. J. Sci. Food Agric. 24: 617-622.

Gould, W.A. (1999). Potato production, processing, and technology, CTI Publ. Inc., Timonium, MA.

Gould, W.A. (1977).Examining potato chipping quality, 26-34. Publ. Inc., Timonium, MA.

Gorun, E.G. (1978). Changes in the vitamin activities of potatoes during production of quick-frozen French fries. In Russian. Kholod. Tekh., no. 10: 15-17.

Greenfield, H., Makinson, R.B. and Willis, H. (1984). Lipids in French fries: a retail and laboratory study. Int. J. Food Sci. and Tech. 19 (2): 239-245.

Guar, P.C., Singh, B., Pandey, S.K., Marwaha R.S. and Kumar, D. (1999). A new high dry matter potato variety for chipping. Current Science 79:722-724.

Hagenimana, V., Karuri, E.G. and Oyunga, M.A. (1998). Oil content in fried processed sweet potato products. J.Food Process.Preserv. 22: 123-137.

Hamernik, A.J. and Hanneman, Jr.R.E. (1998). Breeding 2x haploid X species potato that chip from cold storage. American J. Potato Research 75 (6): 278-279.

Harris, P.M. (1978). The potato crop; Scientific basis for improvement. Chapman and Hall, London.

Hertog, M.L.T.M., Tijskens, L.M.M. and Hak, P.S. (1997). The effects of temperature and senescence on the accumulation of reducing sugars during storage of potato (Solanum tuberosum L.) tubers: A mathematical model. Post-harvest Biology and Technology (Netherlands). 10 (1): 67-79.

Hubbard, L.J. and Farkas, B.E. (1999). A method for determining the Convective heat transfer coefficient during immersion frying. J. Food Process. Eng. 22, 201–214.

Hunt, G.L.T. (1980). Storage environment for potatoes-Ministry of Agriculture, Nairobi-Kenya

Horton, D. (1987). Potatoes; production, marketing and improvement programme for developing countries.

Hubbard, L.J. and Farkas, B.E. (2000). Determination and analysis of oil temperature effects on convective heat transfer coefficients and heat flux in immersion frying. J Food Process. Pres. *24*: 143–162.

International Federation of Fruit Juice Producers (1985). Determination of sugar (Luff Schoorl method). No.4. pp.1-5.

Janusz, M.Z. and Holt, C. (1973). Effect of finish frying conditions on the quality of French fried potatoes. J. Food Sci. 38: 92-95).

Jones, G.P., Briggs, D.R., Wahlquist, M.L. and Flentje, L.M. (1985). Dietary fibre content of Australian foods. J. Food Tech. 37:81-83.

Kabira J.N. (1983). Storage and processing characteristics of three Kenyan potato varieties. MSc. Thesis, University of Nairobi.

Kabira J.N. and Njoroge, J.M. (1984). Status of the potato industry in Kenya. In: Nganga S. (ed.), Potato development and transfer of technology in Tropical Africa. CIP Region III,Nairobi

Kabira J.N. (1987). Potato postharvest technology in Kenya. Presented at the first African Potato Association Triennial General Meeting and Conference. 21st -25th June Nairobi, Kenya.

Kabira, J.N, (1990). Feasibility of small-scale production of solar dried potato (*Solanum tuberosum*) flour and its potential food uses in Kenya. PhD. Thesis, University of Nairobi.

Kabira, J.N. (2000). French fries and crisps processing characteristics of selected potato varieties in Kenya. African Potato Association Conference Proceedings vol.5: 507-511.

Kabira. J.N. (2002). Suitability of four promising clones for storage and processing into potato crisps and frozen chips (French fries). KARI Scientific Conference 11-15 Nov, KARI HQ, Nairobi.

Kabira, J.N and Lemaga, B. (2003). Quality Evaluation procedures for Research and food Industries Applicable in East and Central Africa.

Kabira, J.N and Lemaga, B. (2006). Potato Processing: Quality Evaluation procedures for research and food industries applications in East and Central Africa. Kenya Agricultural Research Publication, Nairobi, Kenya.

Kenya Agricultural Information Center (KAIC), (1981 ; 2000). Technical Handbook on Major Crops Grown in Kenya, Nairobi.

Kirkpatrick. M.E. Heinze, P.H., Craft C.C., Mountjoy B.M., Falatko, C.E., (1956). French fry quality of potato influenced by cooking methods, storage conditions, specific gravity of tubers. U.S.Dept.Agric.Res.Tech.Bull.1142.

Kozempel, M.F., Sulliva, J.F., Della Monica, E.S., Egoville, m.j., Talley, E. A., Jones, W.J and Craig, J.C. (1982). Application of leaching model to describe potato nutrient losses in hot water blanching. J.Food Sci.47:1519-23.

Kumar, D., Singh B.P., Kumar, P. (2004). An overview of the factors affecting sugar content of potatoes. Central Potato Research Institute, Ann. Appl. Biol. (2004) 145:247-256

Kwiatkowska, A.C., Finglas, P.M. and Faulks, R.M. (1989). The vitamin content of retail vegetables in the United Kingdom. J. Human Nutrition and Dietetics. 2(3), 159-172

Landeo, L. and Gastelo, P. (2002). International Potato Center. Lima.

Larmond. E. (1977). Methods for sensory evaluation of food. Food Research Institute, Central Experiment Farm, Canada Dept. of Agriculture, Ottawa.

Lima, I. and Singh, R.P. (2001). Mechanical properties of a fried crust. J. Texture Stud *32*(1), 31–40.

Lloyd, B.J. (2003). Analysis of radiant heating to produce an alternative frying process PhD Dissertation, North Carolina State University, Raleigh, NC.

Lloyd, B.J., Farkas, B.E, Keener, K.M., (2004). Quality comparison of French fry style potatoes produced by oven heating, immersion frying and controlled dynamic radiant heating. J Food processing and Preserv. 28 (2004) 460-472 . Blackwel Publ.

Ludwig, J.W. (1972). Determination of the dry matter content of potatoes by weighing in water. Institute for Storage and Processing of Agricultural Produce (IBVL)-Publ No.247b,Bornsesteeg 59-Wageningen, Holland.

Lulai, E. and Orr, P.H. (1979). The influence of specific gravity on oil content of chips. Am Potato J. 56,379-390.

Lundun, A.P. (1956). Undersøkelser over forholdet mellom poteternes specifikke vekt og deres tørrstoff-og stivelsensindhold. Forsk. Fors. Landbr. 7, 81-107.

Lung'hao, C., Kabira, J.N. (1999). A guide to growing table potatoes. Kenya Agricultural Research Publication, Nairobi, Kenya.

Martin, F.L. and Ames, J.M. (2001). Comparison of flavor compounds of Potato chips in palmolein and silicone fluid. J. Am. Oil Chem. Soc. *78*(8), 863–866.

Martz, S.A. (1984). Potato chips. In: Snack Food Technology. 2nd ed. AVI Publ. Co. Inc Westport conn.

Masamura, A., Sado, H., Honda, T., Shimizu, M., Nabetani, H., Nakajima, M. and Watanabe, A. (1988). Drying of potato by Infrared radiation. Nippon Shokuhin Kogyo Gakkaishi *35*(5), 309–314.

McDonald's C. (2003). McDonald's USA Nutrition Facts for Popular Menu Items, McDonald's Corp, Oak Brook, IL.

Meilgaard, M., Civille, G.V. and Carr, B.T. (1997). Sensory evaluation techniques, 3rd Ed., CRC Press, Inc., Boca Raton, FL.

Melton, L.D., Smith B.G., Fisk, K..J., O'Cornnor C.J. (2001). Fat absorption in French fries as affected by different potato varieties and processing. J Food Sci.Vol.66 (6), 903-908.

Ministry of Agriculture (MoA). (2003). Potato Standards In: The Crop Production and Livestock Act. Kenya Gazette supplement no.38, Nairobi.

Ministry of Agriculture (MoA). (2005). Potato Standards In: The Crop Production and Livestock Act. Kenya Gazette supplement no.38, Nairobi.

Ministry of Agriculture (MoA). (2006). Challenges in potato research In: The National Policy on Potato Industry presentation during the potato stakeholders meeting at KARI head quarters, Nairobi, Kenya.

Ministry of Agriculture (MoA). (2007). Challenges in potato research In: The National Policy on Potato Industry presentation during the potato stakeholders meeting at KARI head quarters, Nairobi, Kenya.

Myers, M. (2003). Commitment to Improving the Potato's Nutrition Image with Top Three Processors, United States Potato Board press release, Denver, CO, July 7.

Nielson, E.K. and Wickel, K.G. (1967). Effects of soil temperature, harvesting sequence and storage on French fry quality of potatoes. European Potato J 10 (4) 312-324.

NIVAA (1984). Modification of Potato French fry colour chart in: Potato Marketing Board Annual Review. Oxford Publ.London.

Oreldo S. (2004). French fries: the facts and history. In Idaho potatoes www.biosetate.edu (8-9-06).

Paul, A.A. and Southgate, D.A.T. (1978). The composition of foods, 4th ed. MRC specia report no.279.HMSO,London.

Pepping, C.E.W. and Temalilwa, C.R. (1988). The composition of foods commonly eater in East Africa. Wageningen Agricultural University, Netherlands.

Pinthus, E.J., Weinberg, P., Saguy S. (1995). Criterion for oil uptake in deep fat frying. J Food Sci. 58 (222): 204-205.

Ramasawmy, G., Oburdhun, D. and Ruggoo, A. (1999). Effects of different preparatior technologies on proximate composition and calorie content of potato products. Sci & Tech. Research j. 4: 1999.

Reeves, A.F., Akeley, R.V., Murphy, H.J., Porter, E.A, Cole, R.H., Watts, J., Christ, B.J. Manzer F.E. and True, R.H. (1990). Somerset: a new chipping potato variety. Am Potato J. 66: 153-161.

Russ, J.C. (1999). The Image Processing Handbook, 3rd Ed., CRC Press, Inc., Boca Raton, FL.

Sandu, C. (1986). Infrared radiative drying in food engineering: a process analysis Biotechnol. Prog. 2(3), 109–119.

Scanlon, M.G., Pang, C.H. and Biliaderis, C.G. (1996). The effect of osmotic adjustmen on the mechanical properties of potato parenchyma. Food Research Internationa (U.K). 29 (5-6): 481-488.

Scheele, c.von, Svensson, G. and Rasmussen, J. (1935). Om bestämning av potatisens stärkelse och torrrsubstanshalt med tilhjälp av dess specifika vikt. Nord. Jordb Forsk., 17-37.

Schwimmer,S.,Bevenue,A., Weston,W.J. and Porter, A.L.(1954). Survey of major anc minor sugar and starch components of white potato. *Agric.Food Chem.*2, 1284-90.

Siegel, R. and Howell, J. (2002). Thermal radiation heat transfer, 4th Ed., Taylor anc Francis, New York.

Sloan, A.E. (2003). Top 10 trends to watch and work on: J Food Technol. 57(4), 30–50.

Smith, O. (1967). Potato: Production, Storage and Processing.3rd Ed. AVI Publ. Co. Inc Westport, Conn.

Smith, O. (1968). Potato: Production, Storage and Processing.2nd Ed. AVI Publ. Co. Inc Westport, Conn.

Smith, O. (1975). Potato chips. In: Potato processing. 3rd Ed. Avi Publ.Co. Inc. Westport Conn.

Smith, O. (1977). Potato chips. In: Potato processing. 2nd Ed. Avi Publ.Co. Inc Westport, Conn.

Sowokinos, J.R. (1996). Advanced potato breeding selections with cold-chipping anc reconditioning potential. Am. Potato J. 73 (8): 386.

Talburt, W.F. and Smith, O. (1967). Potato processing: Frozen French fries and othe frozen potato products. AVI Publ. Co. Inc. Westport, Conn.

Talburt, W.F. and Smith, O., (1977). Potato processing: frozen French fries and othe frozen potato products. AVI Publ. Co. Inc. Westport, Conn.

Tawfik, A.A., Mansour, S.A., Ramadan, H.M. and Fayad, A.A. (2002). Processing qualit of selected potato varieties for chips and French fries in Egypt. African Crop Sci. J 10 (4): 325-333.

Toma, R.B., Augustin, J., Shaw, R.L., True, R.H. and Horgan, J.m. (1978). Proximate composition of freshly harvested and stored potatoes (*Solanum tuberosum* L.) J.Food Sci. 43 (3) 1702-1704.

True, R.H., Hogan J.M., Augustin, J., Johnson, S.R., Teitzel C., Toma, R.B. and Shaw R.L. (1978). Mineral content of freshly harvested potatoes. Am. Potato j. 55: 511 519.

True, R.H., Hogan J.M., Augustin, J., Johnson, S.R., Teitzel C., Toma, R.B. and Orr, P (1979). Changes in nutrient composition of potatoes during home preparation. Am Potato j. 56: 339-350.

USAID. (2001). U.S. Agricultural statistics for French fry production and Consumption USDA National Agricultural Statistics Service, United States Dept. of Agric Washington DC.

USDA. (2003). Code of Federal Regulations, Nutrition Labeling of Food, Title 21. Section 101.9.

Walingo, A., Kabira, J.N., Alexandre, C.E. and Ewell, P. (1997). Potato processing ir Nairobi, Kenya: current status and potential for further development. Workinç Paper (CIP). ISSN 0256-8748.

Walingo, A., Lung'aho, C., N'gang'a, N., Kinyae, P.M. and Kabira, J.N. (2004). Potatc marketing, storage, processing and utilization in Kenya. Proceedings of 6' Triennial congress of the African potato Association, Agadir, Morocco.

Walter, W.M., Truong, V.D. and Espinel, K.R. (2002). Textural measurements anc product quality of restructured sweet potato French fries. Lebensm-Wiss. U. -Tech *35*(3), 209–215.

Walter, W.M., Wilson, P.W. (1992). frozen sweet potato products. In: Sweet potatc technology fro the 21st century. Hill, W.A., Bonsi, C.K., Loretan, P.A. Tuskegee University, Alabama, U.S.A.

Weaver, M.L., Timm, H., Nonaka, M., Sayre, R.N., and Whitehand, L.C., (1979a). Potatc composition: tissue selection and its effect on total nitrogen, free amino acic nitrogen and enzyme activity. Am. Potato J. 55: 319-331.

Weaver, M.L., Reeve, R.M. and Kueneman, R.W. (1979b). Frozen French fries and othe frozen potato products. AVI Publ. Co. Inc. Westport, Conn.

7.0 APPENDICES

Appendix I: Daily record of mean monthly rainfall, temperature and relative humidity at the National Potato Research Station, KARI, Tigoni, January-July 2008

Month	Rainfall (mm)	Temperature (°C) Minimum	Maximum	Mean	Relative humidity (%)
January	26.30	15.29	18.50	16.90	90.26
February	33.30	14.95	18.82	16.88	90.52
March	23.70	15.62	19.00	17 32	86.00
April	472.10	14.40	16.90	15.67	75.63
May	276.40	14.80	17.50	15.63	74.65
June	132.18	13.67	15.67	13.97	76.90
July	27.20	13.00	15.11	14.55	80.68

Appendix II: 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 colour, flavour, 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.

9-point Hedonic scale

Quality	Score
Extremely poor	1
Very poor	2
Poor	3
Below fair/above poor	4
Fair	5
Below good/above fair	6
Good	7
Very good	8
Extremely good	9

The scoring card

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

Appendix III: Table for determination of the sugar content

0.1 thiosulphate solution (ml)	mg reducing sugar
1	2.40
2	4.80
3	7.20
4	9.70
5	12.20
6	14.70
7	17.20
8	19.80
9	22.40
10	25.00
11	27.60
12	30.30
13	33.00
14	35.70
15	38.50
16	41.30
17	44.20
18	47.10
19	50.00
20	53.00
21	56.00
22	59.10
23	62.20
24	64.30
25	66.40
26	69.80
27	72.00