Sensory and nutritional quality of orange-fleshed sweet potato crisps from roots with varying physico-chemical properties

by

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Declaration

I, James Makame declare that the dissertation, which I hereby submit for the degree MSc Food Science at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

SIGNATURE: …………………………..

DATE: ………………………………….

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Dedication

To my children Tadiwanashe, Brightness and Radiance for their inspiration to a bright and radiant future.

To God for His sufficient grace.

Acknowledgement

It goes without saying that *it takes a whole village to raise a child*. This study would not have been a success without immense contributions from other stake holders. I would like to express my gratitude to the following for their contributions in different ways:

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Abstract

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The sensory and nutritional quality of orange-fleshed sweet potato (OFSP) crisps can be optimized by utilizing storage roots with suitable physical and chemical properties. Three root types from the OFSP cultivars Impilo, Bophelo and 199062.1 were evaluated for physico-chemical composition in both raw and deep-fat fried state. Frying significantly lowered the L^*, a^*, b^*, E, h and C colour values for all three root types making the crisps darker compared to raw slices. The dry matter content (%) of Impilo, Bophelo and 199062.1 roots were 19.0, 23.1 and 27.2 respectively. The low dry matter Impilo tubers had the highest glucose content while the high dry matter 199062.1 roots had the lowest, with Bophelo roots intermediate for both the dry matter and glucose content.

Deep-fat frying significantly increased the oil content in the crisps. Crisps from high dry matter roots (199062.1) had significantly lower oil content (25.7 %) compared to those from medium dry matter roots (Bophelo) (32.6 %) and low dry matter roots (Impilo) (35.6 %). This reflects the influence of the physical and chemical properties of the root (e.g. dry matter content) on oil absorption. Medium to high dry matter root (Bophelo and 199062.1) crisps had higher stress and hardness values than low dry matter root (Impilo) crisps based on a compression test. High dry matter root (199062.1) crisps had significantly higher first fracture deformation values compared to low dry matter root (Impilo) crisps, with Bophelo root crisps intermediate.

Crisps prepared from roots of three OFSP cultivars (Impilo, Bophelo and 199062.1) and four other commercial crisp products (butternut, pumpkin, sweet potato and carrot) were further evaluated using Flash Profile (FP) sensory methodology. The sensory profiles of crisps from Bophelo and Impilo roots were more similar and were perceived as more orange and darker, harder, sweeter and less oily compared to 199062.1 crisps. The colour, appearance and flavour of OFSP crisps was influenced by the type and content of sugar in roots, with higher glucose and fructose content in Impilo tubers resulting in darker and sweeter flavoured crisps compared to crisps from Bophelo and 199062.1 roots. The higher β-carotene content of Bophelo roots produced crisps with more intense orange colour, while crisps from 199062.1 roots had the least intense orange colour. OFSP crisps were more orange and darker in colour, and were sweeter relative to commercial samples

High dry matter (199062.1) and high trans-β-carotene (Bophelo) roots can be used to produce value-added crisps with low oil, high trans-β-carotene content and with desirable textural and appearance properties for consumer acceptance. The physico-chemical variations of the OFSP storage root types affect the sensory and nutritional quality of deep-fat fried crisps and this could be exploited in crisp product diversification, in efforts to meet the varied and dynamic sensory expectations of consumers. Using roots with high dry matter (e.g. 199062.1), and high β-carotene content (e.g. Bophelo) in the production of OFSP crisps could optimize product texture, oil content, colour and β-carotene content when compared to root types of low dry matter content (e.g. Impilo). OFSP roots from 199062.1 cultivar may be an ideal choice for cost-effective low fat OFSP crisps with considerable β-carotene content. Low fat crisps would be in tandem with current nutritional thinking on the health benefits of low fat food.

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Chapter 1: Introduction

Sweet potato [*Ipomoea batatas (L.*) *Lam*] is an excellent food security crop because of reliable yields under various rainfall and soil conditions (Ewell, 2010). Sweet potato varieties common in southern Africa are white and cream-fleshed, but new bio-fortified β-carotene-rich orange fleshed sweet potato (OFSP) varieties have been introduced (Tomlins et al., 2012). If routinely consumed, OFSP is reported to confer many health functions to the body including anti-mutagenic, antioxidant, hepato-protective and cardio-protective roles due to its various bio-active compounds (phenolics, β-carotene, anthocyanins, fiber) (Rodríguez-Amaya, 2001; Grace et al., 2014). The β-carotene in OFSP can play a major role in food-based solutions to alleviate vitamin A deficiency (VAD). Despite the improved intervention programmes, VAD is still a significant cause of high mortality and preventable childhood blindness, affecting above 250 million children mainly in Africa and South Asia (Kraemer and Gilbert, 2013). However OFSP is one of the most under-exploited of the world's major crops (Truong et al., 2011; Tomlins et al 2012).

A modern use of OFSP is in the form of crisps as a snack food similar to potato crisps. Crisps are expected to be crispy, with a pleasant taste and odour, free from blisters, greasiness, brown pigmentation and wet centres (Consumer Voice, 2011). These quality attributes may be influenced by the physico-chemistry of the storage roots (dry matter, sugars, moisture content, carotenoid content and colour), because as shown for potatoes, not all varieties will produce high quality crisps (Ndungu, 2007). Crisps from high dry matter tubers (>25 %) can exhibit hard texture and are too brittle, whereas crisps of too low specific gravity are prone to absorption of too much oil which cause a greasy and sticky texture (Setyawan et al., 2013). Dry matter is also an indicator of starch content, which gives the crisp its taste, texture and colour. OFSP storage roots may vary in the type and concentration of sugars, and this affects the flavour and colour of crisps through participating in the Maillard reaction. This makes sensory profiling of OFSP crisps in relation to the physico-chemical properties of the storage roots necessary, because differences in root characteristics may affect the sensory properties of the end product and impact on consumers' acceptance of products.

Sensory characterization of boiled roots from OFSP and non-OFSP cultivars have been reported (Ofori et al., 2009; Leighton et al., 2010; Laurie et al., 2012, Tomlins et al., 2012). Impact assessment studies in Sub-Saharan Africa have shown that consumption of 125g boiled OFSP daily improved vitamin A status in children, lactating and pregnant women (Van Jaarsveld et al., 2005). OFSP cultivars therefore have great potential in both conventional and innovative foods to improve nutritional status and food security in the world, and to expand the market for convenient foods like crisps (Ewell, 2010; Yodkraisri and Bhat, 2012; Nabubuya et al., 2012).

Past research efforts have focussed on converting the nutritious OFSP into various forms such as puree and flour for use as functional ingredients, and little have been reported about the relationship between sensory characteristics and the physico-chemical parameters (dry matter, sugars, moisture content, carotenoid content and colour) of roots (Truong et al., 2011; Tomlins et al., 2012). Carotenoid content has been found to be negatively correlated with dry matter, and OFSP cultivars generally tend to have high carotenoid level, lower dry matter content and soft texture compared to white and cream fleshed cultivars (Lebot, 2010; Tomlins et al., 2012). However, consumers in Africa prefer high dry matter sweet potato varieties which are white or cream-fleshed (Kapinga and Carey, 2003; Laurie et al., 2012; Leksrisompong et al., 2012). These physico-chemical variations in sweet potato roots may act as barriers to consumer acceptance of OFSP products, and sensory research is therefore warranted because superior crop yields and nutritional benefits may not override unacceptable sensory properties.

The carotenoids of OFSP cultivars may add colour, improving the sensory perception of crisps, but their content varies in different cultivars (Abdulla et al., 2014). In one study, deep-fat fried sweet potato crisps from five cultivars showed different fried quality attributes, mainly due to variations in moisture content of the roots (Odenigbo et al., 2012). Roots with the lowest moisture content yielded crisps with lower oil content and desirable crispy texture. Roots with high moisture content led to high oil in crisps.

The current study examined the sensory and nutritional quality of OFSP crisps produced from roots (from cultivars Bophelo, Impilo and 199062.1) with varying physico-chemical properties (dry matter, sugars, moisture, flesh colour, β-carotene, protein, ash content). The results could assist OFSP breeders, food product researchers or marketers in understanding the impact of the physical and chemical composition of the storage root on sensory and nutritional quality of crisps to predict consumer acceptance.

Chapter 2: Literature review

2.1 Origin and description of the sweet potato crop

Sweet potato (*Ipomoea batatas L. Lam*) is a dicotyledonous plant of the Convolvulaceae family (Esan et al., 2013). There is controversy on its origins, but Mexico, Venezuela, Central America and Peru are thought to be its early cradles (Lebot, 2010; Truong et al., 2011). It is an important food crop around the world, with wide ecological adaptability and high yield within short time from planting (Wu et al., 2008; Laurie et al., 2012). In developing countries it plays a crucial role in alleviating major problems of malnutrition and food security (Bovell-Benjamin, 2007). China is the main producer of the world's sweet potato crop (85%) which is processed into industrial starch, alcohol and flour for noodles and other products (Kuuna et al., 2012). OFSP varieties are higher in vitamin A precursors than cream-fleshed varieties, their increased cultivation is encouraged in Africa to aleviate vitamin A deficiency (VAD) (Figueira et al., 2011; Esan et al., 2013). New clones with higher β-carotene content, better agronomic and sensorial attributes are being developed by various organizations and are actively promoted for use in new marketable products for consumption mainly amongst nutritionally vulnerable groups (Ofori et al., 2009; Bechoff et al., 2010).

2.2 Background of OFSP varieties in Africa

Before the 1990s, most Sub-Saharan African (SSA) sweet potato cultivars were white or yellow-fleshed with little β-carotene content (Mwanga et al., 2011). Hence the International Potato Center (CIP) based in Peru introduced OFSP clones to research institutes in different countries. In SSA, the clones were less preferred because, unlike in the USA, consumers liked the texture and eating quality of high dry matter content cultivars, which tend to be white or cream-fleshed with little carotenoid content (Leksrisompong et al., 2012; Laurie et al., 2012). The carotenoid-rich OFSP cultivars often have lower dry matter content (Lebot, 2010; Tomlins et al., 2012). In addition, OFSP cultivars were not adapted to local growing conditions and their adoption was very slow (Mwanga et al., 2011). Breeding improvement programmes were initiated to produce landraces which combined multiple phenotypes, including resistance to sweet potato virus disease (SPVD), enhanced β-carotene content, high dry matter content (above 30%), good root shape and high biomass (Mwanga et al., 2011). The Agricultural Research Council (ARC) of South Africa received among others, OFSP clone 199062.1 from CIP in Peru, and worked on developing improved varieties (e.g. Bophelo and Impilo) adapted to the local needs. Root samples from the three cultivars are shown in Figure 2.1.

OFSP cultivar 199062.1 | OFSP cultivar Impilo | OFSP cultivar Bophelo

Figure 2.1 *Pictures of some root samples from the three OFSP cultivars 199062.1, Impilo and Bophelo grown at the ARC-VOPI, Roodeplaat (Courtesy of Dr Sunette Laurie, ARC-VOPI).*

Bophelo is an ARC cultivar innovated through targeted breeding to address VAD mostly in rural communities in South Africa (Moephuli et al., 2012) (Table 2.1). Cultivar 199062.1 was developed through advanced trials by the Department of Genetics and Crop Improvement of CIP in Peru (CIP, 2003). It has a high harvest index and performs fairly well under drought stress across many environments (Serenje and Mwala, 2010; Kivuva et al., 2014). An "ideal genotype" is one with the highest yield across test environments and ranks the highest in all test environments (Kaya et al., 2006). OFSP cultivar 199062.1 was closest to the "ideal genotype" in yield and stress tolerance in a study involving 24 genotypes in Kenya (Kivuva et al., 2014). The high anti-oxidant activity of cultivar 199062.1 has been attributed to significantly high flavonoid content (El Far and Taie, 2009). The third OFSP cultivar is Impilo, a promising cultivar in all-round performance.

Although Bophelo, Impilo and 199062.1 are among the OFSP cultivars which have been reasonably characterized, the influence of their physico-chemical properties on quality of processed products like fried crisps has not been fully investigated. The characteristics and agronomic potential of OFSP cultivars used in the present study are shown (Table 2.1).

Table 2.1 *Background descriptions and characteristics of tubers from OFSP cultivars used in this study for crisp processing by deep-fat frying.*

	Orange-fleshed sweet potato cultivars		
Parameter	Bophelo	Impilo	199062.1
General description	Orange-fleshed ARC cultivar released in 2011[6] Protected (Plant Breeders' Rights Act No 15 of 1976)[5]	Slightly orange-fleshed ARC cultivar with high yield and stability[4] Wide agro-ecological adaptation Watery boiled tuber texture	CIP cultivar promoted in RSA since 2009[6]. Five month vegetative period[3] Nematode resistant[6]
Physico-chemical and sensory profile	Best orange-fleshed[6]	Sweet-tasting; pumpkin-like flavour Prone to discolouration[4]	Yellow-orange root colour[1] Light-orange fleshed[3]
Dry matter (%)	22.5[6]	19.0 - 23.0[4]	28.1[1]; 32.0[3]
Sugars (%) (glucose, fructose, sucrose, maltose)	No information available	[1.6; 1.4; 3.0][7]; 7.7[4] respectively	No information available
Root yield (t/ha)	31.0[6]	No information available	20.9[1]; 30.0 - 36.0[6]
β-carotene (µg/100g, db.)	No information available	5 091.0[4]	464.7[2] (fresh weight)
SPVR	Susceptible[6]	No information available	Moderate[1]; Relatively resistant
Alternaria blight disease	Medium resistance[6]	No information available	Resistant[4]

[1] Mwanga and Ssemakula (2011); [2] Ofori et al (2009); [3] International Potato Center (CIP) (2003), [4] Lauri et al (2011); [5] Moephuli and Phehane (2012); [6] Laurie et al (2014); [7] Laurie et al (2012). SPVR: Sweet potato virus disease

2.3 Food uses of OFSP

Promoting the utilization of OFSP roots will foster household nutrition diversification (Bechoff 2010). OFSP is traditionally consumed fresh, after boiling, stewing, or can be sun-dried for storage. Pureeing, canning and freezing are further technologies for preserving sweet potatoes post-harvest (Oke and Workneh, 2013). OFSP flours have been evaluated as ingredients in novel and value-added foods, like bread, *mandazi* (East African doughnut) and *chapatis* (round flat unleavened bread that is usually made of whole wheat flour and cooked on a griddle) in Uganda (Bechoff *et al*., 2011). OFSP crisps are also becoming available on the South African market. OFSP crisps can be a potentially nutritious snack when produced from cultivars high in β-carotene (Ali et al., 2012). Frying results in unique flavour, colour and texture which are the main drivers of consumer acceptability of fried products (Odenigbo et al, 2012).

2.4 Nutritional and health promoting properties of OFSP

OFSP is recognized as a healthy food because of its significant content of phytonutrients such as β-carotene, phenolic acids, anthocyanins and dietary fiber (McLaren and Frigg, 2001; Wu et al., 2008; Ravli et al., 2013). Phytochemicals have attracted much attention due to their anti-oxidant role, a chemical property related to their capacity to reduce the risk of cancer, heart disease and other degenerative conditions (Saddozai et al., 2005; Rodriguez-Amaya et al., 2006). In biological systems, β-carotene acts by quenching singlet oxygen and scavenging free radicals (Klein and Kurilich, 2000). It is essential for the visual cycle in the retina of the eye, but it also plays an important role in growth, development and reproduction, and in the immune system (Edem, 2009). Debilitating effects of VAD are well documented, including blindness and increased mortality especially in children (Bechoff, 2010).

An antioxidant is any substance that significantly delays or inhibits oxidation of other molecules (Flora, 2009). Oxidation refers to the transfer of an electron from an electron rich to an electron deficient entity. A dietary antioxidant is "a substance in food that significantly decreases the adverse effects of reactive oxygen species (ROS), reactive nitrogen species (RNS), or both on normal physiological function in humans" (Food and Nutrition Board of the National Academy of Science, 1998). Reactive species can react with important bio-molecules (DNA, RNA, proteins, lipids) and this may cause metabolic disorders. Additional functions of β-carotene are not well understood, as in the regulation of gene expression (FAO/WHO 2002). The nutrient composition of raw and boiled or baked OFSP are shown below.

Table 2.2 *Mean nutrient content of some OFSP cultivars (composite of Resisto, W119, Jewel and A15) showing the benefit of regular consumption of OFSP (Adapted from Leighton et al., 2007).*

		All OFSP Cultivars (n = 5)		
Nutrients	**Unit/100g**	**Raw[1] (n = 6)**	**Cooked[2] (n = 7)**	**OFSP: Skin baked, flesh only (USDA, 1998)**
Ash	g	0.97 ± 0.1	0.97 ± 0.1	
Dry matter	g	21.1± 1.3	21.4 ± 0.9	20.7
Moisture	g	78.9 ± 1.3	79.0 ± 0.9	
Protein	g	1.3 ± 0.2	1.33 ± 0.2	1.7
Fat	g	0.24 ± 0.0	0.22 ± 0.0	0.1
Carbohydrate, calculated	g	18.6	18.5	21.3
Trans-β-carotene	µg	7 128.0 ± 951.0	6 528.0 ± 648.7	13092,0

Superscripts 1 & 2 are mean values for raw and cooked OFSP cultivars (Resisto, W119, Jewel and A15) analysed. Cooked by boiling at 95 ^{o} C, skins on until soft.

2.5 Dietary carotenoids

The chief colour pigments of edible fruits and vegetables are carotenoids, chlorophylls, betalamines, anthocyanins and anthoxanthins, (Saddozai, et al., 2005). Most carotenoids are C_{40} polymers of eight C_5 isoprene units (Ishida and Bartley, 2005; Bechoff, 2010). All-trans-β-carotene ($C_{40}H_{56}$) (Figure 2.2) is one example.

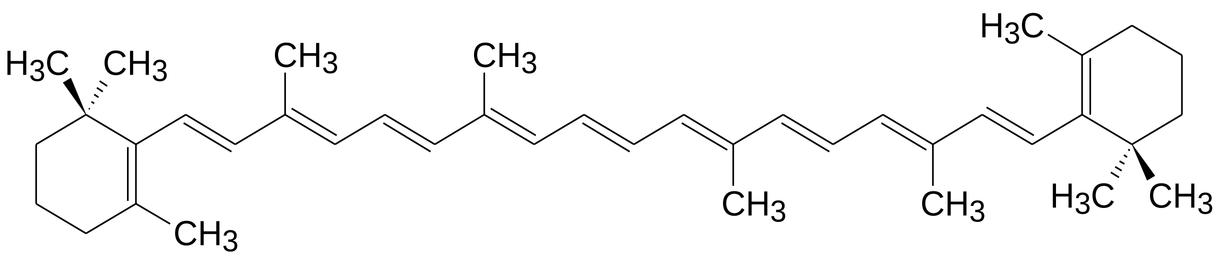


Figure 2.2 *Structure of all-trans-β-carotene showing the conjugated poly-ene chain responsible for its physical and chemical properties.*

(All-trans-β-carotene drawn with the help of Advanced Chemistry Development, Inc., ACD/ChemSketch freeware version 14.01 of 2013. Copyright© 1994-2015).

Carotenoids in foods vary qualitatively and quantitatively depending on agronomic practices, maturity, climate or season, plant part consumed, post-harvest handling, processing and cultivar (Rodriguez-Amaya et al, 2006; Laurie, 2010). More orange foods have higher carotenoid content (Faber and Van Jaarsveld, 2007; Burri, 2011; Wu et al., 2008; Aywan et al, 2012). Plant carotenoids are associated with lipid-protein complexes because of their hydrophobic (lipophilic) nature. In OFSP roots β-carotene is located in cell protoplasts in lipid droplets or bound to a protein that is released during cooking, thereby increasing bioavailability (Kopsell and Kopsell, 2006). *Trans*-β-carotene occur in higher concentration compared to *cis*-β-carotene and exhibits the highest pro-vitamin A activity among the carotenoids (Van Jaarsveld et al., 2006). Some reported β-carotene values for the OFSP from other studies are given below.

__Table 2.3__ β-Carotene content (dry basis) of fresh roots of some sweet potato cultivars and generic types not identified as reported in literature.

Sweet potato cultivar	Flesh colour	Mean β-carotene content, $\mu g.100g^{-1}$	Authority/Country
Rubina®	Dark orange	34 859	Bechoff (2010), UK
Resisto	Dark orange	11 900	Laurie (2001), RSA
Resisto	Dark orange	16 900	Van Jaarsveld et al (2006), RSA
Resisto	Dark orange	16 456	Laurie (2012), RSA
11-20 cultivar	*Not identified*	22 600	Teow et al (2007), USA
Khano	*Not identified*	14 036	Laurie (2012), RSA
SPV-61	*Not identified*	26 600	Takahata et al (1993), Japan
Impilo	Light-orange	5 091	Laurie (2012), RSA
Composite (Resisto, Jewel, W119, A15)	*Not identified*	7 128	Leighton (2007), RSA
Mafutha	Cream-orange	1 870	Laurie (2001), RSA
Not identified	White	Not detected	Aywa et al (2013), Kenya
Not identified	Purple	Not detected	Aywa et al (2013), Kenya
Not identified	Yellow	2 071	Aywa et al (2013), Kenya
Not identified	Orange	4 619	Aywa et al (2013), Kenya
Not identified	Dark-orange	27 770	Xu et al (2013), USA

2.6 Properties of carotenoids and mechanisms of degradation

The unique electrochemical properties of carotenoids derive from their delocalized π-electrons which require little energy to excite to a higher energy state (Ishida and Bartley, 2005). This property explains their supposed efficacy in many health benefits, yet it makes them susceptible to degradation from electrophilic reagents (Bechoff, 2010). Carotenoids absorb light in the visible spectrum and produce intense colours (Naik *et al.* 2003). Colour is important, consumers associate it with flavour, safety, shelf-life, nutrition and satisfaction (Pedreschi et al, 2012).

The poly-ene chain is the cause of carotenoids instability towards oxidation and free-radical chemistry. The usual indication of carotenoid breakdown is the loss of the desirable orange/yellow colour due to chromophore breakdown (Choe and Min, 2006). These changes lower the sensory and nutritional quality of the product. Although a reaction scheme has been suggested concerning carotenoid degradation (Figure 2.3), knowledge on the kinetics of the reactions remains fragmentary (Dutta et al, 2005).

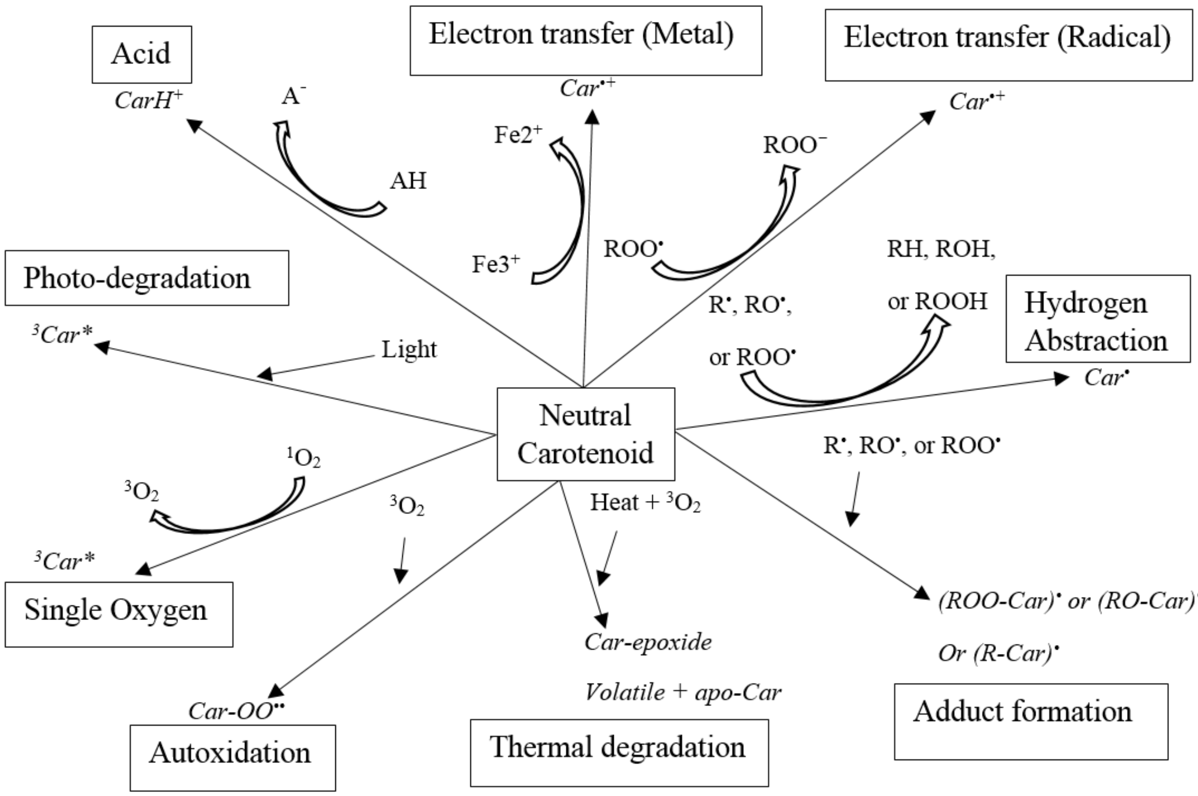


Figure 2.3 *Carotenoids undergo oxidation rapidly when exposed to various oxidizing conditions (Adapted from Boon et al, 2010).*

Processing may cause degradation of *trans*-carotenoids, which represents almost 100 % of total carotenoids in raw OFSP (Dueik et al., 2013). Organic acids released during peeling and slicing provoke *trans*-*cis*-isomerization, especially during thermal processing such as in deep-fat frying (Rodriguez-Amaya, 2006). The *cis*-isomer has about half the pro-vitamin A activity of trans-β-carotene, and *cis*-β-carotene is less bioavailable than *trans*-β-carotene (Rodriguez-Amaya and Kimura, 2004). This is of concern because OFSP promotion is aimed at improving the nutritional status for vitamin A in vulnerable communities. Trans-β-carotene content decreases with longer processing time, higher processing temperatures, cutting and maceration of foods (Laurie, 2010).

Trans-carotenoids such as *trans*-β-carotene oxidize and isomerize under oxygen, heat and uv-light exposure during processing as shown in Figure 2.4.

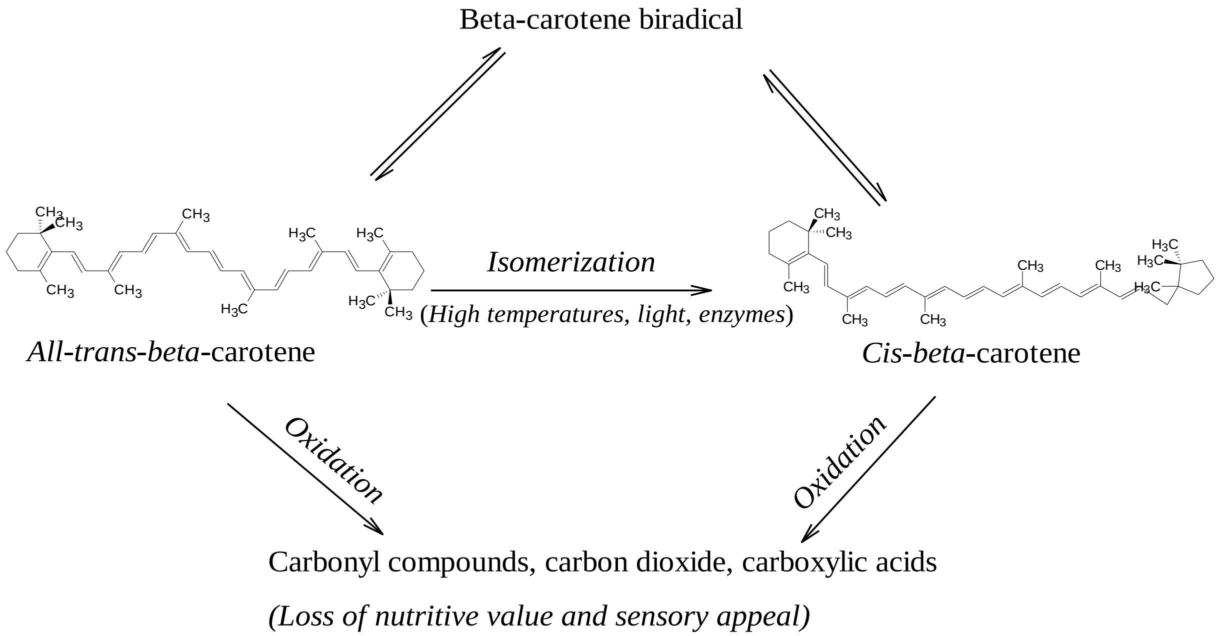


Figure 2.4 *Isomerization and oxidation are the chief degradation pathways for β-carotene.*

Processing however, may improve bio-accessibility of β-carotene by denaturing or weakening cell ultrastructure, protein complexes, and cleaving ester linkages to release carotenoids from the food matrix, which increases the extractability (Dutta et al., 2005). Unlike oxidation, isomerization does not affect the sensory colour impression of β-carotene because the double bonds do not break. Like oxidation, it lowers the nutritive value of food because the cis-β-carotene isomer is less bio-available. Therefore, process optimization is necessary to increase bioavailability without much degradation or isomerization (Rodriguez-Amaya, 2006).

2.7 Specifications for OFSP roots used in crisp processing

Crisp processors set strict specifications for tubers (and roots) to produce quality crisps at minimum costs (NIVAA, 2002). Each cultivar has an inherent genetic tendency to accumulate a certain amount of total solids, which is modified by environmental factors during the growing season (Mazt, 1993). Consequently, only tubers and roots which meet special quality standards and can be processed cost-effectively will qualify for processing.

2.7.1 Dry matter and specific gravity of OFSP roots

The dry matter content is an indicator of processing quality, as it reflects the amount of starch present (NIVAA, 2002). Starch gives the crisp taste, texture and colour. For potatoes *(Solanum tuberosum*), tubers with high dry matter (20 – 24 %), high specific gravity (1.08 – 1.09) and low sugar content are preferred for crisp processing (Miranda and Aguilera, 2006). Specific gravity is the weight per volume of a substance (Pavlista, 1997). It is used for determination of the dry matter content in order to predict the frying potential of roots and tubers (Ndungu, 2007). The sweet potato storage root shows variable starch distribution in different tissues.

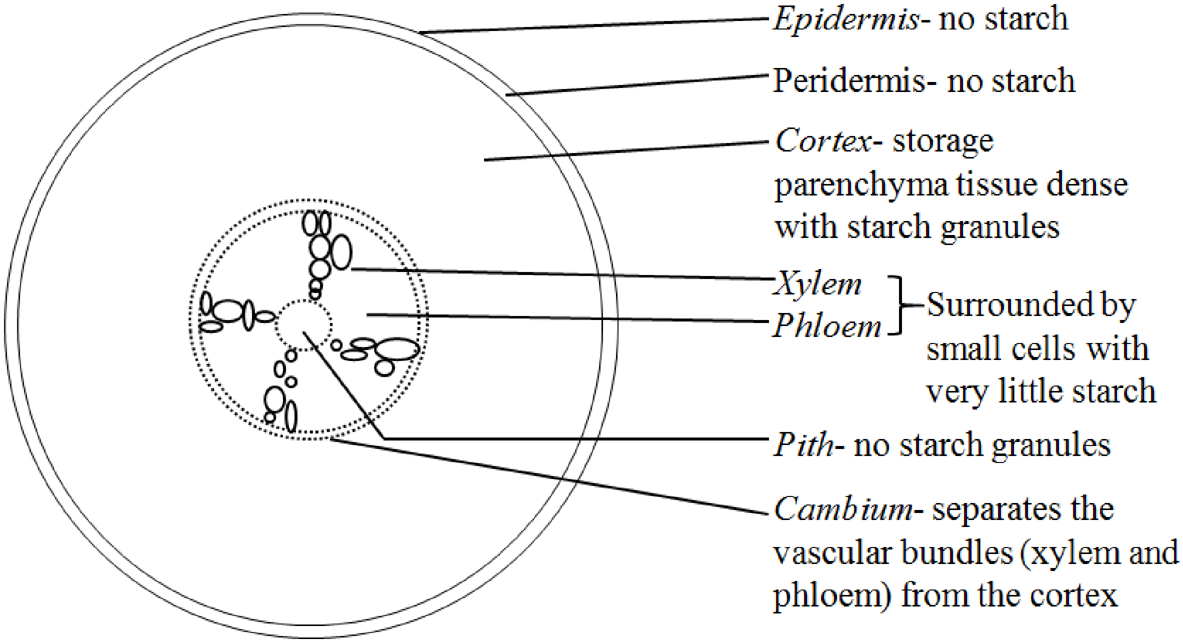


Figure 2.5 *A cross sectional drawing of the sweet potato storage root (Ipomoea batatas (L.) Lam) showing the heterogeneous distribution of starch.*

Numerous starch granules occur in the cortex, but cells adjacent to the phloem and xylem have small and fewer starch granules, while cells in the pith do not accumulate starch. Starch confers texture, colour and flavour, and tubers and roots with high starch content can be thinly sliced and still yield good texture and flavour (TAYTO, 2005). In potato tubers, such wide histological variability of the tissue structure cause high variations in properties of finished products (Miranda and Aguilera, 2006).

Both processing efficiency and crisp quality benefit from a higher dry matter content, by decreasing fat absorption which lowers processing costs and is better for consumers' health (De Meulenaer et al., 2007). However, too high dry matter tubers (>25 %) can yield too brittle and hard textured crisps. To produce good taste and a crispy texture from low dry matter tubers, the slices must be thicker to retain as much flavour as is possible (TAYTO, 2005). If the dry matter content is too low, crisps will be too wet and require more heat energy to dehydrate. This makes processing costly due to the low yield and higher energy consumption. Very low specific gravity roots absorb too much oil causing a greasy and sticky crisp texture (Setyawan et al., 2013).

2.7.2 Sugar content of OFSP roots

The crisp industry carefully monitors the reducing sugar content of roots and tubers used for processing. For potatoes (*Solanum tuberosum (L.) Lam*), the sugar content may not exceed 0.2 – 0.3 % of the fresh weight (NIVAA, 2002). In sweet potatoes, the main sugars are glucose, fructose and sucrose, whose fresh weight content were reported as 0.96 %, 0.70 % and 2.52 %, respectively in the roots (Truong et al., 2011). Sugars provide colour and flavour through the Maillard reaction, but in excess they can produce bitter flavours and colour mottling which lower acceptability. About 90% of the variation in crisps colour is due to sugars (Roe et al., 2006).

Table 2.4 *Variation of sugar content with flesh colour in some sweet potato cultivars in Uganda. (Nabubuya et al., 2012).*

Sweet potato cultivar (Flesh color)	Sugar content (%DM)					
	Sucrose	Maltose	**Glucose**	**Fructose**	Galactose	**Total sugars**
NASPOT 1 (Cream)	8.41^{c}	0.37^{e}	0.22^{b}	0.28^{b}	0.037^{b}	9.31^{c}
Dimbuka (Pale yellow)	5.79^{a}	0.34^{d}	0.15^{a}	0.21^{a}	0.027^{ab}	6.52^{a}
Soroti (Yellow)	9.54^{d}	0.38^{e}	0.55^{f}	0.45^{f}	0.044^{b}	10.96^{e}
Esapat (Yellow)	7.15^{bc}	0.38^{e}	0.32^{c}	0.37^{c}	0.033^{b}	8.25^{b}
NASPOT 2 (White)	7.30^{bc}	0.44^{f}	0.37^{d}	0.39^{d}	0.015^{a}	8.51^{b}
New kawogo (White)	14.42^{e}	0.32^{bc}	0.68^{g}	0.66^{i}	0.031^{b}	16.1^{g}
Kakamega (Pale orange)	7.99^{bc}	0.33^{cd}	0.52^{e}	0.52^{g}	0.072^{c}	10.29^{d}
NASPOT 9 (Orange)	9.33^{c}	0.28^{a}	0.53^{e}	0.42^{e}	0.043^{b}	10.6^{d}
NASPOT 10 (Orange)	10.10^{d}	0.44^{f}	1.37^{h}	1.10^{j}	0.082^{d}	13.59^{g}
Ejumula (Deep orange)	10.35^{d}	0.30^{b}	0.57^{f}	0.63^{h}	0.037^{b}	11.89^{f}

$^{a\text{-}i}$ *Means in the same column followed by different superscripts differ significantly ($p \leq 0.05$). Results are on dry basis.*

Sugar content increased with the intensity of yellow/orange flesh colour, except for *New kawogo* cultivar. The study concluded that sweet potato roots differing in flesh colour had variable sugar concentrations. Truong et al (1986) found total sugars to vary from 5.6% in a Filipino cultivar to 38% in a Louisiana cultivar on a dry weight basis (db.). The differences in sugar quantities reported in literature may result from varietal differences, endogenous amylase activity and environmental conditions (Nabubuya et al., 2012), yet they may suggest possible sensory and nutritional variations, and other quality characteristics of processed products from the roots.

The issue of sugar content is also critical because of concern about its role in acrylamide (a potential carcinogen and neurotoxicant) formation in fried foods (Sickles et al., 2007). Acrylamide is formed by a reaction between a carbonyl compound and amino acid asparagine, eventually forming a decarboxylated Schiff base under high temperatures (Stadler et al., 2004). Maillard reaction and side its reactions in fried crisps and related foods, is outlined below.

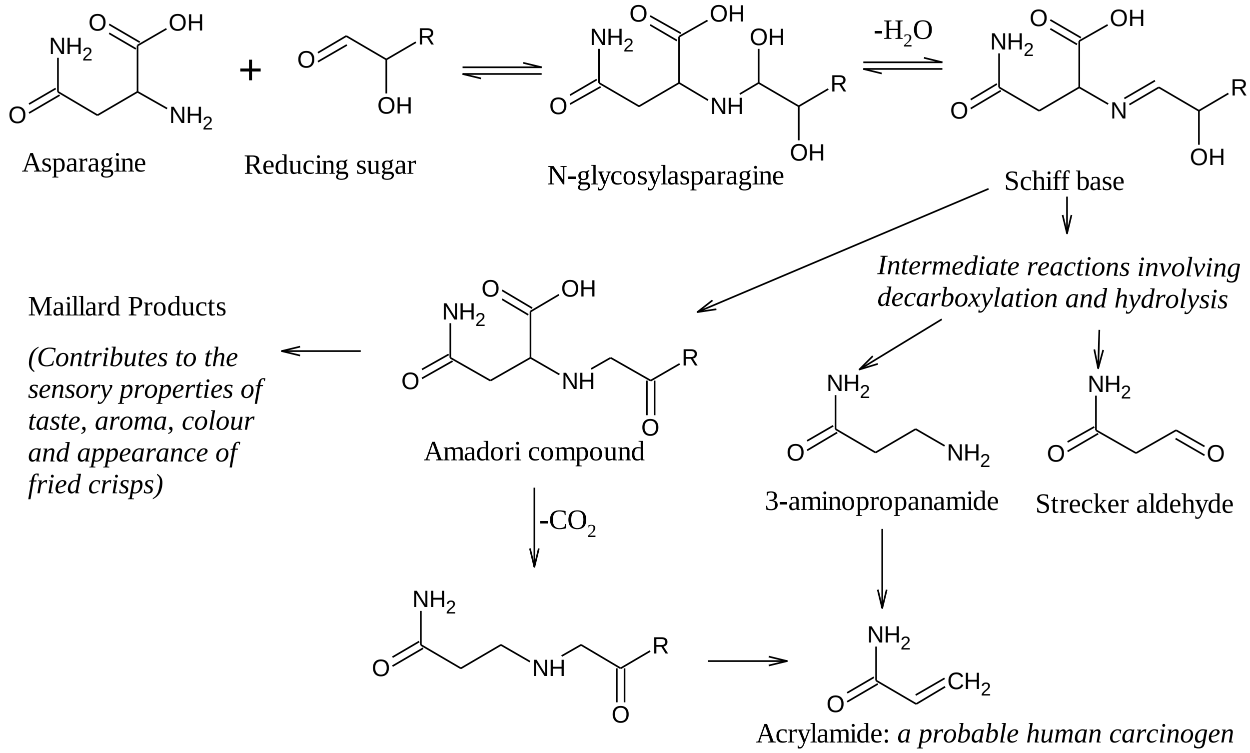


***Figure 2.6** Proposed mechanism for the Maillard reaction and the side reactions, e.g. formation of acrylamide.*

(Scheme drawn with the help of Advanced Chemistry Development, Inc., ACD/ChemSketch freeware, version 14.01 of 2013. Copyright© 1994-2015).

In OFSP asparagine concentration is in excess compared to reducing sugars, so the reducing sugar is the limiting factor in the Maillard reaction (De Wilde et al., 2005). Maillard reaction products are responsible for dark colour and flavour formation in heat processed foods, affecting sensory quality and product acceptance by consumers. Several intermediate products called Amadori products or pre-melanoidins, are rapidly polymerized at frying temperatures forming dark-coloured molecules (melanoidins) (Bordin et al., 2013).

2.8 Deep fat frying of OFSP slices to make crisps

Frying is a widely practised cooking technique for producing snacks with desirable quality (Mujumdar and Devahastin, 2008). It creates unique flavours and texture in fried foods to improve overall palatability (Pedreschi et al, 2012). Food is immersed in oil at temperatures above the boiling point of water. Heat and mass transfer then occur in opposite directions within the frying material, coupled with various physical and chemical reactions (Krokida *et al*. 2000a; Tangduangdee et al., 2003). Mass transfer is characterized by starch, soluble materials and water escaping from the product and oil diffusion into the food. Heat transfer and dehydration promotes the Maillard reaction, protein degradation, gelatinization, retrogradation, and glass transition of carbohydrates and proteins (Tangduangdee *et al*, 2003). Below is a summary of the changes occurring during frying of potato slices.

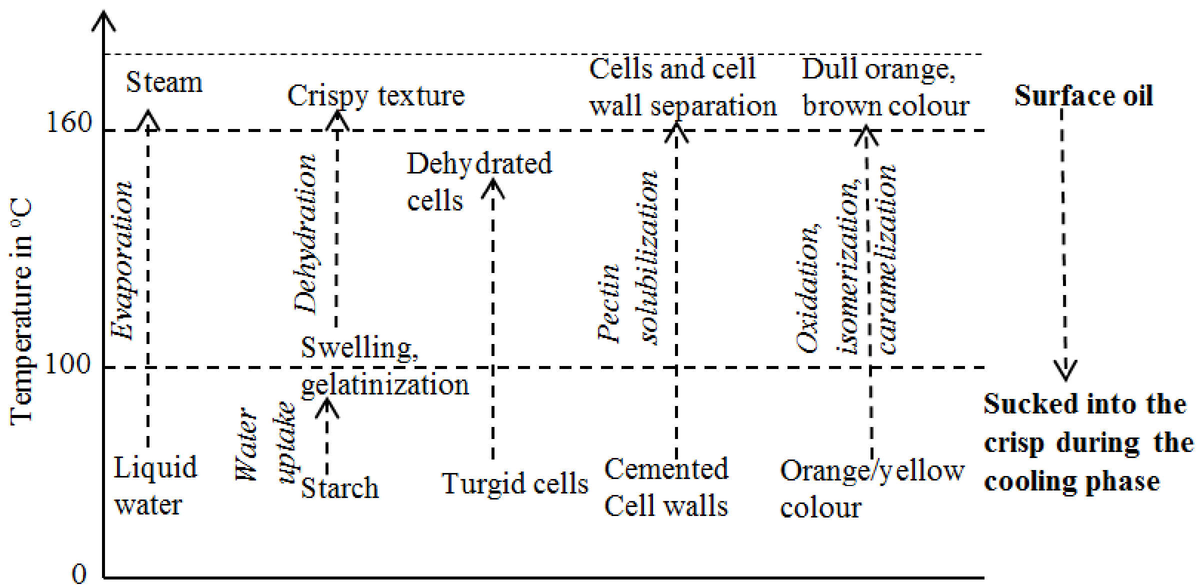


Figure 2.7 *Physical, chemical, and structural changes occurring inside a potato slice during deep-fat frying, (Adapted from Miranda and Aguilera, 2006).*

Caramelization of sugars leads to browning which defines the colour of final products (Arabhosseini et al. 2009). Lipids act as flavour agents, enhancing appearance and imparting a smooth mouth feel to fried products (Saguy and Pinthus, 1995). However, excessive oiliness affects sensory quality and consumer acceptability of crisps, therefore fat absorption should be carefully monitored (Hagenimana et al., 1997). This requires agro-processors to screen for roots and tubers of high dry matter content and specific gravity to reduce oil absorption.

2.9 Mechanisms of oil absorption during deep fat frying of OFSP

Moisture loss from the food during frying could be a viable explanation for oil uptake. Water escape induces the creation of cavities for subsequent oil impregnation (Vitrac *et al*., 2000). Water vapour burrows its way to the product's surface due to pressure and concentration gradients, creating capillary pathways for oil absorption (Ngadi et al., 2009). Pressure difference between atmospheric and vapour pressure inside the crisp due to condensation at cooling also promote oil uptake (He et al., 2012). Crisp cooling creates a "vacuum effect" which draws surface oil inwards (Gamble *et al*., 1987; Food and Health Innovation Service, 2002). In crisps, capillarity is thought to be a major oil absorption mechanism (Mellema, 2003).

2.10 Quality assessment of crisps

Texture is a key factor for the quality of fried crisps (Ross and Scanlon 2004). It defines the consistency, physical characteristics and sensory perceptions of foods. Food texture is dependent on raw material composition, thickness, moisture content and the technological parameters used during processing (Mazt, 1993; Kita 2002; Moyano et al. 2007; Odenigbo et al., 2012). Good quality crisps should have a crispy crust (1-2 mm thick) with a very crunchy texture all the way through. Crispiness indicates freshness and high quality (Troncoso and Pedresh 2007a). Too high frying temperatures make the slices brittle and appear overcooked, too low temperature cause soft and unpleasant to eat slices. Frying 3 to 4 minutes at 160-164°C may be used (TAYTO, 2005). Measuring crisp texture is often difficult due to the inherently variable nature of roots and the cellular and subcellular structural changes in fried slices (Mazt, 1993; Setyawan et al., 2013).

2.10.1 Moisture content of crisps

In crisps, if moisture exceeds a permissible limit (about 3%) product quality will deteriorate through microbial spoilage, hydrolytic rancidity and loss of desirable texture (Ali et al., 2012). Ndungu (2007) reported that the moisture content of potato crisps manufactured from tubers of different physico-chemical properties ranged from 1.2% to 1.9%. In India, a statutory standard stipulates a maximum acceptable level of 2% moisture content for crisps (Consumer Voice, 2011). Crispness is lost as moisture content increases by redistribution or moisture pick-up from the environment. This is detected in instrumental testing as a change in the pattern (jaggedness) and value of parameters from the force-deformation curve (Miranda and Aguilera, 2006).

2.10.2 Colour and appearance of OFSP crisps

For potatoes, crisps should have an attractive uniform colour without brown spots (Consumer Voice, 2011). Consumers respond less favourably to crisps with a mottled appearance and dark brown "burned" areas (Mazt, 1993). Colour development begins following sufficient drying and depends on the drying rate and the heat transfer coefficients during frying (Setyawan et al., 2013). Crisp colour, not just flavour and aroma, is formed by Maillard reaction (Santis et al., 2007). The rate and extent of Maillard reaction depends on the concentration of reducing sugars and amino acids or proteins on the surface of the frying slice, and on the temperature and frying time (Marquez and Anon 1986). For potatoes, tubers with 0.1 % - 0.2 % (fresh weight basis) reducing sugars usually develop desirable golden brown colour when fried but crisps tends to be darker and unattractive with increasing sugar levels, producing bitter or burnt flavour which lowers acceptability (Mazt, 1993). Chemical variability within the same tuber extends also to colour, resulting from the heterogeneous distribution of sugars (Jankowski et al, 1997).

2.11 Descriptive sensory profiling of crisps

Descriptive sensory analysis tests are designed to reflect the total sensory profile of products being evaluated (Stone & Sidel, 2004). They involve detection and description of qualitative and quantitative sensory aspects by trained panellists (Meilgaard *et al.* 2007). For industry, product sensory characteristics are essential information for research and development, quality control, and marketing (Chollet et al., 2011). In product development, understanding the relationship between product sensory characteristics and the raw material is important because product quality drives consumer acceptance (Chapman et al., 2001). Sensory testing provides data on which sound decisions can be made, by producing a description of the appearance, flavour and textural attributes of food and quantifying the nature and intensity of these (Revell et al, 2008; Pedreschi *et al*, 2012). Therefore sensory mapping of new products for quality may contribute to strategic positioning for development and marketing purposes (Chapman et al., 2001).

Leighton et al (2010) applied a lexicon (Table 2.5) to describe the sensory attributes of boiled tubers from five different sweet potato cultivars: four OFSP (Beauregard, Kano, W119, Resisto) and one WFSP (Blesbok).

Table 2.5 *A lexicon for descriptive sensory analysis of boiled roots from five different sweet potato cultivars. For a full lexicon that was used refer to Leighton et al (2010).*

Attribute		Description
Aroma	Earthy	Aromatic notes associated with damp soil, wet foliage or slightly undercooked potatoes
	Sweet potato	Aromatic associated with sweet potato, typical of WFSP
	Burn	An aromatic associated with vegetables that were burnt while cooking
First bite	Denseness	The solidness/compactness of the sample
	Moistness	The amount of wetness/moistness of the sample in the mouth
Flavour	Vegetable sweet	Taste characteristic of sweet vegetable varieties, such as sweet corn, sweet potato, butternut or sweet carrots
	Sweet potato	Flavour notes associated with the taste of cooked [1]WFSP
	YV (Butternut, carrots, pumpkin)	Taste associated with yellow starchy vegetables such as butternut, pumpkin, carrots, and, to a lesser degree, squash
Aftertaste	Sweet	An aftertaste that leaves a sweetness on the tongue and in the mouth which is pleasant

[1] WFSP, white-fleshed sweet potato. YV: yellow vegetables

The authors reported that OFSP differed in colour, was sweeter and displayed flavour characteristics of yellow vegetables when compared with white-fleshed varieties. Ofori et al (2009) used acceptance criteria to study the sensory attributes of both boiled and fried roots from 24 newly bred sweet potato genotypes. Results indicated that sweet potato preference varied with the genotype’s physico-chemical properties for both boiled and fried roots.

In Uganda, the sensory characteristics of boiled roots from eleven sweet potato cultivars with varying carotenoid concentrations (0.4 - 72.5µg/g fresh weight) and dry matter contents (26.8 - 39.4%) were compared through a modified descriptive analysis technique (Tomlins et al., 2012). The logarithm of the carotenoid content varied inversely with the dry matter content of the roots studied (Figure 2.8).

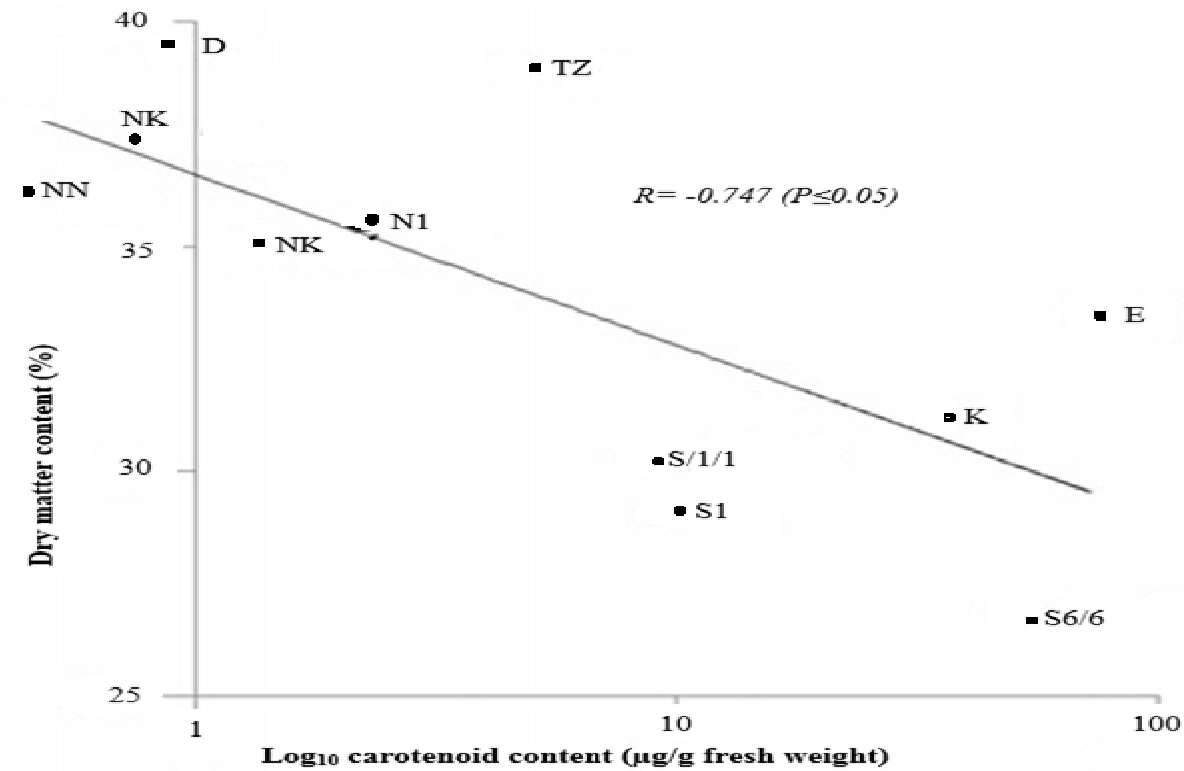


Figure 2.8 *Relationship between dry matter (%) and logarithm of the total carotenoid content of roots from 11 sweet potato cultivars.*

NN, Ndikirya N'omwami; NK, Nakakande; D, Dimbuka; NK, New Kawogo; N1, Naspot 1; TZ, Tanzania; S/1/1, SPK004/1/1; S1, SPK004/1; K, Kakamega; S6/6, SPK004/6/6 and E, Ejumula (Adapted from Tomlins et al., 2012).

In the same study, the intensity of 13 sensory attributes was scored on a 100 mm unstructured scale, anchored with the terms 'not very' at the low end and 'very' at the high end. The sensory attributes used were as follows:

Sweet potato odour (odour characteristic of sweet potato); pumpkin odour (odour characteristic of pumpkins); smooth appearance (sweet potatoes that have an even surface); yellow colour (flesh that is yellow in colour); white colour (flesh that is white in colour); uniform colour (sweet potato that is even in colour and with minimal variation); sweet taste (taste like sugar); pumpkin taste (taste that is characteristic of pumpkin); crumbly texture in the hand (sweet potato is brittle and flaky when compressed by the fingers); soft texture (texture that is squashy and yielding); fibrous texture (the quality of being fibrous) and watery texture (texture that is moist) (Tomlins et al., 2012).

The correlation results showed that pumpkin odour, smooth appearance, orange colour and pumpkin taste were negatively correlated with the dry matter content of the tubers (r = -0.721; -0.645; -0.780 and -0.717 respectively). The same sensory attributes directly correlated with $\log_{10}$ carotenoid content (r = 0.952; 0.673; 0.951 and 0.917 respectively). Sweet taste was positively correlated with the dry matter content (r = 0.725) but negatively correlated with the $\log_{10}$ carotenoid content (r = -0.44) (Tomlins et al., 2012).

Laurie et al (2012) used both descriptive and acceptance evaluations to investigate how the sensory properties of twelve boiled sweet potato cultivars (9 OFSP and 3 cream-fleshed) varied with the tuber physico-chemistry. Their findings confirmed earlier studies on the sensory properties of boiled OFSP and non-orange varieties (Leighton et al., 2010; Ofori, et al., 2009; Tomlins et al, 2007). OFSP roots were associated with pumpkin flavour, watery texture, and orange colour, while yellow and white varieties were associated with creamy colour, starchiness, hard texture, coarse texture, yellow colour, fibrous texture and sweet taste.

Leksrisompong et al (2012) applied a lexicon with reference standards (Table 2.6) to evaluate the sensory characteristics of boiled sweet potato roots with varying flesh colours. OFSP were characterized by fibrousness, moistness and residual fiber texture, earthy/canned carrot, dried apricot/floral flavour and aroma, brown sugar aroma and visually moist, high colour homogeneity and sour taste (Leksrisompong et al., 2012).

Table 2.6 *Sensory attributes used to evaluate the sensory characteristics of sweet potato roots from cultivars with varying flesh colour (orange, purple, yellow) (Leksrisompong et al, 2012).*

Term	Defination	Reference
Visual		
Colour homogeneity	Degree of evenness of colour	2005 Beauregard: 8-9; 2005 NC 414:5-6
Moisture	Degree of surface moisture	2005Beauregard: 7; 2005 NC 414:4.5
Fibrousness	Amount of stringy/fibers present	2005 Beauregard: 2; 2005 NC 414:3.5
Texture in mouth		
Firmness	Amount of force necessary to compress the sample fully between the tongue and the palate	2005 Beauregard: 4; 2005 NC 414:8
Denseness	Degree to whuch the sample is solid, compactness of the cross-section	2005 Beauregard: 4; 2005 NC 414:8
Moistness	Degree to which the sample is moist	2005 Beauregard:8; 2005 NC 414:4
Smoothness	Smoothness of chewed mass	2005 Beauregard: 8; 2005 NC 414:7
Cohesiveness	Degre to which the sample holds together after chewing	2005 Beauregard: 7; 2005 NC 414:8
Fibrousness	Amount of stringy fibers perceived	2005 Beauregard: 5; 2005 NC 414:3
Residual fiber	Amount of stringy fibers perceived after swallowing	2005 Beauregard: 2; 2005 NC 414:3.5
Chalkiness	Degree to which the mouth feels chalky, like raw potato, very fine particles, often perceived on the roof of the mouth	2005 Beauregard: 0; 2005 NC 414:4.5
Aromatics		
Overall	The overall orthonasal aroma impact	
Brown sugar	Aromatic associated with brown sugar	Dixie crystal dark brown sugar
Potato	Aromatic associated with white baked potato	Methional, 100ppm
Earthy/canned carrot	Earthy aromatic associated with canned carrot	Canned carrots, Harris Teeter brand
Dried apricot/floral	Floral aromatics associatedwith dried apricot	Sun Maid mediterranian dried apricots
Vanilla	Aromatics associated with vanilla and vanillin	Marshmallow fluff
Flavour in mouth		
Brown sugar	In-mouth aromatic associated with brown sugar	Dixie crystal dark brown sugar
Earthy/canned carrot	In-mouth aromatic associated with canned carrot	Methional, 100ppm
Dried apricot/floral	In-mouth aromatic associated with apricot floral	Canned carrots, Harris Teeter brand
White baked potato	In-mouth aromatic associated with white baked potato	Baked russet potato
Vanilla	In-mouth aromatic associated with vanillar and vanillin	Marshmallow fluff
Sour taste	Basic taste stimulated by acids	0.05% citric acid in distilled, deionized water = 2 intensity
Sweet taste	Basic taste stimulated by sugar	2 and 5% sucrose in distilled, deionized water = 2 and 5 intensity, respectively
Bitter taste	Basic taste associated with caffeine	0.05% caffeine in distilled, deionized water = 2 intensity
Umami	Basic taste associated with monosodium glutamate	0.5% MSG in distilled, deionized water = 3 intensity
Astringent	Sensation of drying, drawing and/or puckering of any of the mouth surfaces	0.02% alum in distilled, deionized water

NC, North Carolina; MSG, monosodium glutamate

In Kenya, a study which used descriptive sensory evaluation to characterize crisps from different potato (*Solanum tuberosum*) tubers indicated that higher reducing sugar content of tubers significantly lowered the sensory quality of the crisps (dark brown colours and burnt flavours), (Abong et al., 2011b). Ndungu (2007) used descriptive sensory analysis to profile potato crisps [*Solanum tuberosum (L.) Lam*] made from tubers of varying physico-chemical properties and reported that the extent of brown specks, burnt flavour, burnt aroma and dullness of yellow colour were important in discrimination of crisps, as they correlated positively with reducing sugar content of the tubers.

Although the sensory characterization of boiled roots from OFSP and non-orange roots have been reported (Ofori 2009 et al., 2009, Leighton et al., 2010, Laurie et al., 2012, Tomlins et al., 2012; Leksrisompong et al., 2012), research on the sensory mapping of OFSP crisps as influenced by storage root physico-chemical properties is still limited. The sensory fingerprint of a product affects the eating quality and it is an important determinant for the selection and adoption of new varieties.

In quantitative descriptive analysis, training, language development and the need for different panels to describe different products often lead to high costs for companies (Chollet et al., 2011). New rapid descriptive methods are being considered to meet objectives for industry and research. One such method is Flash Profiling (Dairou and Sieffermann, 2002).

2.12 Flash Profile (FP)

Flash Profile (FP) is a descriptive sensory analytical technique adapted from Free Choice Profiling and Ranking methods for rapid sensory positioning of products (Dairou and Sieffermann, 2002). Subjects select their own terms to describe and evaluate a set of products simultaneously, which allows better product discrimination (Varela and Ares, 2012; The Society of Sensory Professionals, 2014). Trained or semi-trained panels of 6 to 12 assessors and consumer panels of 20 to 40 subjects have been used for FP (Varela and Ares, 2012). The attributes should be sufficiently discriminant and descriptive to permit ranking the products, yet hedonic terms should be avoided (Valentin et al., 2012). Samples are ranked according to each attribute's intensity on a scale anchored from low to high, where assessors can apply the same rank value to two or more samples if no difference is perceived (Dehlholm et al., 2012). FP provides a product map in a very short time because the phases of product familiarization, attribute generation and evaluation are integrated into a single step of 2 to 5 hours (Varela and Ares, 2012). It is cost-effective relative to other descriptive analysis methods which require extensive training and a costly set up (The Society of Sensory Professionals, 2014). A repeated blind control is usually included within the sample set to examine individual assessor performance (Ferrage et al., 2010).

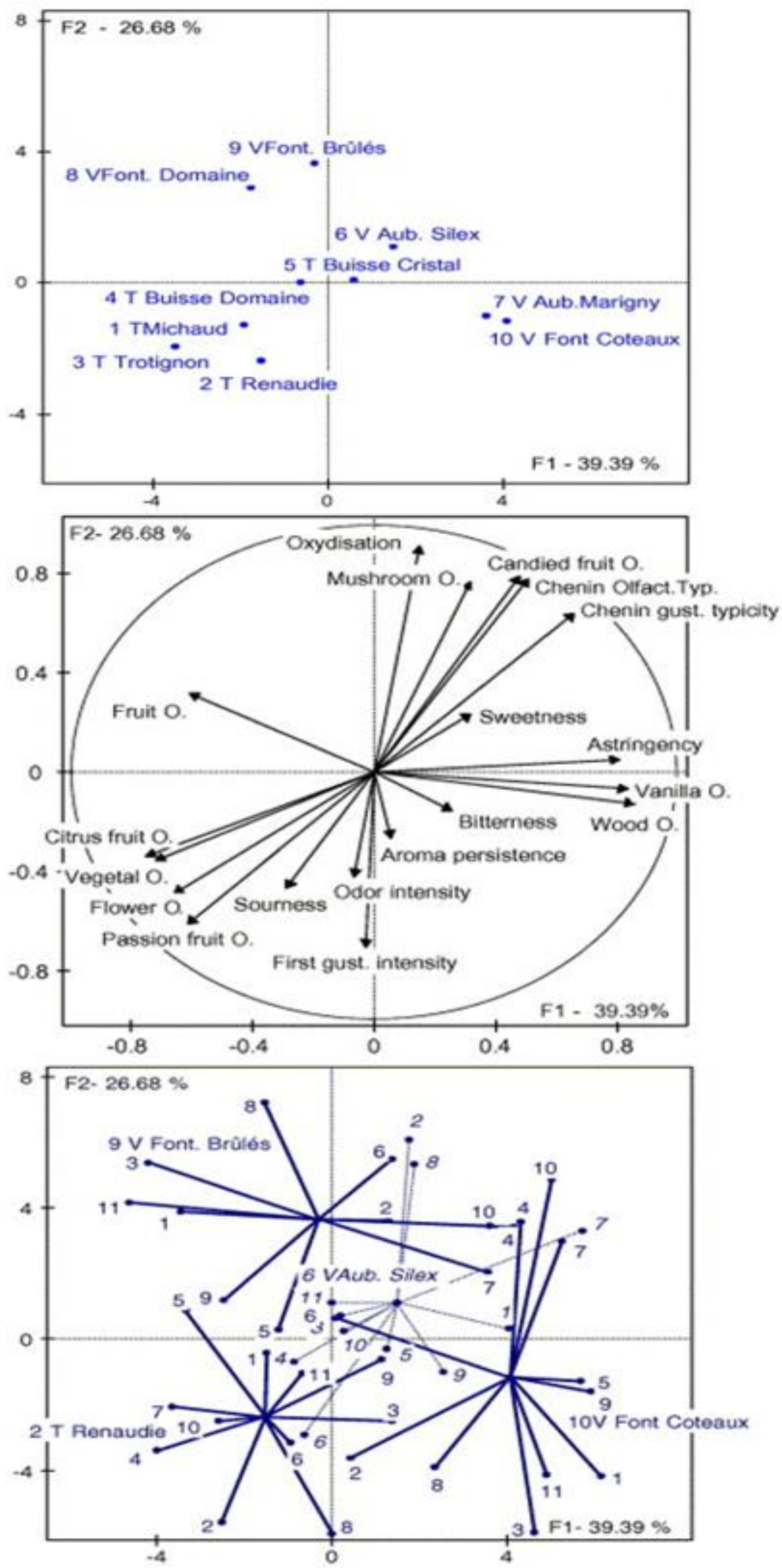
The interpretation of sensory terms during FP is however not easy due to a large number of terms and lack of agreed definitions and evaluation procedure (Albert et al., 2011). In conventional profiling, the "semantic consensus" allows a more accurate description of products (Delarue & Sieffermann, 2004). FP may not be suitable for tasting too many products, as this often produces saturation effects and short-term memory problems. The method is difficult to use with products that require careful temperature control or have persistent sensory characteristics. Expert assessors are preferred over consumers to obtain more reliable data (Delarue & Sieffermann, 2004).

2.13 Statistical techniques for Flash Profile data analysis

Multi-table data analysis techniques, e.g. Generalized Procrustes Analysis (GPA) and Multiple Factorial Analysis (MFA) are applicable, as each subject uses own descriptive terms to evaluate the products. This generates many data matrices which cannot be handled by ordinary PCA (Abdi, Williams and Valentin, 2013). A suitable multi-block technique (e.g. GPA, MFA) is run on all the matrices to obtain the product and attribute configurations. For attributes, consensus comes from the usage of similar attributes by different assessors (Moussaoui & Varela, 2010). Hierarchical Cluster Analysis (HCA) is then applied to identify attributes that are correlated and to check clustering of the blind control as a performance measure (Varela and Ares, 2012).

2.13.1 Multiple Factorial Analysis (MFA)

MFA is an extension of Principal Component Analysis (PCA) designed to handle many data tables with sets of variables collected on the same observations (Abdi et al., 2013). Several data tables are analyzed simultaneously by seeking common structures present and giving results that explain relationships between the observations, variables and tables (Abdi and Valentin, 2007). In a table the variables must be either quantitative or qualitative, but the table types can vary (XLStat, 2014). Pages (2005) used MFA to analyze the perceived sensory inter-distances (napping data) of 10 white wines from Loire Valley, France. The visual representations showed clearly the sensory relations between the wines (Figure 2.9).



*(**a**) Representations of the 10 wines. V: Vouvray (Chenin); T: Touraine (Sauvignon).*

*(**b**) Representations of descriptors provided by the panel.*

*(**c**) Superimposed representations of four wines. Each wine is represented by 12 points: an average point (the one in (a)) and one point per subject (labelled by the number of the subject). The points corresponding to a given wine are related to their average point.*

Figure 2.9 *MFA visual representations of the sensory (napping) data obtained from profiling of ten wines in France (Pages, 2005).*

In (a) from F1 which explained 39.39% of total variation, wine 7 and 10 were correlated in sensory properties and were anti-correlated to wines 1, 2 and 3. The F2 explained 26.68% of the remaining variation, differentiating wines 8 and 9 from the rest. In (b), the positions of sensory descriptors used by panellists corresponds to the wines positions. Larger vector lines mean the attribute was more influential in determining a particular wine's sensory property. Attributes pointing the same direction at the same distance from the center correlate, and are anti-correlated with those in the opposite direction. For instance, *aroma persistence* was less important while *Candied fruit O, Chenin olfact typ* and *Chenin gust typicity* were strongly correlated and significant, but anti-correlated to *Citruc fruit O, Vegetal O, Flower O* and *Passion fruit O*. Diagram (c) shows how each panellist perceived each wine in relation to others and to the global perception. It shows the degree of agreement amongst the panellists. The shorter the vector lines, the closer the approximation of perception is to the mean (global) compromise perception.

MFA seeks to integrate different groups of variables describing the same observations, first by performing on each data set a PCA or a Multiple Correspondence Analysis (MCA). This normalizes data and makes the groups comparable, otherwise straightforward analysis obtained by concatenating all variables would be dominated by the strongest table, or by variables with the largest variance. Tables are merged to form a unique matrix for a global PCA computation in the second step, where a weighted PCA on the columns of all the tables is carried out (Abdi and Valentin, 2007). The weighting of tables makes it possible to prevent those with more variables from weighing too much in the analysis (Escofier and Pages, 1994). If all the sets of variables are introduced as active elements without balancing their influence, a single set can contribute quite by itself to the construction of the first axes (Pages, 2004).

Processing of the global data matrix gives a graphical display of maps of products in which two products are near if they were perceived similar by the whole panel, each one having used and weighted its own criteria (Varela and Ares, 2012). The method allows visualizing in a two or three dimensional space: *a*) the tables (each table being represented by a point), *b*) the variables, *c*) the principal axes of the analyses of the first phase, and *d*) the individuals. In addition, one can study the impact of the other tables on an observation by simultaneously visualizing the observation described by all the variables and the projected observations described by the variables of only one table.

Chapter 3: Physico-chemical and nutritional quality of orange-fleshed sweet potato (OFSP) crisps from roots with varying physico-chemical properties

3.1 Abstract

The quality of orange-fleshed sweet potato (OFSP) crisps can be optimized by utilizing storage roots with suitable physical and chemical properties. Roots from the OFSP cultivars Impilo, Bophelo and 199062.1 were evaluated for physico-chemical properties in both raw and deep-fat fried state. Frying significantly lowered the L^*, a^*, b^*, E, h and C colour values for all root types making crisps darker compared to raw slices. The low dry matter Impilo roots had the highest glucose content while the high dry matter 199062.1 had the lowest, with Bophelo roots intermediate. Final oil content differed significantly, with the high dry matter roots (199062.1, 27.2 %) having significantly lower oil content in crisps (25. 7 %) compared to the medium dry matter roots (Bophelo, 23.1 %) which resulted in crisps with 32.6 % oil content. The least dry matter Impilo roots (19.0 %) had crisps with the highest oil content (35.6 %). This shows the influence of the physico-chemical properties of roots (e.g., dry matter content) on oil uptake. Medium to high dry matter roots (Bophelo and 199062.1) crisps had higher stress and hardness values than low dry matter tuber (Impilo) crisps from a compression test. High dry matter (199062.1) crisps had significantly higher first fracture deformation values compared to low dry matter (Impilo) crisps, with Bophelo crisps intermediate. High dry matter (199062.1) and high trans-β-carotene (Bophelo) roots can be used to produce value-added crisps with low oil, high trans-β-carotene content and with desirable textural and appearance properties for consumer acceptance. The physico-chemical variations of the OFSP roots affect the sensory and nutritional quality of deep-fat fried crisps. Using roots with high dry matter (e.g. 199062.1), and high β-carotene content (e.g. Bophelo) in the production of OFSP crisps could optimize product texture, oil content, colour and β-carotene content when compared to roots of low dry matter content (e.g. Impilo). Roots from 199062.1 cultivar may be an ideal choice for cost-effective low fat OFSP crisps with considerable β-carotene content. Low fat crisps would be in tandem with current nutritional thinking on the health benefits of low fat food.

Key Words: *OFSP crisps; physicochemical properties; Modulus of deformation, texture.*

3.2 Introduction

Sweet potato [*Ipomoea batatas (L.) Lam*] is an important food crop worldwide and OFSP cultivars are recognized as healthy foods because of their significant β-carotene, phenolic acids, anthocyanin and dietary fiber content (Turner and Burri, 2001). The crop is being promoted in the developing world as a source of provitamin A to alleviate vitamin A deficiency (VAD) (Laurie and Van Heerden, 2012). OFSP crisps are taken as an appetizer or as a snack food (Yodkraisri and Bhat 2012*).*

Research by Odenigbo et al (2012) showed that sweet potato products from different cultivars had different fried quality attributes. This assertion has not been investigated in OFSP crisp processing. Consumers expect food to be of appropriate colour, because this is what they critically evaluate when selecting for a particular brand (Davies, 2005; Abong, 2011). It is expected that the colour of OFSP crisps will be influenced by the amount of reducing sugars in the tuber, which depends on the cultivar, agronomic practices and root storage conditions.

Measuring the oil content of snack foods is essential for quality control to ensure that products meet nutritional value specifications. The amount of oil absorbed is also important in terms of the effect it may have on the texture and perceived quality of the product and the significant cost of the raw material (Oxford Instruments Molecular Biotools Limited, 2006). Both health and sensory aspects should be addressed to meet consumer demand (Pedreschi, 2009). Consequently, modern manufacturing methods aim to remove fats, or prevent its incorporation into the food matrix (Food and Health Innovation Service, 2012).

In potatoes, Abong et al (2011c) found that the oil content of crisps decreased with increasing dry matter content of the raw tubers. Screening and use of OFSP roots with higher solids content could lower the fat content in crisps. The effect is to lower processing costs and to improve the health of consumers. Roots with high dry matter improve processing efficiency and quality of crisps, yet if the dry matter is too high brittle crisps will result. Conversely, roots and tubers with low dry matter content cause too soft and too wet crisps which are expensive to produce due to higher energy demands in evaporating the high moisture content from raw slices (NIVAA, 2002). For crisps, a dry matter content of 22 - 24.4 % (specific gravity of 1.1) is preferable.

Testing for moisture content is done in order to predict the frying performance of OFSP roots, storage stability and textural quality of the crisps. Beyond a certain critical limit (≈ 2.5 %) (Segnini et al., 1999), moisture can deteriorate the quality of snack foods through loss of crispy texture, hydrolytic rancidity and microbial activity. The standard set for the maximum moisture content in crisps in India is 2% by mass (Consumer Voice, 2011). Reducing sugar content of tubers is important for colour and flavour development, yet too high levels yield bitter flavours and darker frying colours which are not acceptable in crisps. In potatoes for crisp processing, reducing sugar content may not exceed 0.2 - 0.3% of the weight of the fresh tuber (NIVAA, 2002).

3.3 Experimental Design

The experimental design (Figure 3.1) was applied in studying the effect of OFSP roots varying in physical and chemical properties on the sensory and nutritional quality of crisps. The investigation was done in three stages: a) OFSP root characterization, b) crisp processing and post-fry physico-chemical characterization, c) sensory profiling of the OFSP crisps.

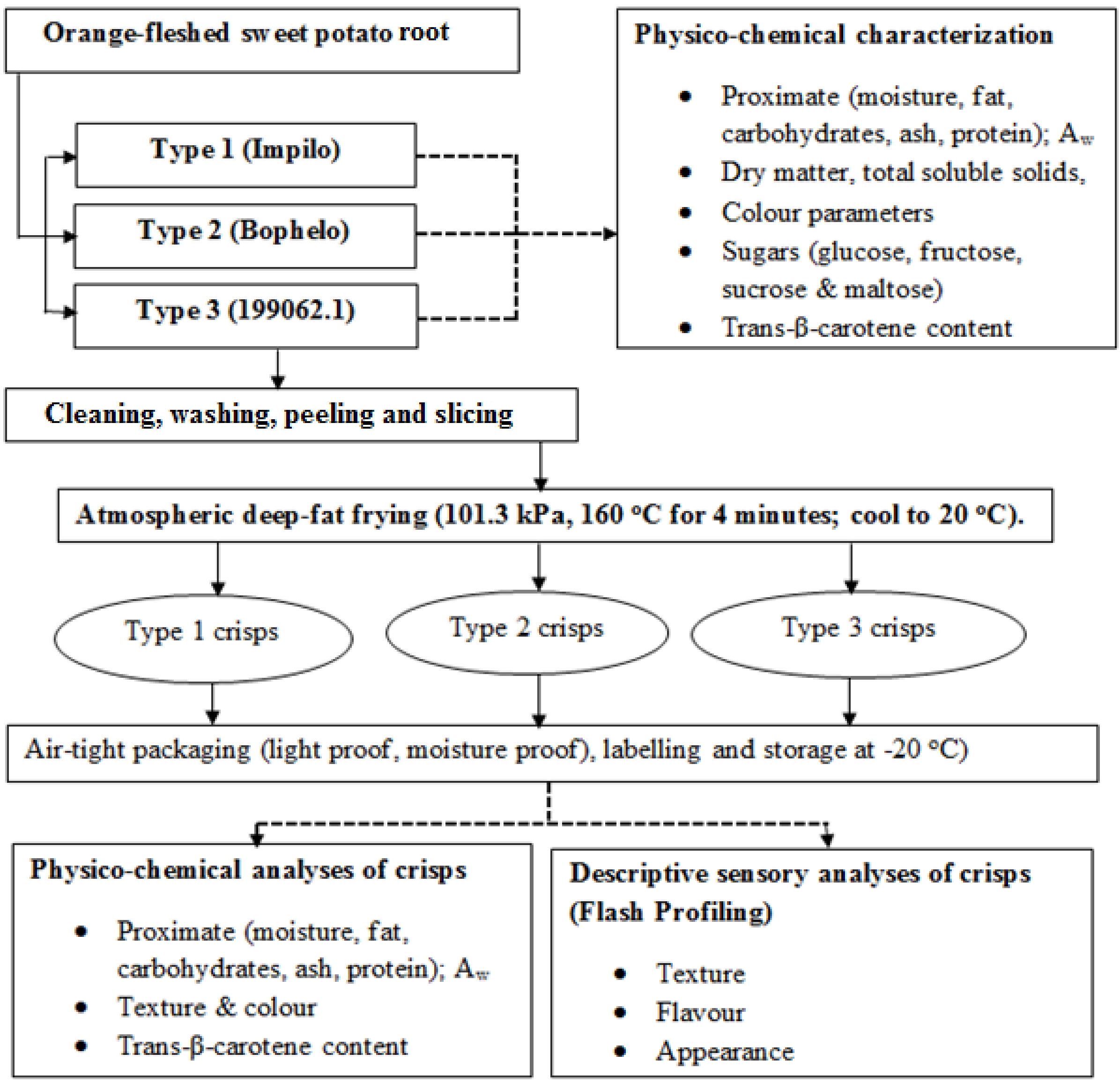


Figure 3.1 *The experimental design for root characterization, processing and post-frying characterization of crisps from OFSP roots of varying physical and chemical properties.*

3.3.1 Hypothesis 1: (OFSP root characterization)

The three types of OFSP roots from different cultivars (Impilo, Bophelo and 199062.1) will vary in physico-chemical properties (flesh colour, dry matter, moisture, oil, glucose, fructose, sucrose, maltose and trans-β-carotene content).

Sweet potato roots vary in colour and chemical composition of the storage root flesh due to genetic and environmental factors (Bovell-Benjamin, 2007; Lebot, 2010). Flesh colour of the root is influenced by the variable concentration of β-carotene which is genetically controlled (Kabira and Lemaga, 2006; Wu et al., 2008; Viklund et al., 2010; Vimala et al., 2011). Generally, roots with high dry matter and starch content have a white to cream flesh and low sugar content; those with low dry matter content are high in sugar and carotene contents. Although sweet potato yield is sensitive to genotype x environment interactions, these qualitative characters are controlled by only one or two set(s) of genes, by additive genes or by polygenes, and this determines the physical and chemical properties of cultivars (Lebot, 2010). The intensity of the flesh colour directly relates to the amount of trans-β-carotene present (Burri, 2011).

3.3.2. Objective 1

To determine the physico-chemical properties (dry matter, moisture, oil content, glucose, fructose, sucrose, maltose content, flesh colour and trans-β-carotene content) of the three types of OFSP roots, with the aim of predicting and optimizing their performance in crisp processing by deep-fat frying.

3.4. Materials and Methods

The OFSP roots for the study were sourced from the Agricultural Research Council-Vegetable and Ornamental Plants Institute (ARC-VOPI). Cultivars Impilo (tuber type 1) and Bophelo (tuber type 2) have been bred at the ARC-VOPI, while cultivar 199062.1(tuber type 3) is an import from the International Potato Centre (CIP) in Peru. After harvest all three types of OFSP roots were stored for 7 days at 6 ^{o}C prior to processing.

3.4.1. Sample preparation for moisture, total solids (dry matter), oil content and colour analysis of raw roots

Sample preparation was done following a procedure by Faber et al (2013) with slight modifications. Five roots from each type were washed with cold water and peeled in an abrasive peeler (Hobart model 6115; Hobart Corporation, Troy, Ohio 45374). Peeled roots were quartered longitudinally and two opposite quarters per root were combined and homogenized into a smooth paste using a blender (IKA A11 Basic, IKA, Staufen, Germany) at low speed followed by high speed for 20 seconds. Homogenized root specimens from each type were subjected to physico-chemical analyses. The remaining fractions from each root type were freeze-dried for 2 days and stored at -20^{o}C before use in protein, sugar and β-carotene analysis.

3.4.2. Moisture content and total solids content of raw OFSP

For each root type a 5 g aliquot of the homogenized fresh paste was dried for 6 hours at 70 ^{o}C ± 1 ^{o}C in a vacuum oven at 10 kPa (AOAC 930.06). Moisture content was determined by weight loss after drying. Tests were done in triplicate. The difference after subtracting moisture content gave the total solids (dry matter) content (%).

3.4.3. Oil content of raw tubers

Oil content was measured by Soxtec/Randall Extraction-Submersion method using Soxtest Fat Extractor (Raypa®) (Barcelona, Spain) and petroleum ether (analytical grade) as solvent (AOAC, 2003.05 with slight adaptations). Medical grade defatted cotton wool was initially added into the thimble to absorb some fat which may melt during the drying phase. A fresh homogenized 5 g test portion for each type of root was weighed directly into tarred cellulose thimbles and dried at 102 ± 2 ^{o}C for 2 hours in an oven, to remove water and avoid extraction of water-soluble components like carbohydrates. A defatted cotton plug was then placed on top of samples to keep them immersed in the solvent during boiling and prevent loss of test portion from the top of the thimble. Extraction cups with 3 glass boiling beads were dried for 30 minutes at 102 ± 2 ^{o}C, transferred to a desiccator and left to cool to room temperature followed by weighing and recording mass to nearest 0.1 mg. A two-step extraction process was used involving immersion boiling (20 minutes) followed by rinsing (40 minutes) and a few further minutes of solvent evaporation. Extraction cups were transferred to a clean surface fume hood to complete solvent evaporation at low temperature followed by drying in an oven at 102 ± 2 ^{o}C for 30 minutes. The cups were cooled in a desiccator and weighed to nearest 0.1 mg and values used to calculate crude fat % as follows:

Equation 4.1 Fat Content

$$\%\ Crude\ fat, petroleum\ ether\ extract = \left(\frac{F-T}{S}\right) \times 100$$

Where **F** = weight of cup + fat residue, g

T = weight of empty cup, g

S = test portion, g

The test was performed in triplicate.

3.4.4. Colour of raw OFSP sample

The flesh colour of fresh OFSP roots was measured with a Chroma meter CR-400 series ver. 1.07, (Konica Minolta 2000 – 2004, Minolta sensing Inc.) pre-calibrated against a Perfect Reflecting Diffuser Plate (Y = 87.70, X = 0.3166, y = 0.3242) as follows:

L* =94.36, a* = -0.68 and b* = 4.08

For each cultivar, three representative slices were randomly selected, homogenized in a blender and analyzed according to Nunes and Moreira (2009). Samples were transferred to labelled transparent petri dishes and scanned using a Chroma meter. Five replicates for L*, a* and b* coordinates per sample were recorded from different areas over the petri dishes randomly chosen. Recordings were used to compute values for colour chromaticity (C), colour intensity (E) and hue angle (H) using formulae described in the results section.

3.4.5 Sample preparation for the analysis of protein, ash, sugar and trans-β-carotene content

For each OFSP root type, 10 chips/flakes of freeze-dried fractions from a previous sample preparation (3.4.1) that were preserved under frozen storage (-20 ^oC), were ground into a powder with a commercial coffee mill (IKA A11 Basic, IKA, Staufen, Germany) for 90 seconds. Frozen storage prevents the degradation of carotenoids due to the heat generated by friction with blades during pulverization. The flour samples were kept vacuum-packed in a freezer (-20 ^oC) in darkness prior to analysis.

3.4.6 Protein Content of raw OFSP roots

The protein content was analyzed according to the Dumas Method, AOAC 968.06 (AOAC International, 2012) by combusting 120 mg of ground freeze-dried tuber samples in a Dumatherm Nitrogen/Protein analyzer (Gerhardt & Co., Northants, UK) at 1000 ^oC. Windows NT based "Dumatherm Manager" software automatically controlled and processed measurements. A nitrogen factor of 6.25 was used to calculate protein content. Duplicate assays were made per sample.

3.4.7. Ash content of raw OFSP roots

The ash content was measured according to AOAC 942.05, (AOAC, 2012) with adaptations. Crucibles were washed and ashed at 550 ^oC overnight to burn off organic impurities. Then 5 g of the freeze dried raw OFSP powder from each tuber type was weighed into cooled crucibles and preheated over low Bunsen flame till no fumes were emitted. Samples were transferred into a muffle furnace and heated at 550 ^oC for 6 hours followed by cooling in a desiccator. The difference in weight after ashing was expressed as % ash content. Test was performed in triplicate.

3.4.8. Carbohydrate and Sugar content in raw OFSP roots

The carbohydrate content for each OFSP root sample (as-is) was calculated by the difference method (100% - oil % - moisture % - ash % - protein %) and converted to dry basis.

Extraction of sugars was done at South African Bureau of standards (SABS) Food and Pharmaceuticals division. Approximately 1 g of OFSP flour per type of OFSP root from the ground freeze-dried samples was extracted with a 40 mL mixture of acetonitrile, water and ethanol (10:10:80 v/v) and homogenized by vortexing for 1 min. The mixture was incubated in a water bath at 80 ^{o}C for 60 minutes to extract the soluble sugars. After centrifugation at 12000 g for 15 min, the supernatant was dried in a rotary evaporator at 60 ^{o}C. Dried sample was dissolved in 2 ml of 50% acetonitrile, filtered through a 0.45 μm nylon filter and 60 μL of the sample was injected into the HPLC separation system. The sugars were analyzed using an HPLC (Hewlett Packard Agilent 1100 series) with a refractive index detector. A carbohydrate analysis column (5um 250 x 4.6 mm, i.d.) was used for the separation of sugars. An isocratic run was performed with acetonitrile: water (75: 25, v/v) at a flow rate of 2 ml/min. The identification of the sugars was achieved by comparing their retention times with known sugar standards (D (+) glucose #BCBJ1156V, sucrose #BCBJ6029V, fructose #BCBD3399V and maltose #BCBH5048V) supplied by Sigma (St Louis, MO, USA). Interfering peaks were observed on the glucose peak, therefore samples were re-injected on a monosaccharide Ca^{2+} column with water as the mobile phase to separate the glucose peak from the interfering peaks. The amount of each identified compound was expressed as g/100g of dry sample.

3.4.9. Trans-β-carotene content of raw OFSP flour

Sample extraction was performed according to Van Jaarsveld et al (2006) with slight modifications. A 1 g portion of flour for each tuber type, previously kept vacuum-packed in a freezer (-20 ^{o}C) in darkness was weighed into a conical flask. Extraction of carotenoids was done for 20 minutes with 10 ml acetone containing 0.1% butylated hydroxyl toluene (BHT) using a magnetic stirrer for agitation. The acetone extraction was repeated 3 more times until the residue was clear of pigment. Extracts were collected and filtered through a Buchner funnel lined with filter paper (Whatman no.1), and more acetone used to rinse the residue, funnel and filter paper. For each tuber type sample, the organic extracts were combined and the carotenoid solution was made up to volume 40 ml with acetone. An 8 ml aliquot of extract was dried in a rotary evaporator at 35 ^{o}C. The volume of extract collected was decided based on previous studies (Nzamwita, 2012). Each dried sample was dissolved in 2 ml of methyl-*tert*-butyl ether (MTBE) containing 0.1% butylated hydroxyltoluene (BHT), filtered through a 0.2 µm PTFE syringe filter directly into amber sample vials, and 10 µL were injected into the Prominence Ultra-Fast Liquid Chromatograph (UFLC) system (Shimadzu, Tokyo, Japan). The extraction was done under subdued light and aluminium foil was used to cover all glassware to minimize photo-degradation of the carotenoid analyte. Each sample was extracted and analyzed in duplicate.

3.4.9.1. Preparation of β-carotene standard and quantification by external standardization

A Sigma β-carotene standard (synthetic, crystalline, Type II, product C4582) (St Louis, MO, USA) was used to prepare a stock solution (1 mg/10mL MTBE) which was kept at -4 ^{o}C prior to further experimentation following standard validation. A single prominent β-carotene peak was observed with UFLC without any interfering peaks, confirming the high purity of the standard. Then, a standard curve of six dilution levels (0.1, 0.5, 1, 2, 4 and 6 µgmL^{-1}) was constructed. The curve passed through the origin and had a coefficient of correlation of 0.999, indicating excellent linearity of the UFLC's response and the high accuracy of the standard solution concentrations. The fitting equation of the standard curve (best-fit-line) was as follows:

Equation 4.2. Trans-β-carotene standard curve

$$x = \frac{y-15600}{1000000}$$

Where: ***x*** is sample concentration in µgm.L^{-1}; **y** is the chromatographic peak area of the sample.

3.4.9.2 Quantitative analysis of carotenoids

This was done using a Prominence UFLC (Shimadzu, Tokyo, Japan) with a SIL-20A Prominence auto-sampler, a DGU-20A3 Prominence degasser, a CTO-10AS VP Shimadzu column oven and an SPD-M20A Prominence diode array detector. Detection was done at 450 nm and UV/Vis spectra of carotenoids were recorded between 200 to 600 nm. The separation of carotenoids was performed at 25 ^{o}C on a C_{30} YMC carotenoid column (250 x 4.6 mm, i.d, 5 µm particle size) by isocratic elution with methyl-*tert*-butyl ether (MTBE) as a mobile phase, at a flow rate of 0.5 ml/min. A calibration curve of β-carotene standard was used for carotenoid quantification, and vitamin A content estimated as retinol activity equivalents (RAE) using a factor of 12 μg β-carotene to 1 μg retinol which corrects for the bio efficacy of carotenoids in a mixed diet eaten by healthy people in developed countries (van Jaarsveld et al., 2006).

3.5. Statistical analysis

Statistical analysis was done using Statistica software (Statsoft.Inc, Tulsa, USA). Single-factor analysis of variance (ANOVA) was conducted to assess the effect of OFSP root types on the physical and chemical parameters of the roots.

3.6. Results

3.6.1. Flesh colour of the three types of OFSP roots

The results for the colour values of fresh OFSP samples from the OFSP roots are given below.

Table 3.1 *Effect of OFSP root type on the colour values of fresh root pastes.*

	Raw OFSP roots types			
Color Parameter	**Type 1 Impilo**	**Type 2 Bophelo**	**Type 3 199062.1**	**p-value**
L	$56.9^{a} \pm 4.3$	$59.8^{a} \pm 3.2$	$60.3^{a} \pm 4.8$	0.33
a	$7.5^{a} \pm 1.0$	$16.8^{b} \pm 2.6$	$5.8^{a} \pm 2.2$	**≤ 0.01**
b	$12.6^{a} \pm 2.6$	$19.1^{b} \pm 3.5$	$14.5^{a} \pm 3.7$	**≤ 0.01**
C	$14.7^{a} \pm 2.9$	$25.4^{b} \pm 4.3$	$15.7^{a} \pm 4.0$	**≤ 0.01**
E	$58.8^{a} \pm 4.8$	$65.1^{b} \pm 4.5$	$62.4^{ab} \pm 5.7$	**≤ 0.05**
H	$(-)0.1^{b} \pm 0.2$	$0.5^{c} \pm 0.1$	$(-)0.9^{a} \pm 0.4$	**≤ 0.01**

Results for the same parameter with different superscripts are significantly different at cited p-values. Values are Means and Standard deviations of 5 replicates.

$C = \sqrt{(a)^2 + (b)^2}$ $E = \sqrt{(L)^2 + (a)^2 + (b)^2}$ $H = Tan^{-1}\left(\frac{b}{a}\right)$

*Key: **L**, lightness (0 to 100); **a**, greenness/redness (from – to +); **b**, blue –yellow; **E**, overall colour intensity; **H**, hue angle (indicating the primary colour ranging from 0^{o} for pure red, 90^{o} for pure yellow, 180^{o} for bluish-green, and 270^{o} blue); **C**, Chroma (0 to 100) measures the colour saturation from grey (low saturation) to pure hue (full saturation) (Xu et al., 2013).*

The three OFSP roots types were similar in their *L* value. Bophelo root samples had the highest *a* and *b* colour values for the fresh flesh, whereas Impilo samples were the lowest in *b* value with 199062.1 as lowest in the *a* value. Significant variations in *C*, *E* and *H* values of the samples were also apparent.

3.6.2 Proximate, sugar, total solids and trans-β-carotene content of raw samples from the three OFSP root types

The information below shows the quantitative chemical properties for the three OFSP types.

Table 3.2 *Proximate analysis, sugars, total solids and trans-β-carotene content for three fresh raw OFSP root types studied in relation to crisp processing by deep-fat frying.*

	Raw OFSP storage root types			
Response Parameter (%)	**Type 1 (Impilo)**	**Type 2 (Bophelo)**	**Type 3 (199062.1)**	**p-values**
Proximate (as is)				
Oil Content	$0.07^{a} \pm 0.00$	$0.06^{a} \pm 0.00$	$0.10^{b} \pm 0.00$	**< 0.01**
Moisture	$81.00^{c} \pm 0.30$	$76.90^{b} \pm 0.30$	$72.90^{a} \pm 0.30$	**< 0.01**
Protein	$1.14^{a} \pm 0.02$	$1.42^{b} \pm 0.02$	$1.38^{b} \pm 0.02$	**< 0.01**
Ash	$0.95^{a} \pm 0.01$	$1.00^{a} \pm 0.01$	$1.26^{b} \pm 0.01$	**< 0.01**
Carbohydrate	$15.66^{a} \pm 1.90$	$19.89^{ab} \pm 1.90$	$25.79^{b} \pm 1.90$	**< 0.01**
Sugars (dry basis)				
Glucose	$4.8^{c} \pm 0.2$	$4.2^{b} \pm 0.0$	$2.0^{a} \pm 0.0$	**< 0.01**
Fructose	$5.2^{c} \pm 0.1$	$4.6^{b} \pm 0.2$	$2.1^{a} \pm 0.2$	**< 0.01**
Sucrose	$8.7^{b} \pm 0.1$	$7.3^{a} \pm 0.0$	$9.1^{c} \pm 0.1$	**< 0.01**
Maltose	< LOD*	< LOD*	< LOD*	**…**
Total solids (dry matter)	$19.0^{a} \pm 0.6$	$23.1^{ab} \pm 0.6$	$27.2^{b} \pm 0.5$	**< 0.01**
***Trans*-β-carotene (μg/100g, d.b.)**	$6\,526.6^{b} \pm 33.7$	$15\,861.1^{c} \pm 101.0$	$3\,858.9^{a} \pm 7.1$	**< 0.01**
Vitamin A Value (μg RAE/100g, d.b.)ᶲ	$543.9^{b} \pm 2.8$	$1\,321.8^{c} \pm 8.4$	$321.2^{a} \pm 0.6$	**< 0.01**

[abc] Same parameter results with different superscrips are significantly different at cited p-values.Values are means and standard deviations of at least 2 replicates. Oil content is an ether extract.
ᶲ RAE (Retinol activity equivalents): 12 μg β-carotene = 1 μg retinol = 1 μg RAE(van Jaarsveld et al., 2006).
LOD: detection limit, the minimal analyte concentration an instrument can measure (0.7g/100g for Maltose).*

Roots samples from 199062.1 OFSP type had the highest dry matter and lowest initial moisture content, converse to Impilo roots ($p \leq 0.05$). Bophelo roots were intermediate Impilo and

199062.1 roots in the value for dry matter content. Raw 199062.1 roots had the highest carbohydrate content, with raw Impilo having the lowest. In terms of trans-β-carotene content and vitamin A value, Bophelo roots had the highest concentration, while 199062.1 roots had the lowest.

Trans-β-carotene is a critical nutrient and phytochemical in OFSP and its analysis is therefore often used to estimate the nutritional value of OFSP products. It is also an essential colour pigment, influencing Bophelo roots' most intense yellow colour (*E*) and high chromaticity (*C*) while roots from Impilo cultivar measured the lowest for both colour parameters (Table 3.1), consistent with *trans*-β-carotene content values. For sugars, Impilo roots were the highest in both glucose and fructose content, while 199062.1 roots were the lowest. Bophelo roots were lowest in sucrose content for which 199062.1 was highest.

3.6.3 Summary of findings on the characterization of OFSP root types

The three OFSP root types (Impilo, Bophelo and 199062.1) differ in flesh colour, dry matter, moisture, protein, ash, carbohydrate, glucose, fructose, sucrose, trans-β-carotene content and vitamin A value. These physico-chemical differences among the OFSP root types may influence the sensory (texture, oiliness, appearance and flavour) and nutritional quality of crisps when deep-fat fried. Variation in dry matter content may affect oil absorption and crisp texture, while variation in glucose, fructose, sucrose and trans-β-carotene content may affect crisp colour and flavour.

3.7 Hypothesis 2: (prediction of physico-chemical and nutritional quality in crisps)

The physico-chemical and nutritional quality of deep-fat fried OFSP crisps will vary as influenced by the type and physico-chemical properties of the roots used for processing.

Oil uptake in fried vegetable products is influenced by the moisture, starch and dry matter content of the raw material (Basuny et al., 2009). Moisture loss determines the extent of crust formation and hence the volume available for oil infiltration (Dueik et al., 2010). In high moisture content tubers, large steam volumes are trapped between unbroken cells during deep-fat frying creating large cavities that will fill with oil (Mazt, 1993; Mehta and Swinburn, 2001). Different cultivars follow different moisture loss and oil uptake kinetics because of their storage tuber physico-chemical properties, microstructure and how moisture is held within the tubers (Odenigbo et al., 2012). For colour parameter, the *b* value is related to the amount of trans-β-carotene present (Nunes and Moreira, 2009).

3.7.1. Objective 2

To quantify the physico-chemical and nutritional quality attributes of deep-fat fried OFSP crisps from different sets of roots in order to understand the impact of storage root physico-chemistry on crisp quality.

3.7.2. Materials and Methods

3.7.3. Sample preparation for crisp processing

Cold water washed OFSP roots were peeled in an abrasive peeler (Hobart model 6115; Hobart Corporation, Troy, Ohio 45374) and thinly sliced using an industrial food processor, Robot Coupe R301 Ultra (Robot-Coupe S.N.C., France). A slicing attachment (blade ES2) was used to produce slice thickness of 1.8 – 2.0 mm. Slices were kept in iced water at 4 ^{o}C to prevent enzymatic browning, extracted from the cold water and allowed to drain surface water for a minute before immersion into hot oil.

3.7.4 Atmospheric deep-fat frying experiment

Frying was carried out in a double pan, laboratory-scale electric deep-fat fryer (model: FFA 2002, Joburgonline Catering Supplies, Roodepoort, South Africa). For each, cultivar 8 – 10 slices (≈ 50 g) per run were placed into the frying basket and immersed into hot palm olein oil (Willowton Group, Pietermaritzburg, South Africa) at 160 ^{o}C for 4 minutes. A high temperature thermo probe monitored the frying temperature, with gentle agitation of the basket during frying to achieve uniform heat distribution and to prevent crisps from floating. Samples were removed from the oil and suspended on slotted stainless steel grids for oil drainage and cooling to room temperature (≈ 20 ^{o}C). Crisps were then packaged in air-tight and moisture-proof packaging (110 mm × 185 mm) and stored in a light-proof generic cardboard box at 7 ^{o}C awaiting subsequent analysis. Frying oil was replaced after every three frying cycles.

3.7.5 Moisture content of OFSP crisps

The moisture content of fried crisps was determined as for the raw orange-fleshed sweet potatoes (section 3.4.2). OFSP crisps were first crushed and then pulverized in a blender (IKA A11 Basic, IKA, Staufen, Germany) prior to analysis.

3.7.6 Oil content

OFSP crisps analytical samples were prepared by grinding 10 crisps in a blender (IKA A11 Basic, IKA, Staufen, Germany) at low speed then high speed for 20 seconds. The oil was extracted and quantified as described in section 3.4.3.

3.7.7 Colour of deep-fat fried OFSP crisps

OFSP crisps were crushed and pulverized in a blender (IKA A11 Basic, IKA, Staufen, Germany) and the colour of crisps was measured with a Chroma meter CR-400 series ver. 1.07 (Konica Minolta 2000 – 2004, Minolta sensing Inc.) as described in section 3.4.4 for raw samples.

3.7.8 Texture of OFSP crisps

A rupture test was used to measure OFSP crisps texture using a uniaxial compression method described by Ravli et al (2013) with slight modifications. A single crisp was placed on an 18 mm hollow cylinder, and a ball probe with a diameter of 2.54 mm was used to break the chips. A 50 N load cell was used with the probe at speed 0.1mm/s. The probe passed 5 mm after the crisp broke. The EZ Test texture analyzer (Shimadzu Corporation, Tokyo, Japan) recorded the force-deformation events over time using Trapezium X software. Higher modulus of deformability values were presumed indicative of stiffness while higher hardness values on the force × displacement curve were assumed to reflect a lower brittleness of crisp structure. Stress, strain, fracturability, first fracture deformation and force peak count values were also analyzed. Ten crisps per cultivar were tested. The equation below was used to compute the modulus of deformation:

Equation 4.3 Modulus of deformation

$$E_c = \frac{\sigma_c}{\varepsilon_c} = \frac{F/A_0}{\Delta L/L}$$

where:

$\mathbf{E_c}$, $\boldsymbol{\sigma_c}$, $\boldsymbol{\varepsilon_c}$ are the Modulus of Elastic deformation from compression, compressive stress$_{(0.5\ \mathrm{seconds}-1.5\ \mathrm{seconds})}$ and compressive strain$_{(1.5\ \mathrm{sec})}$ respectively. **F** is the applied force, $\mathbf{A_0}$ the original un-deformed cross-sectional area of the sample, **ΔL** is the net deformation of specimen and **L** is the original sample length.

3.7.9 Protein content of deep-fat fried OFSP crisps

The protein content was analyzed on flours of the crisps prepared following a procedure outlined in section 3.4.5. The Dumas Method, (AOAC 968.06) (AOAC International, 2012) was used for analysis as described in section 3.4.6. Duplicate assays were made per sample.

3.7.10 Ash content of deep-fat fried OFSP crisps

The ash content was measured according to AOAC 942.05 (AOAC, 2012) with adaptations, as described in section 3.4.7. The analysis was performed in triplicate.

3.7.11 Trans-β-carotene content of OFSP crisps

Sample preparation was done according to section 3.4.5. Analysis and quantification of all-trans-β-carotene in OFSP crisps was done according to the procedure described in section 3.4.9.

3.8 Statistical analysis

Statistical analysis was done using Statistica software (Statsoft.Inc, Tulsa, USA). Two-factor analysis of variance (ANOVA) was conducted to assess the effect of tuber type, deep-fat frying (raw/crisp) and its interaction effect on physical and chemical parameters. Where applicable, significant differences in mean values were evaluated using Fischer's LSD test at $p < 0.05$. Correlation analysis on the relationship between the oil content of crisps and the dry matter content of raw roots was done using Microsoft Excel 2013.

3.9 Results

3.9.1 Texture of Fried OFSP slices

Table 3.3 shows the effect of the dry matter content of roots on the textural attributes of OFSP crisps measured by instrumental methods.

Table 3.3 *The dependence of textural parameters of deep-fat fried OFSP crisps on the dry matter content (a physico-chemical property) of the roots used for crisping.*

Textural Parameter$^{\phi}$	OFSP crisp types: Low dry matter (Impilo cultivar)	Intermediate dry matter (Bophelo cultivar)	High dry matter (199062.1 cultivar)
Stress (N/mm)	71.5 ^{a} ± 25.4	95.6 ^{b} ± 21.3	94.5 ^{b} ± 33.5
Variation Coefficient (%)	*35.5*	*22.3*	*35.4*
Strain	0.4 ^{a} ± 0.4	0.5 ^{a} ± 0.4	0.8 ^{b} ± 0.5
Variation Coefficient (%)	*100.0*	*80.0*	*62.5*
Hardness (N)	5.7 ^{a} ± 1.6	8.3 ^{b} ± 1.8	7.0 ^{ab} ± 2.9
Variation Coefficient (%)	*28.1*	*21.7*	*41.4*
Fracturability (N)	3.1 ^{a} ± 2.2	4.2 ^{a} ± 3.2	2.7 ^{a} ± 1.6
Variation Coefficient (%)	*71.0*	*76.2*	*59.3*
1st Fracture Deformation (mm)	0.71 ^{a} ± 0.2	0.74 ^{ab} ± 0.3	1.10 ^{b} ± 0.8
Variation Coefficient (%)	*28.6*	*42.9*	*72.7*
Force peak count	5.1 ^{a} ± 3.5	6.5 ^{a} ± 4.0	6.7 ^{a} ± 4.5
Variation Coefficient (%)	*68.6*	*61.5*	*67.2*

$P \leq 0.05$. Within a row, results having a common superscript are not significantly different. Variation coefficient = (100 × standard deviation) / mean.
$^{\phi}$ Values are means and standard deviations of 10 replicates.

Significant differences were observed amongst the crisp types for all analyzed textural parameters, except fracturability and force peak count. Crisps from low dry matter roots (Impilo) were the least hard while those from medium dry matter roots (Bophelo) were the hardest ($p < 0.05$). Peak stress values for crisps from medium to high dry matter roots (Bophelo and 199062.1) were equal and significantly higher relative to crisps from low dry matter roots (Impilo). First fracture deformation patterns also reflected that the probe required the greatest displacement to fracture high dry matter 199062.1 crisps in comparison to crisps from medium and low dry matter roots (Bophelo and Impilo). Higher dry matter content roots (199062.1 and Bophelo) therefore tended to yield comparatively harder crisps compared to lower dry matter type (Impilo) when deep-fat fried, since they required a much greater force per unit area to break.

In figure 3.2, a stress-strain curve that was produced when ten (10) OFSP crisps from each type of OFSP roots were subjected to uniaxial compression test is shown.

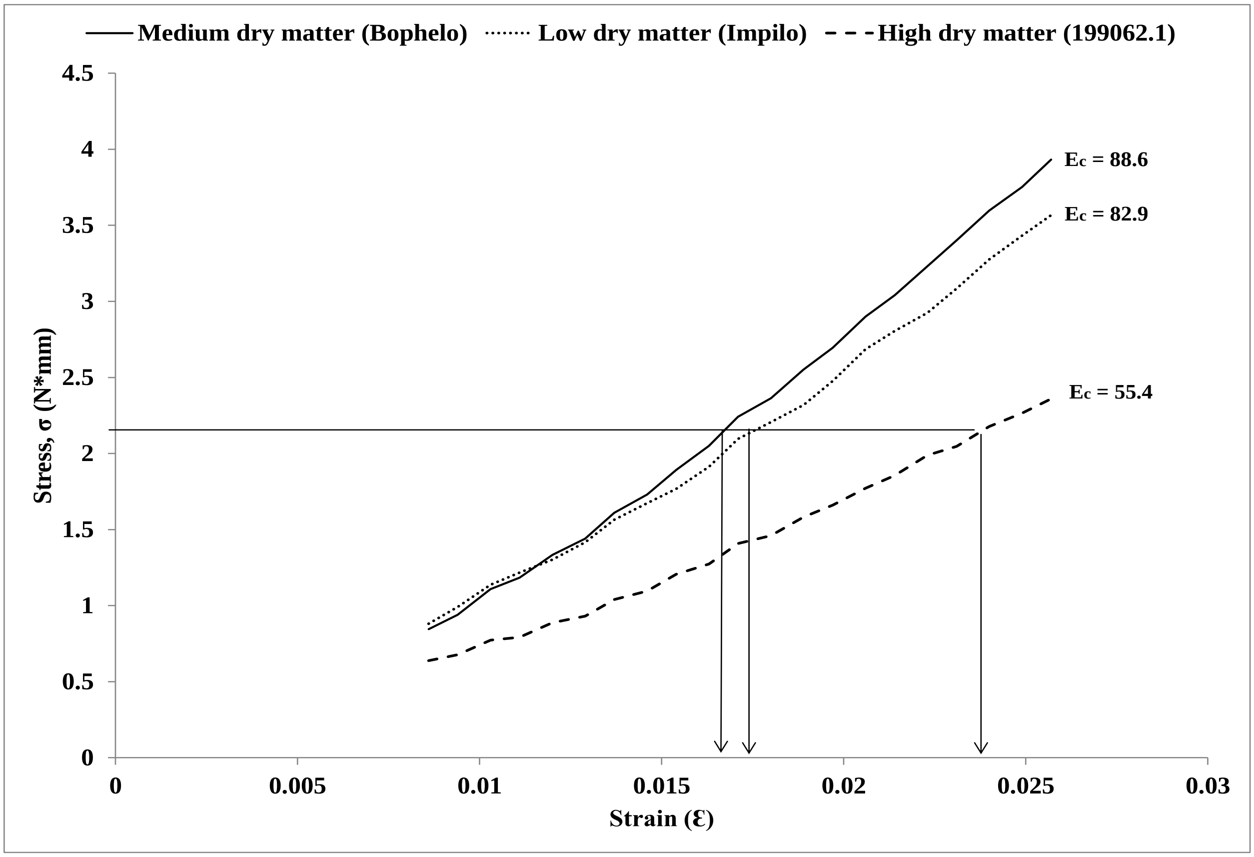


***Figure 3.2** Stress-strain curves showing the effect of OFSP root type on the modulus of deformability from compression (Ec) of deep-fat dried crisps.*

***E_c**, is calculated from compressive stress$_{(0.5\ seconds\text{-}1.5\ seconds)}$, **$\sigma_c$** and compressive strain$_{(1.5\ sec)}$, **ε_c**:*

$$E_c = \frac{\sigma_c}{\varepsilon_c} = \frac{F/A_0}{\Delta L/L}$$

***F** is the applied force, **A_0** the original un-deformed cross-sectional area of the sample, Δ**L** is the net deformation of specimen and **L** is the original sample length.*

When a constant stress (force per unit length) of e.g. ≈ 2.2 N/mm was applied to the crisp samples, the strain response (change in length, %) varied according to the OFSP root type. Crisps from medium dry matter roots (Bophelo) experienced the smallest change in length (more stiff) while crisps from high dry matter roots (199062.1) showed the greatest change in length (less stiff). The moduli of deformation for crisps from the three types of OFSP roots showed that those from medium to low dry matter roots (Bophelo and Impilo crisps) had higher E_c values when compared to crisps from high dry matter (199062.1) roots. The modulus of deformability (E_c) gives an estimate of the stiffness of a food sample. A force-displacement curve from a uniaxial compression of ten (10) OFSP crisps for each root type is shown (Figure 3.3).

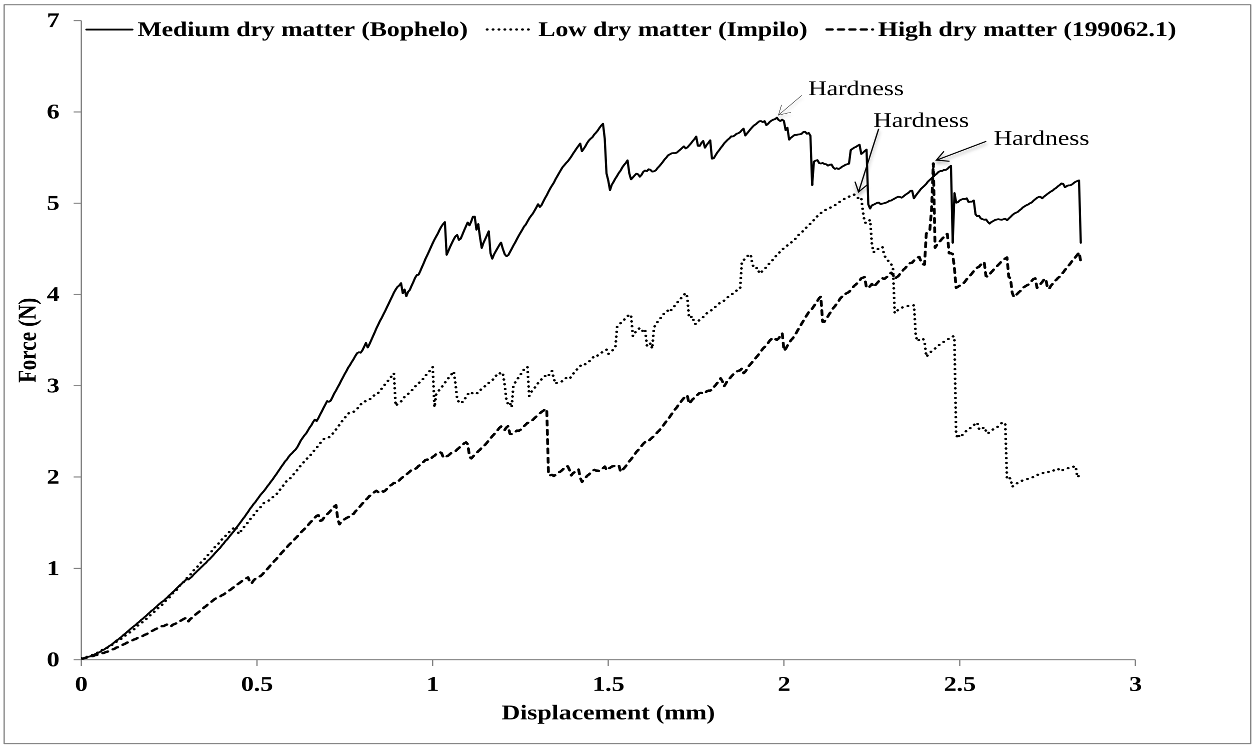


Figure 3.3 *Force-displacement curves showing the effect of OFSP root type on hardness values and the slope of the force-deflection plot for deep-fat fried crisps.*

Data represents mean values of ten crisps per storage root types.

The crisps processed from medium dry matter roots (Bophelo) had the highest gradient and hardness value, as opposed to high dry matter (199062.1) crisps.

3.9.2 Colour of raw and fried OFSP slices

Table 3.4 shows the influence of using three types of OFSP roots with different physico-chemical properties, on the colour values of deep-fat fried crisps.

Table 3.4 *Effect of variation in physico-chemical properties of three types of OFSP roots on the colour values of deep-fat fried crisp.*

		OFSO roots types				Effect significance ($p \leq 0.05$)		
Colour parametr		**Low β-carotene [Type 1: Impilo]**	**High β-carotene [Type 2: Bophelo]**	**Very low β-carotene [Type 3: 199062.1]**	*Raw/Crisp*	**Root type**	**Raw/Crisp**	**Root type*Raw/Crisp**
L	Raw	56.9^{b} ± 4.3	59.8^{bc} ± 3.2	60.3^{c} ± 4.8	59.0^{y} ± 4.2		**≤ 0.01**	
	Crisp	45.2^{a} ± 1.0	47.1^{a} ± 1.9	47.3^{a} ± 2.4	46.5^{x} ± 2.0			0.8
	Root type	*49.6^{A} ± 6.3*	*51.9^{B} ± 6.8*	*52.2^{B} ± 7.3*		*0.03*		
a	Raw	7.5^{b} ± 1.0	16.8^{d} ± 2.6	5.8^{a} ± 2.2	10.0^{y} ± 5.3		**≤ 0.01**	
	Crisp	7.0^{ab} ± 0.4	9.7^{c} ± 1.5	6.6^{ab} ± 0.6	7.8^{x} ± 1.6			**≤ 0.01**
	Root type	*7.2^{A} ± 0.7*	*12.4^{B} ± 4.0*	*6.3^{A} ± 1.4*		*≤ 0.01*		
b	Raw	12.6^{cd} ± 2.6	19.1^{e} ± 3.5	14.5^{d} ±3.7	15.4^{y} ± 4.1		**≤ 0.01**	
	Crisp	7.0^{a} ± 1.4	9.7^{bc} ± 3.0	9.4^{ab} ± 3.1	8.7^{x} ± 2.8			0.1
	Root type	*9.1^{A} ± 3.3*	*13.2^{B} ± 5.6*	*11.3^{B} ± 4.1*		*≤ 0.01*		
C	Raw	14.7^{bc} ± 2.9	25.4^{d} ± 4.3	15.7^{b} ± 4.0	18.6^{y} ± 6.1		**≤ 0.01**	
	Crisp	10.0^{a} ± 1.2	13.8^{bc} ± 3.1	11.6^{ab} ± 2.7	11.8^{x} ± 2.9			**≤ 0.01**
	Root type	*11.7^{A} ± 3.0*	*18.2^{B} ± 6.8*	*13.2^{A} ± 3.7*		*≤ 0.01*		
E	Raw	58.8^{b} ± 4.8	65.1^{c} ± 4.5	62.4^{bc} ± 5.7	62.1^{y} ± 5.4		**≤ 0.01**	
	Crisp	46.3^{a} ± 1.2	49.1^{a} ± 2.7	48.7^{a} ± 3.0	48.1^{x} ± 2.7			0.4
	Root type	*51.0^{A} ± 6.9*	*55.1^{B} ± 8.6*	*53.9^{B} ± 7.9*		*≤ 0.01*		
H	Raw	(-)0.1^{b} ± 0.2	0.5^{cd} ± 0.1	(-)0.9^{a} ±0.4	(-)0.2^{x} ± 0.6		**≤ 0.01**	
	Crisp	0.7^{d} ± 0.2	0.7^{d} ± 0.4	0.2b^{c} ± 0.5	0.5^{y} ± 0.4			**≤ 0.01**
	Root type	*0.4^{B} ± 0.4*	*0.6^{B} ± 0.3*	*0.2^{A} ± 0.7*		*≤ 0.01*		
ΔE (raw - crisp)		14.2^{a} ± 4.1	17.1^{a} ± 6.9	15.1^{a} ± 7.2		0.72		

*Values are Means and Standard deviations of 5 replicates. Results for the same parameter with different superscripts are significantly different at cited p-values. ^{abcde} : Significant differences due to OFSP root type*Raw/Crisp effects; ABC : Significant differences due to OFSP root type effects, with raw/crisp pooled; ^{xy} : Significant differences due to raw/crisp effects, with OFSP root type pooled.*

$C = \sqrt{(a)^2 + (b)^2}$ $E = \sqrt{(L)^2 + (a)^2 + (b)^2}$ $H = Tan^{-1}\left(\frac{b}{a}\right)$

The high β-carotene content raw Bophelo slices were intermediate Impilo and 199062.1 raw slices regarding the *L* value. Raw 199062.1 slices were the lightest (highest *L* value) of the three root types, although frying lowered the *L* values of all crisps from the three root types to the same level. Frying significantly reduced the *a* values, except for 199062.1 roots where it increased. Raw Bophelo slices had the highest *a* value and Impilo crisps the lowest.

Similarly, the *b* values significantly decreased with frying. High β-carotene content (Raw Bophelo) slices had the most intense orange colour which faded with frying yet they still had the highest *b* value in crisps form. Crisps from low β-carotene Impilo tubers had the lowest *b* value. Regarding chromaticity (*C* value), raw slices were more saturated than fried crisps. Deep frying lowered the *C* value of the slices, the effect of which differed with the root type. The slices from the low β-carotene Impilo roots had the highest loss of colour saturation showing the lowest *C* values, while the high β-carotene roots (Bophelo) slices were the most chromatic (higher *C* values) both in the raw and fried states.

When colour intensity (*E*) was considered, the 'root type effect' was more pronounced in fresh OFSP slices with raw Bophelo slices (high β-carotene) showing highest *E* values. Frying significantly lowered the *E* values of OFSP slices to the same level regardless of root type. The changes in colour intensity between the raw and fried slices (ΔE) were similar for all the OFSP root types. Significant variations in hue (*H*) values both for raw and fried slices were also apparent, with values increasing in fried crisps ($p<0.01$).

Figure 3.4 shows the visual images of OFSP raw and crisp samples, and flours from freeze-dried raw slices of the three OFSP types. The high β-carotene Bophelo slices were the most orange while the very low β-carotene 199062.1 roots were the least orange in colour. Colour intensity (*E*) and colour saturation (*C*) decreased in fried crisps.

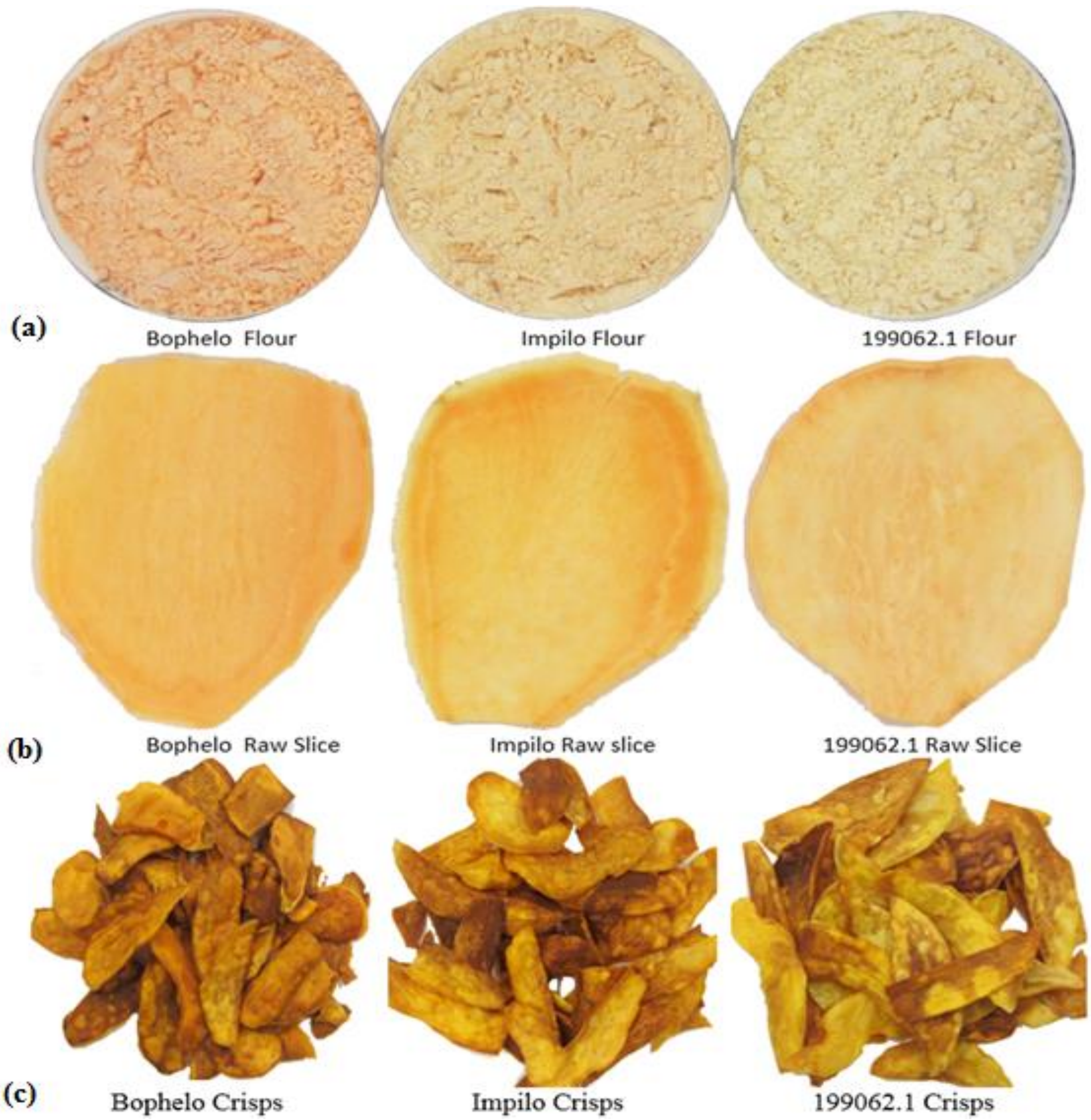


Figure 3.4 *(a) Flour samples from freeze-dried raw OFSP root slices, (b) Fresh raw slices from three types of OFSP roots, (c) Deep-fat fried crisps from the three types of OFSP roots. (Canon, Powershot SX 230HS, Canon Incorporated, Japan).*

3.9.3 Nutritional content of raw and fried OFSP slices

The effect of OFSP root type on the vitamin A value, oil, protein, ash, carbohydrate and trans-β-carotene content for three OFSP types studied for crisp manufacture is shown in table 3.5.

Table 3.5 *The effect of type of OFSP root on the proximate, trans-β-carotene content and vitamin A value of the raw OFSP storage root slices studied before and after processing by deep-fat frying.*

		Orange-flesh sweet potato (OFSP) root types				**Effect significance (p ≤ 0.05)**		
Response Parameter (%)		**[1]LDM, Lβ-c (Type 1: Impilo)**	**[2]MDM, Hβ-c (Type 2: Bophelo)**	**[3]HDM, VLβ-c (Type 3: 199062.1)**	*Raw/crisp*	**Root type**	**Raw/Crisp**	**Root type*Raw/crisp**
Oil Content (d.b.)	raw	0.3^{a} ± 0.00	0.2^{a} ± 0.0	0.4^{a} ± 0.0	0.3^{x} ± 0.1		**< 0.01**	
	crisp	36.3^{c} ± 5.5	33.4^{c} ± 5.2	26.2^{b} ± 2.0	31.3^{y} ± 6.0			**< 0.01**
	Root type	22.3^{B} ± 18.1	20.5^{B} ± 16.7	16.2^{A} ± 12.8		**<0.01**		
Protein (d.b.)	raw	6.2^{c} ± 0.0	6.4^{c} ± 0.0	5.3^{a} ± 0.0	5.7^{x} ± 0.5		**< 0.01**	
	crisp	8.0^{e} ± 0.4	6.8^{d} ± 0.0	5.6^{b} ± 0.0	6.6^{y} ± 1.0			**< 0.01**
	Root type	7.2^{C} ± 1.0	6.4^{B} ± 0.2	5.3^{A} ± 0.2		**< 0.01**		
Ash (d.b.)	raw	5.2^{e} ± 0.0	4.4^{c} ± 0.0	4.8^{d} ± 0.0	4.7^{y} ± 0.3		**< 0.01**	
	crisp	3.6^{a} ± 0.1	3.9^{b} ± 0.0	4.7^{d} ± 0.1	3.9^{x} ± 0.5			**< 0.01**
	Root type	4.0^{A} ± 0.8	3.9^{A} ± 0.3	4.6^{B} ± 0.1		**< 0.01**		
Carbohydrate (d.b.)	raw	82.5 ± 6.4	85.9 ± 6.4	95.0 ±6.4	87.8^{y} ± 3.7		**< 0.001**	
	crisp	61.7 ± 6.4	64.7 ± 6.4	60.9 ± 6.4	62.4^{x} ± 3.7			ns
	Root type	72.1^{A} ± 4.5	75.3^{A} ± 4.5	77.9^{A} ± 4.4		ns		
Trans-β-carotene (μg/100g, d.b.)	raw	6 527^{e} ±34	15 861^{f} ± 101	3 859^{d} ± 7	8 747^{y} ± 5 639		**< 0.01**	
	crisp	1 347^{b} ± 7	2 627^{c} ± 35	452^{a} ± 7	1 475^{x} ± 978			**< 0.01**
	Root type	3 937^{B} ± 2 991	9 244^{C} ± 7 640	2 153^{A} ± 1 964		**< 0.01**		
Vitamin A Value (μg RAE/100g, d.b.)ᶲ	raw	544^{e} ± 3	1 322 ^{f} ± 8	321^{d} ± 1	729^{y} ± 470		**< 0.01**	
	crisp	112^{b} ± 1	219^{c} ± 3	38^{a} ± 0.6	123^{x} ± 82			**< 0.01**
	Root type	328^{B} ± 249	770^{C} ± 637	179^{A} ± 164		**< 0.01**		
Vitamin A Retention (%)#	crisp	20.7 ^{c} ± 0.0	16.6^{b} ± 0.3	11.8^{a} ± 0.2		**< 0.01**		

Values are means and standard deviations of at least 2 replicates. Oil content is an ether extract. ᶲ *RAE (Retinol activity equivalents): 12 μg* β-carotene *= 1 μg retinol = 1 μg RAE (van Jaarsveld et al., 2006).* [#] *Percent of the total trans-* β-carotene *retained after deep-fat frying (101.3 kPa; 160* ^{o}*C; 4 minutes) compared to fresh, freeze dried- OFSP.*

[abcdef]*: Values with different superscripts differ significantly due to root type*raw/crisp effects;* [ABC]*: Values with different superscripts differ significantly due to root type, with raw/crisp pooled;* [xy]*: Values with different superscripts differ significantly due to raw/crisp effects, with root type pooled.* [1] *Low dry matter, low* β-*carotene ;* [2] *Medium dry matter, high* β-*carotene ;* [3] *High dry matter, very low β-carotene.* [ns]*: p-value showing that the effect was not significant.* [d.b] *: analyte expressed on a dry basis where the moisture content of the sample was zero.*

The low dry matter roots (Impilo) absorbed as much oil as the intermediate dry matter roots (Bophelo) during frying. Crisps from low and medium dry matter roots had higher oil content values compared to high dry matter (199062.1) crisps. Trans-β-carotene content decreased with deep-frying across all three OFSP types, although Impilo crisps retained β-carotene better compared to Bophelo and 199062.1 roots. Contrary to proteins, carbohydrates and ash content decreased variably with frying. Interestingly, a dramatic decline in ash for slices from low dry matter tubers (Impilo) with frying was noted, inconsistent with the other root types. High dry matter roots (199062.1) had significantly higher ash content with good retention in crisps while medium dry matter Bophelo slices lost a notable amount with frying.

OFSP storage root dry matter content had a good inverse correlation (R^2 = -0.9116) with the final oil content of fried crisps (Figure 3.5), suggesting that high dry matter OFSP roots can yield deep-fat fried crisps with significantly lower oil content.

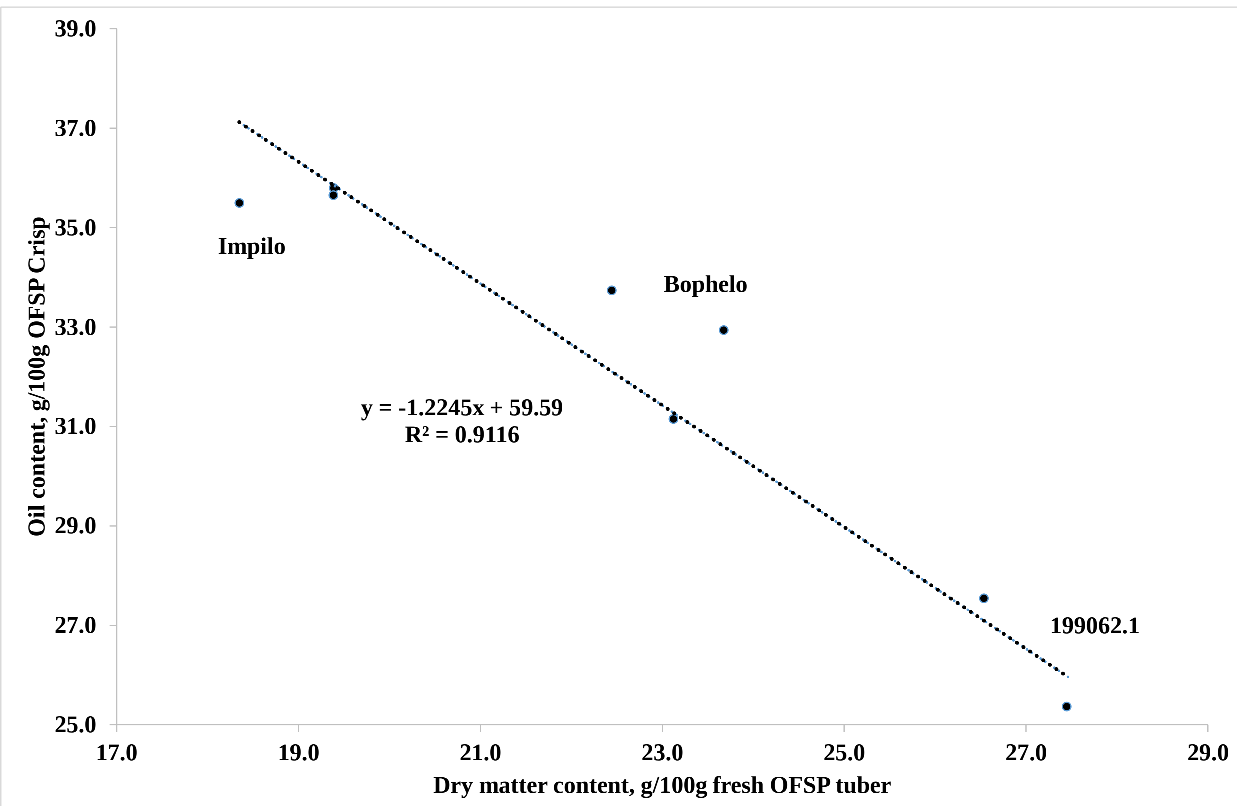


Figure 3.5 *The effect of dry matter content of raw OFSP roots on the oil content of fried crisps.*

Figure 3.6 gives the HPLC chromatograms from the analysis of flour samples from raw and fried OFSP slices.

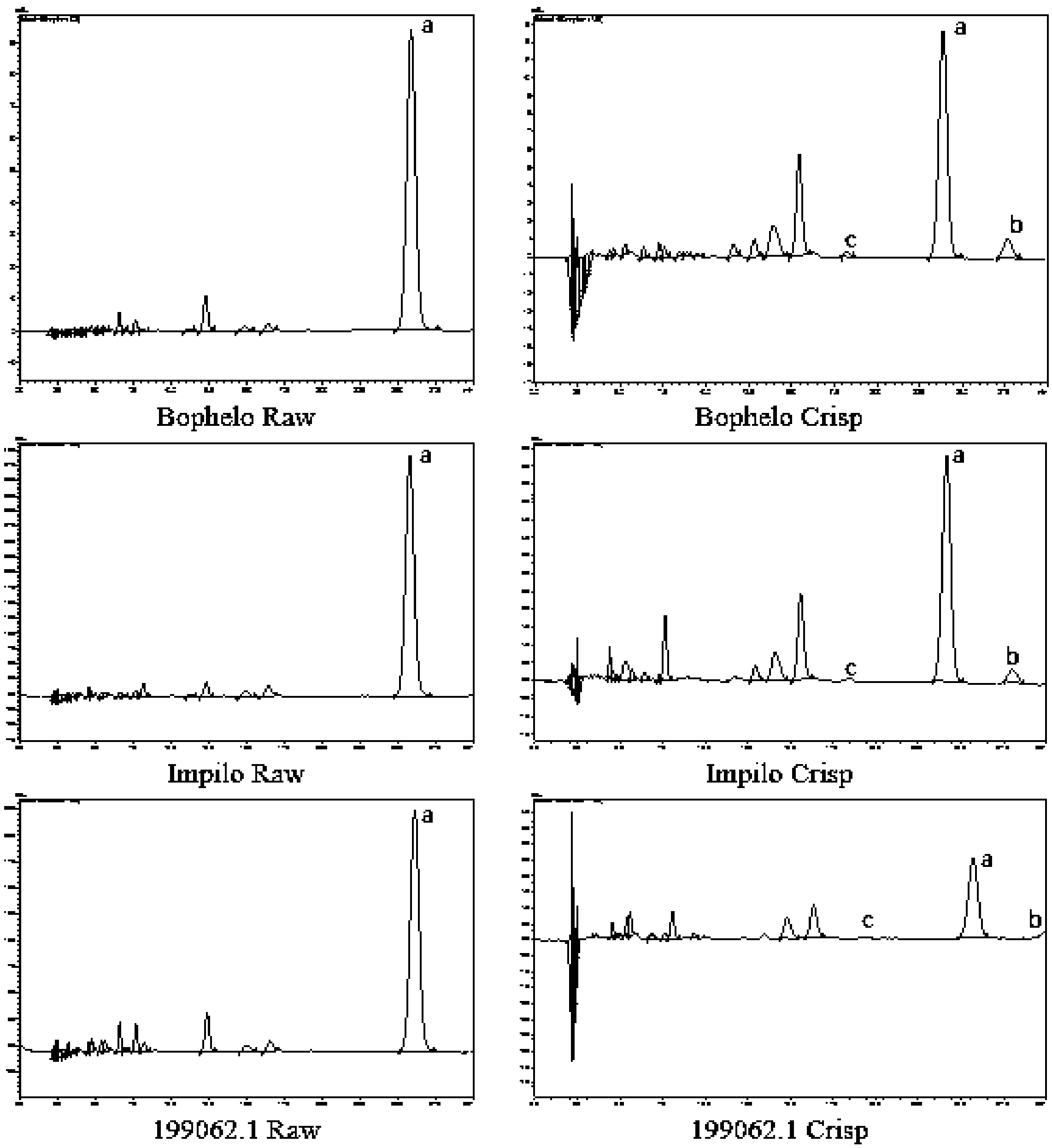


Figure 3.6 *HPLC chromatograms of OFSP samples obtained with a reverse-phase YMC C30 column by isocratic elution.*

The vertical axis is the chromatographic response in milli-absorbance units (mAu) and the horizontal axis is retention time (minutes). The predominant peak ***(a)*** *is all-trans-β-carotene. New peaks* ***(b)*** *and* ***(c)*** *are probably 9-cis- and 13-cis-β-carotenes respectively. Subsidiary peaks are unidentified cis-carotenoids. Detection at λ = 450 nm.*

In all three OFSP root types the predominant chromatographic peak was trans-β-carotene. Additional peaks (b and c) appeared with frying, which are probably breakdown products (9-cis- and 13-cis-β-carotenes) of all-trans-β-carotene.

3.10 Discussion

Crisps from roots with low dry matter content (Impilo) were the least hard, with lower stress, strain and 1st fracture deformation values, whereas intermediate dry matter content roots (Bophelo) produced significantly harder crisps than high dry matter roots (199062.1). Crispy materials are brittle and rapidly fracture under stress at low strains (Miranda and Aguilera, 2006). Lower strain values imply a more brittle structure. The results indicated that crispy texture depends mainly on total solids, with high dry matter roots (>25 %) showing higher hardness and lower final oil content. High dry matter (99062.1) crisps had higher strain and 1st fracture deformation values and were the least brittle. First fracture deformation measures the distance travelled by the probe to effect initial rupture (first significant force-drop) in a food sample, lower values indicating a more brittle structure. First fracture deformation was consistent with the dry matter content of raw OFSP roots, because it required a greater probe displacement to fracture the more dense 199062.1 crisps from high dry matter roots compared to the lighter Impilo crisps from lower dry matter roots. Higher 1st fracture deformation signifies a higher elastic component (stiffness) in the visco-elastic food sample.

The lower hardness value for crisps from high dry matter (199062.1) roots compared to crisps from medium dry matter (Bophelo) roots was however unexpected. This may have resulted from variations in the final moisture content of the crisps from the two OFSP types (Bophelo crisps, $2.4^{b} \pm 0.3$ % and 199062.1 crisps, $1.8^{a} \pm 0.3$ %). In deep-fat fried potato products, it has been demonstrated that crisp texture is also influenced by the final moisture, apart from dry matter content of the tubers (Matz, 1993). In the current study, crisps from Bophelo roots were significantly less dehydrated compared to 199062.1 crisps. Hardness was shown to be directly proportional to moisture content of potato crisps up to about 2.5%, beyond which softening ensued (Segnini et al., 1999). It would therefore require more force to rupture internal bonds holding the composite matrix together in crisps from medium dry matter Bophelo roots than in high dry matter 199062.1 crisps when moisture content is considered. Water is a plasticizer, enhancing the strength of cohesive forces in very low moisture crispy products (Murano, 2003). Variation in moisture-texture behaviour of the crisps could be attributed to the heterogeneous distribution of starch and other compounds in the different storage root types, and to the tissue structure after frying as observed for potato tubers (Miranda and Aguilera, 2006).

Elastic modulus, E_c (modulus of deformability) directly measures the stiffness of dried products (Odenigbo et al, 2012). Interestingly, high dry matter (199062.1) crisps were the lowest in E_c value (least stiff hence most brittle) while crisps from medium dry matter roots (Bophelo) had the highest Elastic modulus (E_c) value. This suggest that interaction effects (OFSP root type*raw/crisp) rather than dry matter alone could be significant in the E_c values of crisps from the different OFSP types. Crispiness and brittleness have also been explained in terms of the *gradient* of the force-displacement curve, and the amount of force required to break (*hardness*) the sample. A higher gradient show high crispiness whereas a lower hardness value implies higher brittleness (Anton and Luciano, 2007). Accordingly, 199062.1 crisps could be interpreted as the most brittle but least crispy, while Bophelo crisps were the crispiest yet least brittle (Figure 3.3), although only sensory analysis can provide a more reliable measure of crispness.

Texture characterization in fried products is often a challenge (high variation coefficients) because frying *per se* introduces critical structural changes in the product, apart from the inherent anisotropic nature of tubers. However, textural data within the linear visco-elastic region of food samples (e.g. E_c) is critical for the prediction of the material properties of food. In this region, food behaves like an ideal elastic material: deformation occurs instantly when stress is applied and disappears instantly when stress is removed as if it possesses a memory (Borwankar, 1992).

Preservation of natural pigments and controlled development of desirable colour are important indices of quality in deep-frying of OFSP. Food should be of appropriate colour because this is often critically evaluated by consumers and forms the basis for preferring a particular brand of crisps (Davies, 2005). Changes in the colour values for crisps implied that frying degraded carotenoids under atmospheric conditions (Table 3.4). The higher *b* values for raw Bophelo positively correlates with its higher β-carotene content compared to Impilo and 199062.1

cultivars, because the *b* value is related to the amount of β-carotene present (Nunes and Moreira, 2009).

In potato crisps, colour darkening depends on the content of reducing sugars and proteins, temperature and time of frying (Abong et al, 2011b). Frying induces Maillard reactions and caramelization of sugars which lower the *a* values of fried slices (Ngadi et al, 2009). A decrease of the *L*, *a* and *b* values may also be attributed to the degradation of *trans*-α- and *trans*-β-carotenes which are directly related to the *a* and *b* colour parameters since they are yellow and orange pigments respectively (Dueik et al, 2013). Chroma (C) describes how vivid or dull (grey) the colour is. The chromatic variation in fried slices may have resulted from the formation of brown pigments due to non-enzymatic browning reactions that may also include chemical oxidation of phenols (Dueik and Bouchon, 2011b).

The *all-trans*-β-carotene content of 6 526.6µg/100g for Impilo in the current study is consistent with a range of 2 978.0 - 7 034.0µg/100g (29-70ppm) reported by HarvestPlus (2014). Differences in mean concentrations of *all-trans*-β-carotene in fresh roots of the three OFSP types were in agreement with preceding local and international findings (Laurie et al., 2012; Xu et al., 2013) on β-carotene levels in other sweet potato varieties. OFSP types from all three cultivars in the current study exceeded a general breeding target of 30 ppm (Low et al., 2013), but only Bophelo (15 861.1 µg/100g) doubled the HarvestPlus breeding target of 7 500 µg.100 g^{-1} (Laurie et al., 2012), which makes it a very important cultivar for food-based nutrition intervention programs for VAD.

All-trans-β-carotene retention in deep-fat fried samples was very low ($11.8^{a} \pm 0.2\% - 20.7^{c} \pm 0.0\%$), reflecting the degradative nature of normal atmosphere deep-frying on carotenoid quality and quantity. Retention is defined as the proportion of carotenoids remaining in processed sweet potato relative to amount originally present. Xu et al., (2013) reported 33.1 % *trans*-β-carotene retention in sweet potato crisps conventionally deep-fat fried for 2 minutes at 160 ^{o}C. The even reduced retention of $11.8^{a} \pm 0.2\% - 20.7^{c} \pm 0.0\%$ in the current study could reflect the time-dependence of *trans*-β-carotene degradation kinetics. Deep-fat frying of OFSP for 4 minutes at 160 ^{o}C in an exposed fryer had a destructive effect on *all-trans*-β-carotene. The observed increase in the proportion of *cis*-β-carotene isomers suggests an increased oxidation and isomerization rate with prolonged deep frying.

These results provide evidence that thermal processing by deep-frying leads to loss of *all-trans*-β-carotene and the formation of less bioavailable *cis*-isomers (9-*cis*- and 13-*cis*- and *15*-cis isomers) through isomerization, oxidation or cyclization at elevated temperatures (Dueik et al., 2010). *Trans*-*cis* isomerization lowers the vitamin A activity and antioxidant capacity of carotenoids.

The low oil content in raw OFSP roots (0.2 ± 0.01% – 0.4 ± 0.01 %) confirmed previously reported values (0.2 % – 1.8 %) by Figueira et al (2011). The oil content increased significantly with frying according to OFSP root type. The oil content values for crisps from medium and low dry matter roots (Bophelo, 33.4% and Impilo, 36.3%) matched the declared fat content range for some local brands (Simba Chips, 35% fat; Lay's® Potato Chips, 33% fat in salted crisps and 36% other flavours) of deep-fat fried chips, while crisps from high dry matter 199062.1 roots were a better product regarding the reduced oil content (26.2%). The two-way heat-mass transfer events during deep-frying, characterized by moisture leaving slices and creating extensive voids, which get impregnated by oil mainly during cooling, caused an increase in final oil content (Ziaiifar et al, 2008; Amany et al, 2012). Significant variation in moisture content and dry matter content amongst the three OFSP types influenced the oil content differences in fried crisps. Moisture loss affects the extent of crust formation and volume available for oil impregnation (Dueik et al, 2010).

Oil absorbed by the crisps showed a significant inverse correlation (R^2 = -0.9116) with the dry matter content of slices from the three OFSP roots. The regression line $y = 59.59 - 1.2245x$ was found suitable for the estimation of the final oil content of crisps (*y*) on the basis of dry matter content (*x*) in OFSP roots. Higher dry matter content 199062.1 roots contributed to lower final oil content in the crisps, confirming the findings (Baumann and Escher, 1995) in potatoes-that high total solids content tubers tend to absorb less oil and often give superior yield. Dry matter content influences oil uptake during frying due to its relationship with water loss (Ziaiifar et al, 2008). Each tuber or root type has an inherent tendency (genetic pre-disposition) to develop a certain percentage of total solids, although this can be influenced by the conditions prevailing during the growing season (Matz, 1993). A dry matter content of 19.4 % previously reported for Impilo (Laurie et al., 2012) matches with present findings. This lower dry matter content has been an important factor leading to a significantly higher final oil content value of 36.3% for crisps from Impilo roots.

Frying dehydrated OFSP slices to moisture content level of ~ 2 % (1.8[a], 2.0[a], 2.4[b]) and a maximum water activity (A_w) of 0.38, which confers optimal physico-chemical and sensorial quality to fried crisps (Dueik, Robert and Bouchon, 2010) and slows hydrolytic rancidity (Matz, 1993). A A_w of $\leq$ 0.44 was shown to be crucial for microbial stability, better carotenoid preservation, and optimal crispness (Katz and Labuza, 1981; Lavelli et al, 2007). Above A_w of 0.47, loss of crispness follows and sensory acceptability decreases (Miranda and Aguilera, 2006). The protein content for raw OFSP was significantly higher (5.3 – 6.4%) relative to previously reported values of 1.9 % – 4.4 % (Burlingame et al 2009; Figueira et al 2011; Ali et al 2012) yet in agreement with some reported range of 4.91 % - 8.44 % (Bradbury, 1988; Wolfe, 992). The present findings also agree with a 7.4 – 8.4 % protein range declared on nutrient label panels for some local potato crisp brands (Lays/Simba chips fried in vegetable oil).

Although a decrease in ash content of OFSP roots occurred with frying, the content in both the roots and fried crisps was slightly higher (3.6 % - 4.8 %) compared to previously reported values for some raw sweet potato cultivars (1.55 % - 4.4 %) (Walter and Catignami, 1981; Wolfe, 1992). It is probable that mineral ions reacted under aggressive frying conditions leading to losses through volatile oxide compounds formation. It could also be suggested that mineral ions in fresh OFSP flesh matrices are in dynamic equilibrium between the *adsorbed phase* on organic polymer sites of plant material (starch, cellulose, pectin, hemicellulose, protein etc.) and the *desorbed phase* as free ions in plant tissue matrix solution.

Impilo's lower solids content may also mean few active sites for cation retention during deep-fat frying leading to quite a significantly lower final ash level in crisps relative to the ash content for crisps from higher dry matter roots (Bophelo and 199062.1). While mineral substances are present as salts of organic or inorganic acids or as complex organic combinations, they are in many cases dissolved in cellular juice (FAO, 2004). The higher water loss for Impilo upon frying may have caused a high mineral leach rate. Ash content is influenced by the physico-chemistry of the root, which itself depends on cultivar effects (genetic factors), soil type and agronomic practices.

3.11 Conclusions

Variations in the physico-chemical properties of roots of different OFSP types were examined, and the effect of these on the quality of deep-fat fried crisps was investigated. The findings suggest that using roots with high dry matter (e.g. 199062.1), and high β-carotene content (e.g. Bophelo) in the production of OFSP crisps could optimize product texture, oil content, colour and β-carotene content when compared to roots types of low dry matter content (e.g. Impilo). Roots from 199062.1 cultivar may be an ideal choice for cost-effective low fat OFSP crisps with considerable β-carotene content. However, the poor trans-β-carotene retention in OFSP crisps with conventional deep-fat frying suggests that better processing methods which preserve carotenoids need much consideration. Low fat crisps would be in tandem with current nutritional thinking on the health benefits of low fat food.

Chapter 4: Descriptive sensory evaluation of orange-fleshed sweet potato and other vegetable crisps by the Flash Profiling method

4.0 Abstract

The effect of utilizing roots of varying physico-chemical properties on the sensory quality of deep-fat fried orange-fleshed sweet potato (OFSP) crisps was explored. Crisps prepared from roots of three OFSP cultivars (Impilo, Bophelo and 199062.1) and four other commercial crisp products (butternut, pumpkin, sweet potato and carrot) were evaluated using Flash Profile (FP) methodology. The sensory profiles of crisps from Bophelo and Impilo roots were more related and were perceived as more orange and darker, harder, sweeter and less oily compared to 199062.1 crisps. The colour, appearance and flavour of OFSP crisps was influenced by the type and content of sugar in roots, with higher glucose and fructose content in Impilo tubers resulting in darker and sweeter flavoured crisps compared to crisps from Bophelo and 199062.1 roots. The higher β-carotene content of Bophelo roots produced crisps with more intense orange colour, while crisps from 199062.1 roots had the least intense orange colour. OFSP crisps were more orange and darker in colour, and were sweeter relative to commercial samples. Variations in physico-chemical profiles of OFSP roots lead to differences in the sensory profiles of crisps and this could be exploited in crisp product diversification, in efforts to meet the varied and dynamic sensory expectations of consumers.

Keywords: Orange-fleshed sweet potato; flash profile; multiple factor analysis; inertia; projected points.

4.1 Introduction

OFSP is recognized as a healthy food crop because of significant content of β-carotene, phenolic acids, anthocyanins, and dietary fiber in many cultivars (Turner and Burri, 2001; Yodkraisri and Bhat 2012). OFSP roots can be used to produce convenient food products like crisps, which are eaten as an appetizer or as a snack food. The objective of the study was to understand how the sensory profiles of crisps are influenced by differences in physico-chemical properties (dry matter, moisture, oil content, glucose, fructose, sucrose, flesh colour and trans-β-carotene content) of the roots used. The sensory characterization of boiled OFSP and non-orange varieties have been reported (Ofori et al., 2009, Leighton et al., 2010, Laurie et al., 2012, Tomlins et al., 2012). Boiled orange-fleshed roots were associated with pumpkin flavour, orange colour and uniform colour. However, research on the sensory mapping of OFSP crisps as influenced by the physico-chemical properties of the roots is limited.

For sweet potatoes, high dry matter content roots are often associated with good eating quality (Lebot, 2010). Dry matter is negatively correlated with carotenoid and sugar content but positively correlated with starch content (Lebot, 2010). Changes in the dry matter content of roots affecting a wide range of sensory attributes across the entire sensory spectrum (odour, appearance, taste and texture), were shown to be related to variations in the carotenoid content of the roots (Tomlins et al., 2012). Methods like Flash Profiling (FP) (Dairou and Sieffermann, 2002) may be used to generate descriptive sensory data of OFSP crisps in order to understand the links between the physical and chemical parameters of roots, and the sensory quality of crisps.

FP is a rapid descriptive sensory evaluation technique that involves ranking products for each attribute on an intensity line scale, with assessors using their own free-choice attributes (Perrin and Pages, 2009). The flexibility of FP makes it ideal for positioning products rapidly according to their sensory attributes. Depending on the objective, it eliminates the need to train a sensory panel or familiarize it with samples beforehand, and this reduces evaluation costs (Revell, 2008). In this study FP was chosen because limited sample quantities were available and the storage life of the tubers was short, which precluded extensive panel training. To the author's knowledge, there are no reports to date on the use of flash profiling to describe OFSP crisps quality.

4.2 Hypothesis 3 (prediction of sensory properties in crisps)

Deep-fat fried crisps processed from OFSP roots varying in physico-chemical properties (flesh colour, trans-β-carotene, dry matter, glucose, fructose and sucrose content) will show differences in sensory properties as affected by the OFSP type used for processing.

- Crisps from high trans-β-carotene content roots (e.g. Bophelo) will be more orange in colour compared to those from low trans-β-carotene roots (e.g. Impilo) or very low trans-β-carotene roots (e.g. 199062.1).
- Crisps from higher dry matter content roots (e.g. 199062.1) will be crispier and less oily compared to those from medium (e.g. Bophelo) and lower (e.g. Impilo) dry matter roots.
- Crisps from higher glucose content roots (e.g. Impilo) will be darker with more caramel flavour compared to those from lower glucose content roots (e.g. 199062.1).
- Crisps from higher fructose, high sucrose roots (e.g. Impilo) will be sweeter compared to those from medium (e.g. Bophelo) and lower fructose and sucrose roots (e.g. 199062.1).

The intensity of the orange colour in OFSP crisps is influenced by the *trans*-β-carotene content, an orange pigment in OFSP roots (Ali et al 2012; Dueik *et al*., 2013). The sensory aspects of food (flavour, colour, aroma formation, and texture) are affected by the Maillard reaction depending on the chemical composition of the plant material (The CIAA, 2009). Reducing sugar content is the limiting factor in the Maillard reaction and largely determines colour and flavour of crisps. Higher glucose concentration in tubers increases non-enzymatic browning during frying (Odenigbo *et al*., 2012). Sugars can also caramelize at frying temperatures leading to colour darkening of crisps (Arabhosseini et al. 2011). For potatoes, high dry matter, low reducing sugar content tubers (0.1 - 0.25% wet basis) tend to yield crispy textured, good flavoured light yellow to golden brown colour in crisps (Abong et al., 2011b; Medeiros Vinci et al., 2012).

4.3 Objective 3

To determine the effect of the physico-chemical properties (flesh colour, trans-β-carotene, dry matter, glucose, fructose and sucrose content) of fresh OFSP roots on the sensory properties (texture, flavour and appearance attributes) of deep-fat fried crisps, in order to optimize sensory quality for better consumer acceptance.

4.4 Materials and Methods

4.4.1 Crisp processing, sample preparation and presentation

Seven crisp types, three from OFSP roots belonging to different cultivars (Bophelo, Impilo and 199062.1) and four commercial crisp types (Pumpkin, Butternut, Sweet potato and Carrot) purchased from a local processor were used in the study. OFSP crisps processing has been reported in chapter 3. The processing history of the commercial samples was not disclosed.

4.5 Sensory Evaluation

A panel of eight assessors (two male and six females between 19 and 35 years) with experience in descriptive sensory analysis methodology participated in the FP evaluation. The evaluation was performed according to Dairou & Sieffermann (2002) in a single session with three stages.

Introductory phase

The panel was advised of the objective for the evaluation, which was to describe the sensory differences between the crisp types. Assessors were informed that they would be provided with a set of 8 crisp samples per individual in the sensory booths for familiarization prior to the actual evaluation. They would taste, smell, feel the texture and observe appearance, and record individually lists of attributes that would distinguish between the crisp types without using hedonic terms. Each assessor would then have access to the attribute lists from other assessors in order to update their own lists if desired, but not necessarily seeking consensus. In the second stage, assessors were advised that they would evaluate and rank the crisps types on an intensity line scale (10 cm long) from 'low' to 'high' for each attribute, where ties would be allowed if no difference was perceived. It was explained to the assessors that they would be allowed pauses during evaluation to avoid fatigue, and sparkling water was to be used as a palate cleanser in-between oral testing experiences. Assessors would take a 10 minute break and proceed on to the third (final) stage which would be a replicate of the second stage.

Crisp evaluation phase

Crisp types were presented (10 g) in the sensory booths in transparent zip-lock packs (100x110mm, 40μm) labelled with a randomly generated three digit code, assessors carried out the FP evaluation as described in the introduction stage. The presentation order on the trays was randomized using Compusense® five software (Compusense® Inc, Guelph, Canada) following a Williams' Design (8 treatments, Type: Quantitative Descriptive) to counter-act first order carry-over effects. Stage one (sample familiarization, attribute generation) took 30 minutes followed by a 10 minute break. Assessors then proceeded on to the second and third stages (actual ranking tasks) which took about 25 minutes each and were separated by a 10 minute break.

The whole evaluation process lasted approximately 2 hours and was conducted in standardized booths (ISO 8589:2007) in a Sensory Science laboratory. All the crisp types were presented simultaneously at each stage. The commercial sweet potato crisp was duplicated as a blind sample to check for assessors' performance. The evaluation data was collected and organized into a suitable matrix for multivariate analysis.

4.6 Statistical data analysis

Collective treatment of the FP data was done using two-way analysis of variance (two-way ANOVA) with interaction, on the attributes with frequency of use, $f^* \geq 3$. This analysis included the panel effect, products effect and the interaction between the two. For each attribute from each assessor one-way analysis of variance (one-way ANOVA) was applied on rank values to determine the significance of attributes. This ANOVA model shows which attributes are important in contributing to sensory differentiation of the samples under evaluation (de Jesus Ramirez-Rivera *et al.,* 2012). Differences were considered significant at $p \leq 0.05$. Regressor vector (R_V) co-efficient values calculated from Multiple Factor Analysis (MFA) were used to measure the degree of agreement between assessors two by two, with high R_V co-efficient values considered strongly consensual. Mathematically, it can be shown that the R_V co-efficient corresponds to the Pearson's correlation co-efficient after rearranging the original matrices into vectors (Reinbach et al., 2014).

MFA was applied to the eight data matrices from eight assessors to visualize the global sensory mapping for the seven crisp types. MFA is a multivariate statistical technique for integrating different groups of variables describing the same observations, and subsequently finding a few latent variables which explain the greatest variability in the data (Reinbach et al., 2014). The global product positioning on MFA spaces represents the overall sensory perception of the panel. For this set of quantitative data, MFA was used to first carry out a principal component analysis (PCA) for each table. Rows were the observations (samples) while the columns were the sensory attributes. The various tables were weighed and the weighted PCAs of all tables were used to generate MFA plots for the global matrix. This consensus configuration reflected the underlying data structure and indicated which crisps were more similar and which ones differed strongly from each other.

Inspection of partial points of the projected matrix and R_V coefficients was conducted to understand the configurational congruence between assessors and the overall MFA plot (Dehlholm et al., 2012). Agglomerative Hierarchical Cluster analysis (AHC) was also performed on collective attributes for all crisp samples using Ward's method (dissimilarity) with automatic truncation. Clustering and analysis of the Euclidean distance were used to indicate differences between the samples. Cluster Analysis reveals clusters of attributes or products that are correlated (Valentin et al., 2012). Statistica software (Version 10, Statsoft, Tulsa, USA) was used for ANOVA tests whereas MFA and AHC were performed using XLSTAT® (Addinsoft™, New York, US).

4.7 Results

4.7.1 Attribute diversity and importance in the sensory discrimination of crisps

Table 4.1 shows the sensory attributes for crisps generated by assessors. Each assessor proposed between 13 and 22 terms for a total of 54 attributes. For each assessor only attributes which significantly discriminated between the crisp types (in bold) were used in MFA irrespective of their frequencies (f*). Orange/yellow colour was the only attribute used by all assessors and which significantly discriminated the crisp types for all assessors.

Table 4.1 *Significance levels (p-values) for attributes used by assessors (As) to differentiate among crisp types using Flash Profiling (One-Way ANOVA on each attribute for each assessor).*

	Assessors and p-values								
Attribute	**As 1**	**As 2**	**As 3**	**As 4**	**As 5**	**As 6**	**As 7**	**As 8**	**f***
Orange/yellow	**0.003**	**0.002**	**0.000**	**0.000**	**0.037**	**0.000**	**0.002**	**0.000**	8
Sweetness	**0.011**	**0.023**	0.472	0.528	**0.034**		0.252	0.157	7
Oiliness		0.326		**0.008**	0.101	**0.026**	0.079	**0.005**	6
Crispness		**0.000**	**0.001**	**0.033**	0.239		0.400	**0.005**	6
Saltiness	0.843	0.069		0.528		0.395	**0.007**	0.078	6
Rough crust	0.112	**0.011**		0.503	0.698	0.214			5
Burnt taste/flavor	**0.003**			**0.016**	**0.004**			**0.003**	5
Hardness	0.112	0.083			0.137	0.160		0.475	5
Brown colour	0.070	**0.001**	0.088		0.073	**0.002**			5
Chewiness		**0.028**	0.098	0.143			0.088	**0.048**	5
Herby smell/aroma			0.620	0.856	0.535	0.118			4
Thickness		0.275	0.595	0.090					3
Burnt appearance			**0.021**		0.547		**0.012**	**0.000**	3
Crunchiness				**0.026**		**0.034**	0.356		3
Pumpkin flavour		0.417			**0.038**			0.062	3
Used oil smell/rancid			**0.032**			0.445	0.000		3
Burnt smell/aroma				**0.043**			**0.018**	**0.023**	3
Sweetpotato taste/flavor	0.151				0.105		**0.002**		3
Bubbles n blisters	0.287	0.420						**0.001**	2
Spongy	**0.000**						0.263		2
Dryness		0.094		**0.030**					2
Dried fruit appearance		**0.000**			0.263				2
Earthy flavour	0.231			0.528					2
Sweetpotato smell			0.458				**0.003**		2
Smoky aftertaste	0.079							**0.043**	2
Savoury	0.089		**0.041**						2
Buttery taste		0.207						**0.002**	2
Pumpkin seed taste			0.589			0.296			2
Aftertaste				0.074			0.270		2
Nutty taste					0.270			**0.002**	2
Cooked potato chips		**0.038**							1
Dark peach colour					**0.000**				1
Lightness								**0.039**	1
Potato-ish								0.290	1
Crackling sound								**0.003**	1
Easiness to break			0.212						1
Moistness		0.073							1
Toughness			**0.006**						1
Starchy								0.290	1
Rubbery texture								**0.006**	1
Butternut flavour		0.139							1
Fresh roll smell			**0.002**						1
Sweet smell					0.749				1
Oily flavour									1
Spicy smell			0.146						1
Syrup smell			0.577						1
Vetkoek smell						0.479			1
Mango aroma						**0.039**			1
Cinnamon taste			0.667						1
Vetkoet taste					**0.009**				1
Staleness								**0.036**	1
Cornflakes taste					0.214				1
Red pepper taste						0.102			1
Sweet-chilli taste								**0.009**	1

For each assessor, attributes with p-values in bold significantly discriminated between the vegetable crisps ($P \leq 0.05$). f is the number of assessors using a particular attribute.*

Table 4.2 shows specific appearance (orange/yellow colour, brown colour, burnt appearance), flavour (sweetness, saltiness, burnt taste/flavour, pumpkin flavour, used oil smell, burnt smell/aroma, sweet potato taste/flavour) and texture properties (oiliness, hardness, chewiness, crunchiness) that discriminated the crisps ($p \leq 0.05$). Only attributes used by at least three assessors were considered in the collective panel evaluation.

Table 4.2 *Significance levels from 2-Way ANOVA showing panel effects, sample effects, and their interaction effects on the sensory attributes of the crisps.*

			Significance ($p \leq 0.05$)		
	Attribute	**f***	**Panel**	**Samples**	**Panel x Sample**
1	Orange/yellow colour	8	1.000	**0.000**	**0.000**
2	Sweetness	7	0.999	**0.010**	0.107
3	Oiliness	6	1.000	**0.000**	0.206
4	Crispiness	6	1.000	0.758	1.000
5	Saltiness	6	1.000	**0.036**	0.581
6	Rough crust	5	1.000	0.610	**0.040**
7	Burnt taste/flavour	5	1.000	**0.000**	**0.000**
8	Hardness	5	0.999	**0.036**	0.240
9	Brown colour	5	1.000	**0.000**	0.204
10	Chewiness	5	1.000	**0.000**	0.211
11	Herby smell/aroma	4	1.000	0.869	0.816
12	Thickness	3	0.996	0.260	0.421
13	Burnt appearance	3	1.000	**0.001**	0.434
14	Crunchiness	3	1.000	**0.009**	0.305
15	Pumpkin flavour	3	1.000	**0.025**	0.433
16	Used oil smell/rancid	3	1.000	**0.003**	0.323
17	Burnt smell/aroma	3	1.000	**0.021**	**0.003**
18	Sweetpotato taste/flavour	3	1.000	**0.004**	0.113

Attributes with p-values for samples in bold were significant in sensory discrimination of crisps at $p \leq 0.05$. Only attributes used by at least 3 assessors were analysed by two-way ANOVA.
f is the number of assessors using a particular attribute.*

Consistency among assessors was fairly high as shown by the low occurrence of significant effects for panel × sample interaction, and the non-significant panel effects for all attributes indicating similar ranking by the assessors. The significant panel × sample interaction effects for orange/yellow colour, rough crust, burnt taste and burnt smell suggests that at least one assessor did not use the scale similarly to the rest of the panel for these attributes.

The R_V coefficient of relationship values obtained by comparing the sensory scores of pairs of assessors, and also individual assessors with the overall MFA perception is given in table 4.3.

Table 4.3 *Regressor vector (R_V) co-efficient of relationships (pair-wise comparison) between assessors (As).*

**	As1	As2	As3	As4	As5	As6	As7	As8	MFA
As1	**1.00**								
As2	**0.62**	**1.00**							
As3	**0.61**	**0.73**	**1.00**						
As4	**0.61**	0.46	**0.58**	**1.00**					
As5	**0.53**	**0.79**	**0.65**	**0.57**	**1.00**				
As6	**0.59**	0.46	0.43	**0.55**	0.38	**1.00**			
As7	**0.65**	**0.65**	**0.56**	0.48	**0.61**	0.45	**1.00**		
As8	**0.62**	**0.91**	**0.70**	0.48	**0.72**	0.36	**0.73**	**1.00**	
MFA	**0.82**	**0.88**	**0.82**	**0.74**	**0.83**	**0.65**	**0.80**	**0.86**	**1.00**

***As1 to As8 are Flash Profile assessors numbered from 1 to 8.*

Values in bold show fairly good to high agreement between assessors ($R_V \geq 0.50$).

The more the attributes of one assessor are related to those of the second assessor or the overall panel, the higher the R_V coefficient value. Results show fairly high configurational similarities (R_V co-efficient ≥ 0.50) (in bold) between evaluations by different assessors except for a few cases. The highest agreement was between assessors 2 and 8 ($R_V = 0.91$), and there were fairly good agreement on sensory attributes rankings between individual assessors and the global MFA matrix (R_V co-efficient values 0.65 – 0.88).

Figures 4.1 and 4.2 show coordinates of the projected points in a consensus space for data collected by the eight assessors. The figures indicate the performance of individual assessors in comparison to the other panel members and to the compromise position for each of the evaluated crisp types. Factor scores for the replicated commercial sweet potato crisp are very close to each other in both cases which is expected for sub-samples of the same population, showing much congruence in the evaluation of the panel.

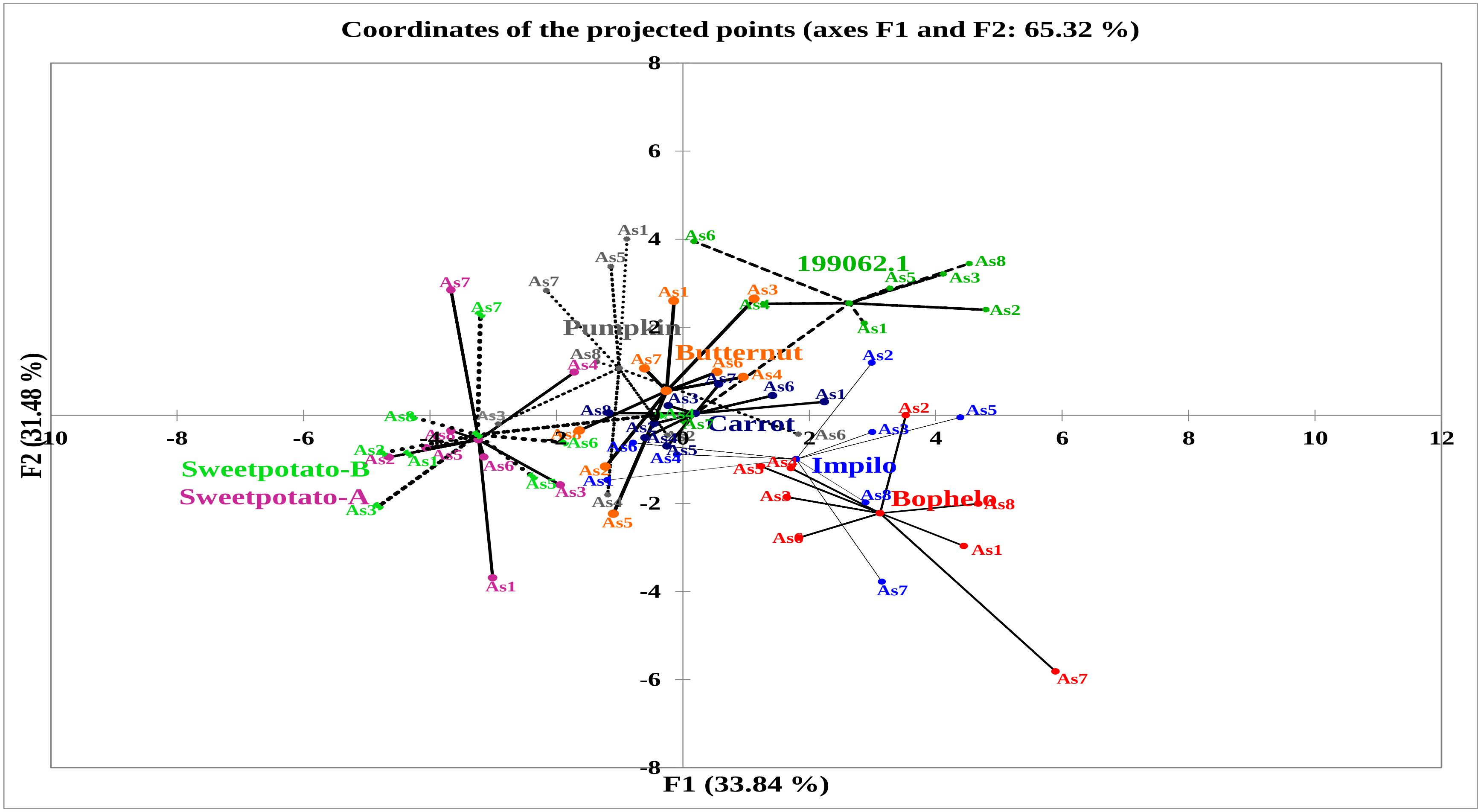


Figure 4.1 *Multiple factor analysis (MFA) first and second principal components showing the projected points for crisps evaluated by Flash Profile (FP) method.*

Centroids represent factor scores for crisps, and assessors' partial factor scores (numbered) are projected into the compromise (centroids) as supplementary elements. Vector lines link assessors' (As) products projections to the global product position (centroid) for each crisp. The shorter the lines, the greater the consensus between assessors and the factor score.

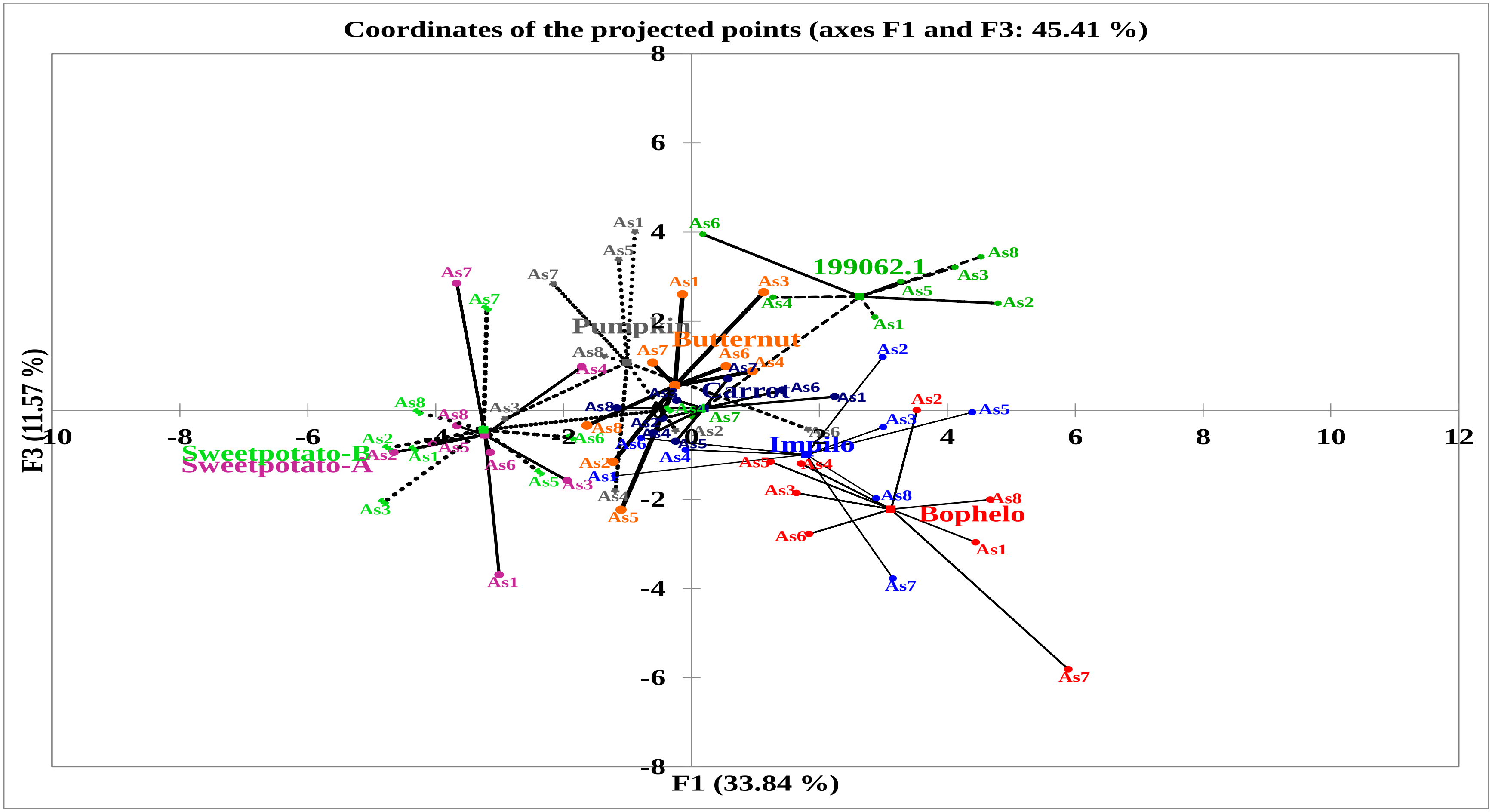


Figure 4.2 *Multiple factor analysis (MFA) first and third principal components showing the projected points for crisps evaluated by FP method.*

Centroids represent factor scores for crisps, and assessors' partial factor scores (numbered) are projected into the compromise (centroids) as supplementary elements. Vector lines link assessors' (As) products projections to the global product position (centroid) *for each crisp. The shorter the lines, the greater the consensus between assessors and the factor score.*

4.7.3 Sensory characterization of crisps: MFA

Figure 4.3 shows the observations (crisp types) in the global product space for the first three principal components which explained 76.89% of the total variance. Only attributes that were significant ($p \leq 0.05$) in showing sensory differences among the crisps types for each assessor (Table 4.1) were used in MFA and AHC analyses. F1 explained 33.84 % of the inertia. It separated Impilo, Bophelo and 199062.1 crisps from commercial sweet potato crisps. Carrot, butternut and pumpkin crisps appear to cluster in between these two extremes. F2 explained an additional 31.48 % of the inertia. It contrasted pumpkin, butternut and carrot crisps to both commercial sweet potato crisp samples and 199062.1 crisps. F3 explained a further 11.57 % of the inertia. It separated 199062.1 crisps from Bophelo and Impilo crisps.

In Figure 4.4 the global space configuration for sensory variables of the seven crisp types is displayed. It is reflected in the F1 versus F2 consensus space (Fig 4.4a) that F1 was defined by textural and flavour attributes. It separated crunchy and crispy crisps on the left (commercial sweet potato crisps) from crisps with more intense burnt taste, darker yellow colour and stale flavour on the right (OFSP crisps). In the F2 dimension commercial sweet potato duplicate samples A, B and OFSP crisps were positively related, and this appears to be explained by their lightness of colour as opposed to pumpkin, carrot and butternut crisps. F3 (Fig 4.4b) weakly separated for texture in terms of crispness and crunchiness at the bottom (Impilo and Bophelo crisps) against rubbery, spongy, oily and chewy at the top (199062.1 crisps).

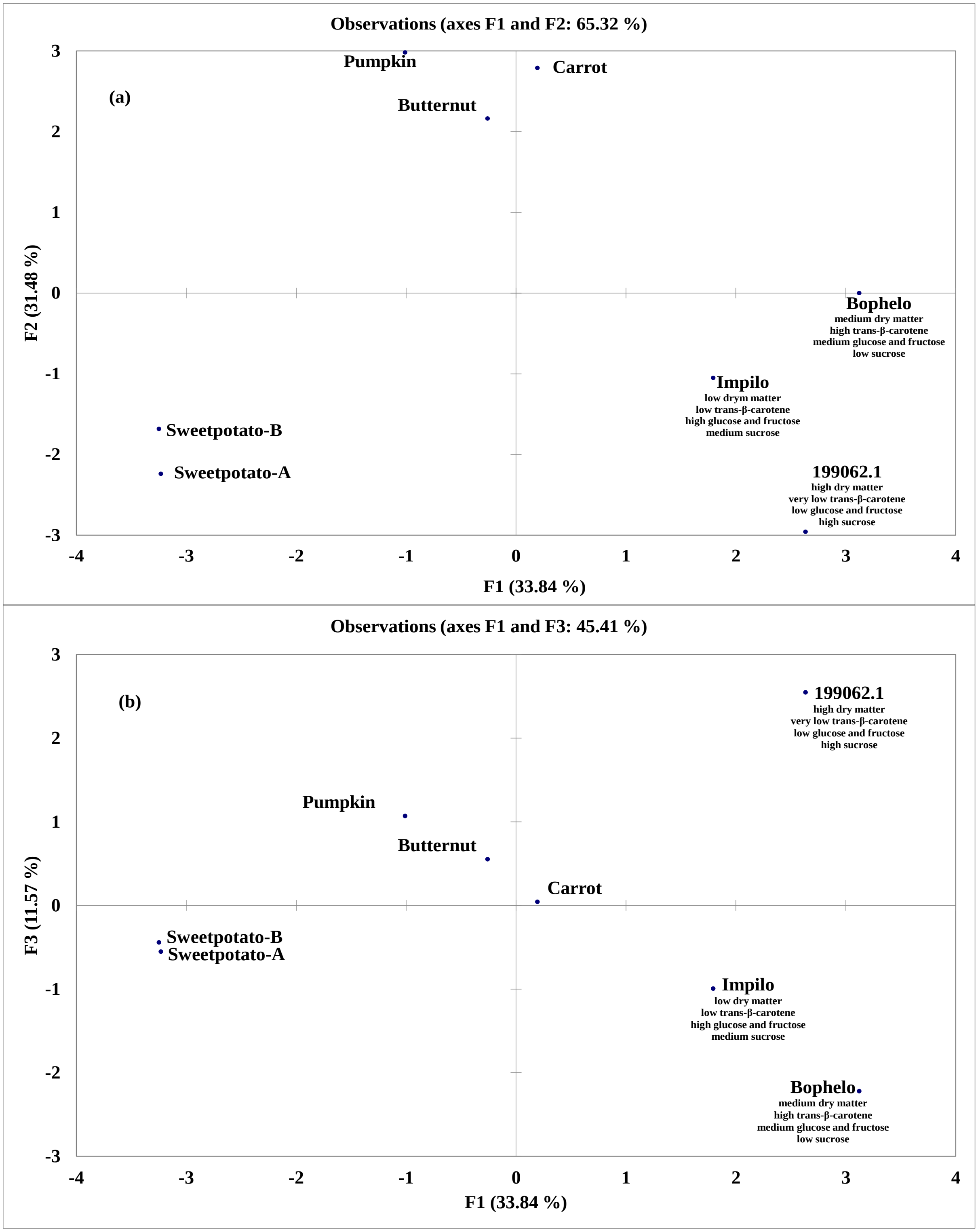


Figure 4.3 *MFA consensus space for the seven crisp types evaluated by FP method.*

(a) F1 and F2 dimensions. (b) F1 and F3 dimensions. Commercial sweet potato crisp was duplicated (A and B) as a control. Physico-chemical properties for the OFSP tubers are shown.

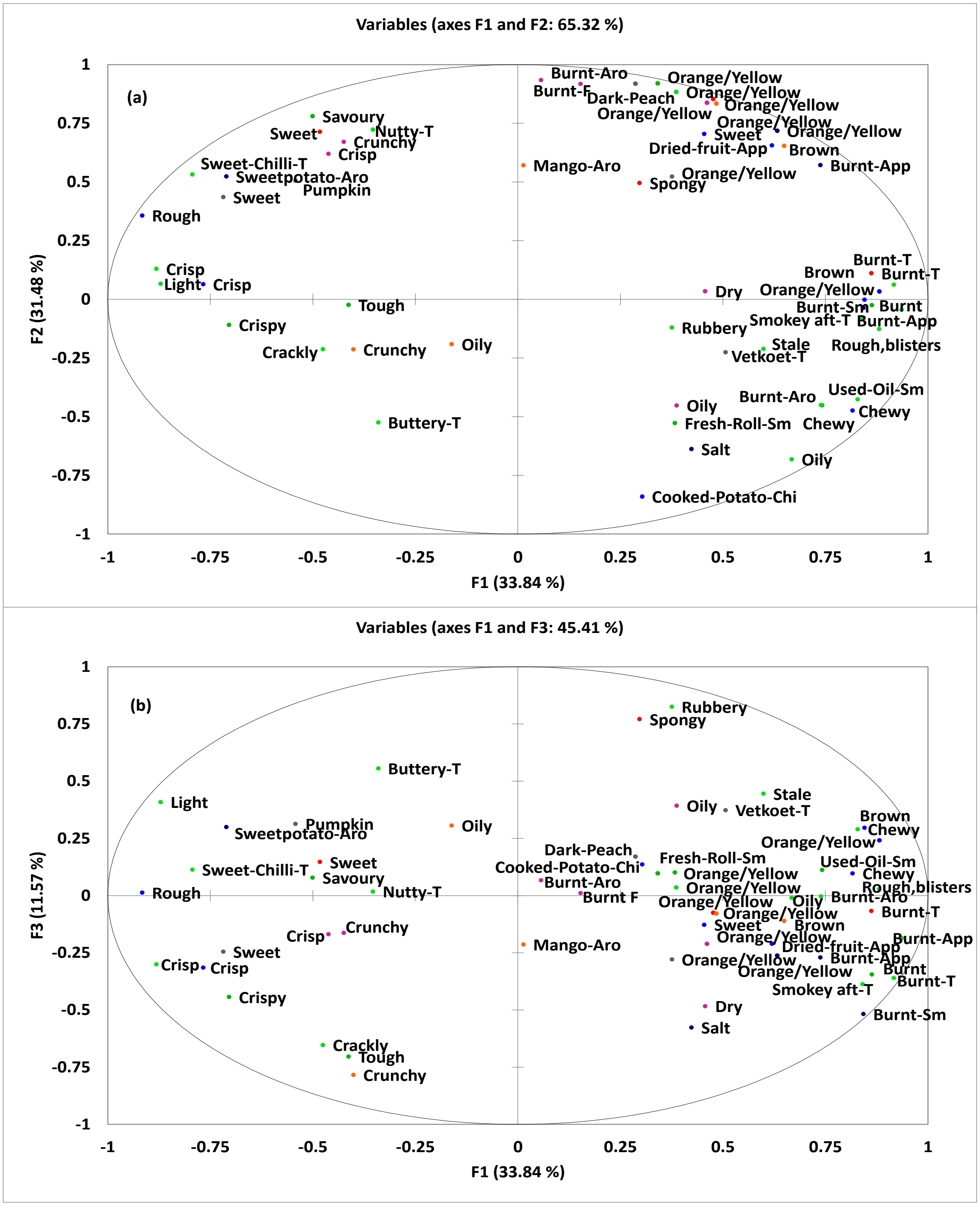


Figure 4.4 *MFA variables correlation plots for seven different crisps evaluated by FP method.*

(a) F1 versus F2 principal components. (b) F1 versus F3 principal components. T: taste; Sm: smell; App: appearance; Aro: aroma; Chi: chips and F: flavour.

Figure 4.5 shows a plot of the seven crisp types based on collective sensory attributes from all assessors. The dendrogram indicates three clusters: cluster 1 (OFSP crisps), cluster 2 (sweet potato A and sweet potato B crisps) and cluster 3 (butternut, pumpkin and carrot crisps). This revealed that OFSP crisps were distinct from commercial crisp sample types (clusters 2 and 3) in their sensory quality.

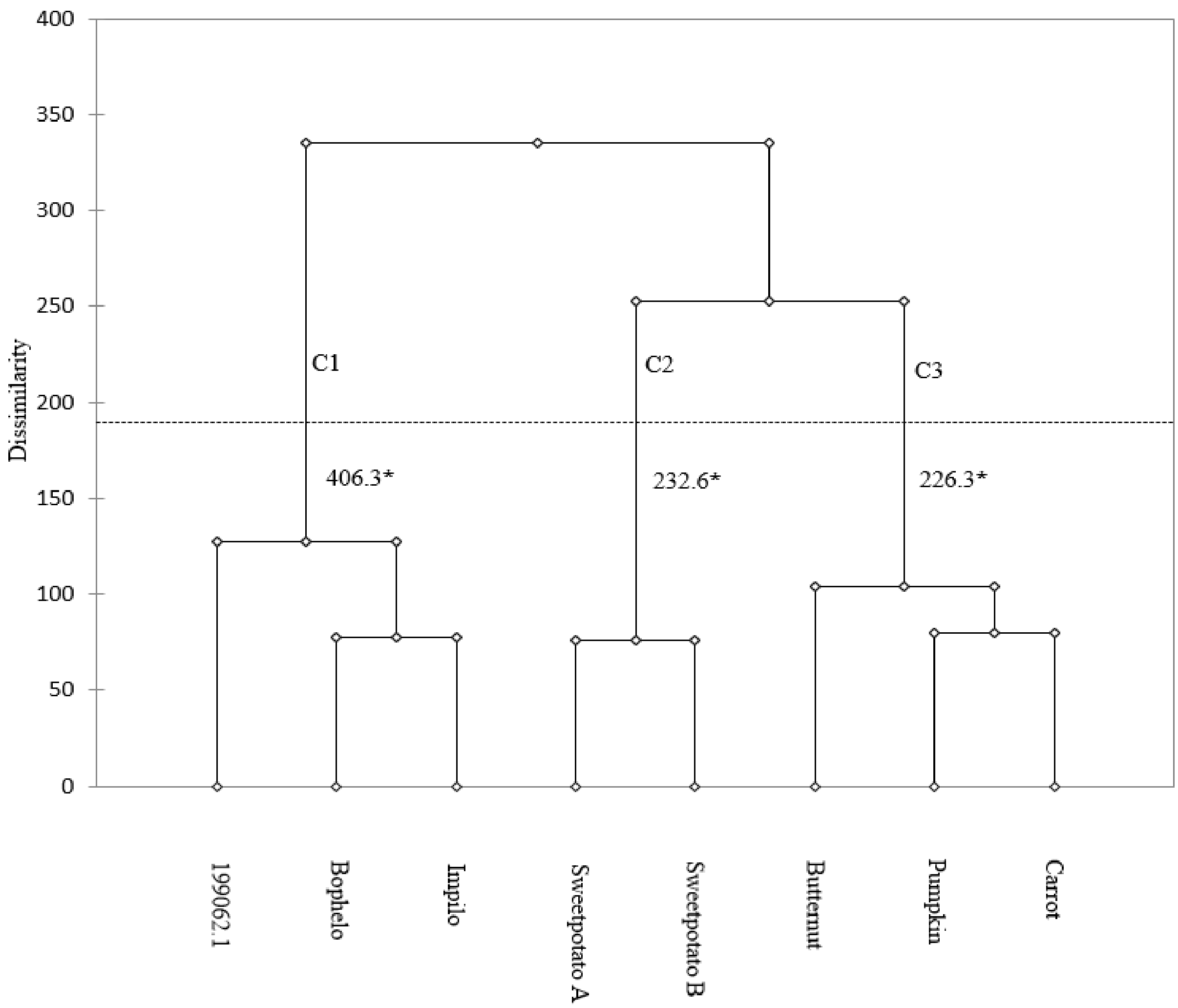


Figure 4.5 *Agglomerative hierarchical clustering (AHC) of crisps by Wards' dissimilarity method using sensory data from flash profiling.*

**Values indicate within-class variance.*

The relationships in the "sensory fingerprints" of crisps from the three OFSP cultivars can be clearly portrayed when their maps are considered exclusively (Figure 4.6).

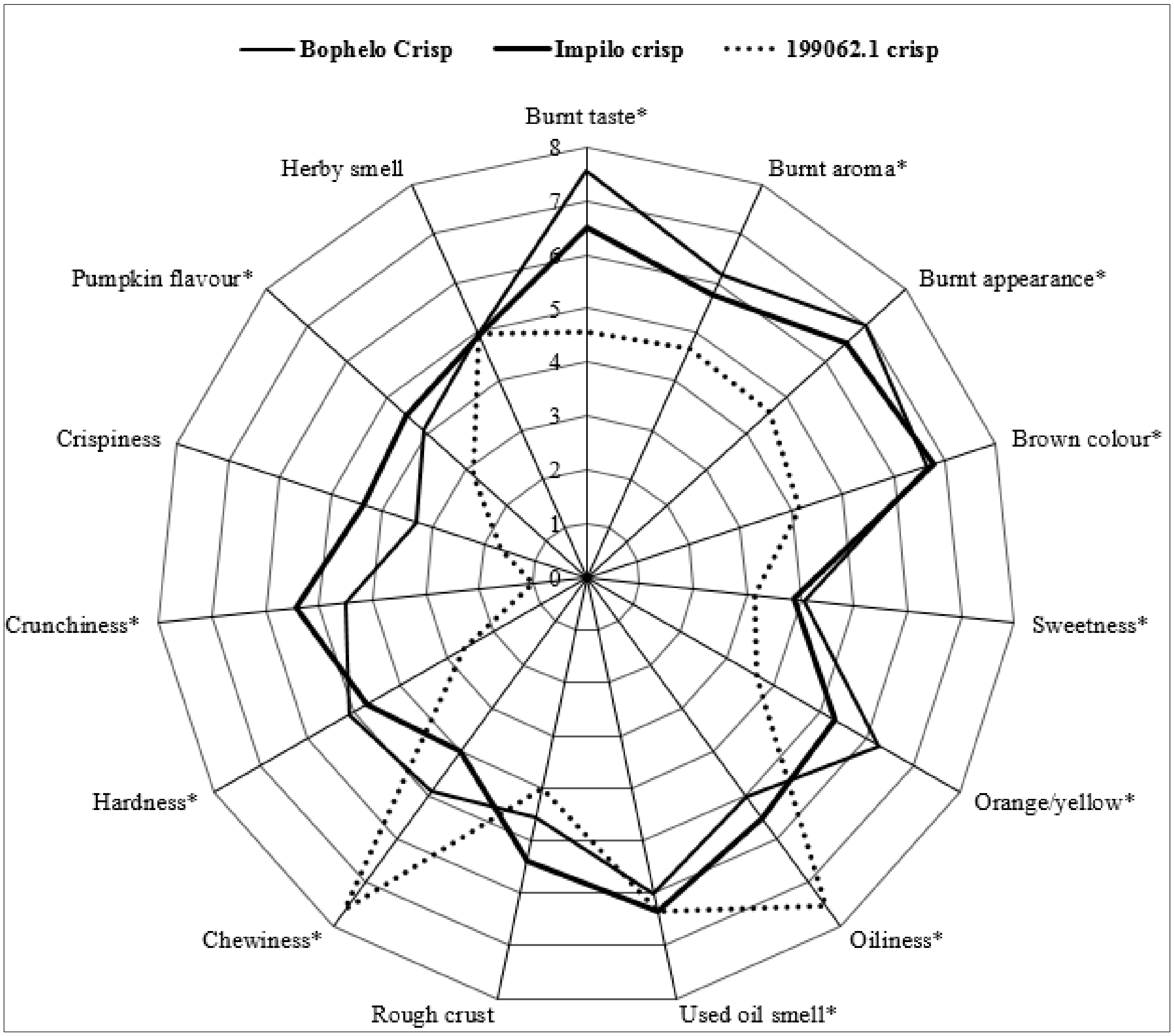


Figure 4.6 *A spider plot showing descriptive sensory profiles of crisps produced from three types of OFSP roots varying in physico-chemical properties.*

**Attributes were significant in discriminating among the crisp types ($p \leq 0.05$).*

Browning characteristics (brown colour, burnt aroma, burnt taste and burnt appearance) of crisps were more pronounced in crisps from Impilo and Bophelo roots than 199062.1 crisps. Bophelo crisps were the most orange and 199062.1 crisps the least. Crisps processed from 199062.1 roots were the most oily and chewy, but they were least in sweetness, hardness, crunchiness and pumpkin flavour compared to crisps from Bophelo and Impilo roots.

4.8. Discussion

The sensory quality of OFSP crisps processed from roots varying in physico-chemical properties were investigated. Browning characteristics (brown colour, burnt flavour and appearance) observed in OFSP crisps were previously reported for deep-fried sweet potato crisps (Nunes and Moreira, 2009; Ravli et al., 2013). These sensory quality attributes appear to be directly related to the glucose content of the raw OFSP roots and were more pronounced in Impilo and Bophelo crisps compared to 199062.1 crisps.

Roots of 199062.1 cultivar had the lowest glucose content and produced the least brown crisps, while crisps from Impilo roots were the most brown consistent with its highest glucose content in raw state (Chapter 3). Exposure to high frying temperatures promotes the occurrence of non-enzymatic browning reactions, which result in fission products and Strecker aldehydes responsible for the dark colour, desirable flavour and sometimes off-flavours (Dueik et al., 2013). Glucose reacts with amino acids and certain amino groups on proteins in OFSP slices in a Maillard reaction, producing dark substances (melanoidins, furfural polymers) responsible for the overcooked colour and burnt flavours (Dueik and Bouchon, 2011a; Dueik and Bouchon, 2011b). Heating reducing sugars also cause caramelization which adds to browning and flavour development (Arabhosseini et al., 2011). The lightness of crisps from 199062.1 roots was expected as was the more browned appearance for crisps from Impilo and Bophelo roots because of their differences in the glucose content. The rate and extent of both the Maillard reaction and caramelization increase with glucose concentration.

The results on colour development in the OFSP crisps during deep-fat frying were consistent with findings by Abong et al (2011b) using potato tubers, that crisp darkening was dependent on glucose content of tubers. Sensory scores on orange/yellow colour for crisps from the three types of OFSP tubers were in tandem with instrumental determinations for β-carotene as the main colour pigment of OFSP, and agree with Burri (2011) that the intensity of the orange/yellow colour is directly related to the amount of β-carotene in the sample (Chapter 3). However, the overcooked appearance (Bophelo and Impilo crisps) also indicated oxidative thermal destruction of carotenoids under aggressive frying conditions (Dueik et al., 2013), as supported by the significantly lower β-carotene content values for deep-fried crisps compared to raw slices

(Chapter 3). This diminishes the appetizing orange/yellow colour leading to a decline in sensory quality. Food colour is the first quality parameter evaluated by consumers and is critical for product acceptance before it even enters the mouth (Santis et al, 2007). Consumers tend to associate an appropriate colour with flavour, safety, shelf-life, nutrition and satisfaction (Pedreschi et al, 2012).

Although some consumers like potato crisps with an overall brownish colour, most consumers appear to prefer crisps having a yellowish appearance, and nearly all consumers do not like crisps with dark brown, burned areas (Matz, 1993). However, consumer preferences of OFSP crisp colour is yet to be fully studied. In a previous study involving boiled OFSP roots, orange colour was identified as the most important carotenoid content-related trait visible to consumers which can influence marketing and promotion (Tomlins et al., 2012). In the present study orange colour was an important attribute because all assessors used it to discriminate between crisp types. In potato crisp processing, quality control is mainly linked to sensory perception of colour, flavour and texture (Troncoso et al., 2009), yet appearance defects occur even in the best managed plants due to the inherent variability of raw materials and the impossibility of unifying the frying conditions for all the crisps processed each day. Consequently, industry employs strict quality control checks and grading to make crisps more acceptable to consumers (Mazt, 1993).

The oily perception of crisps from 199062.1 roots was unexpected, considering its highest dry matter content tubers and its lowest final oil content crisps when compared with Bophelo and Impilo roots and crisps (Chapter 3). This may suggest that oiliness could be a complex perception that is influenced not only by the final oil content of crisps, but also by the composite microstructure of the food after frying. Fried product microstructure could influence how the oil is distributed in the crisp, depending on the physical and chemical properties of the root. Further studies with advanced techniques e.g. nuclear resonance imaging, electron scanning microscopy, confocal microscopy may be considered to understand potential links between the physico-chemistry of roots and structural changes occurring during deep-fat frying, which seem to affect the precise location of oil in the crisp and consequently sensory properties such as oiliness.

The lower sweetness for crisps from 199062.1 roots compared to crisps from Bophelo and Impilo roots was consistent with the variation in fructose content among roots of the three cultivars (Chapter 3). Of the sugars glucose, fructose and sucrose, fructose mainly influences sweetness because it is the sweetest of the three (Lab Cat, 2009).

Projection maps and R_V co-efficient values reflected strong congruency between individual assessors and the global panel. Values higher than $R_V = 0.67$ are considered strongly acceptable and consensual (Nestrud and Lawless, 2008). However lower R_V values between some assessors could be partially resulting from within-sample variability in sensory properties of crisps due to the anisotropic nature of the plant raw material (Miranda and Aguilera, 2006) and from the fact that without training, panellists often have very different ideas or concepts of what they mean by a particular term (Revell, 2008). This in part explains the significant panel × sample interactions observed for the orange/yellow colour, rough crust, burnt taste/flavour and burnt smell.

4.9 Conclusions

Descriptive sensory profiling of deep-fat fried crisps from three types of OFSP roots varying in physico-chemical properties was explored. OFSP crisps from Bophelo and Impilo roots are configurationally more similar to each other compared to crisps from 199062.1 roots in many sensory attributes especially orange colour and sweetness. The colour, appearance and flavour of OFSP crisps is influenced by the sugar type and content, with higher glucose and fructose content for Impilo roots resulting in darker and sweeter flavoured crisps respectively, compared to crisps from Bophelo and 199062.1 roots. The higher β-carotene content of Bophelo roots produce crisps with higher intensity in orange colour, while the least intense orange colour was in crisps from 199062.1 roots. Crispiness is similar for the three types despite differing dry matter contents of the roots. Not as expected, the high dry matter content 199062.1 roots yielded oily crisps that were less hard and less crunchy compared to crisps from medium dry matter (Bophelo) and lower dry matter (Impilo) content roots. The kind of association between the absorbed oil and the crisp matrix seem to significantly influence texture. The use of roots varying in physico-chemical properties for crisp processing by deep-fat frying lead to significant variations in sensory profiles of OFSP crisps. Further studies to determine consumer preferences are recommended in order to accurately predict the market potential of OFSP crisps.

Chapter 5: General Discussion

The chapter discusses the findings of the study of OFSP storage root characteristics, and strengths and limitations of methods applied in the study and suggestions for improvement. Figure 5.1 outlines the main findings of the research.

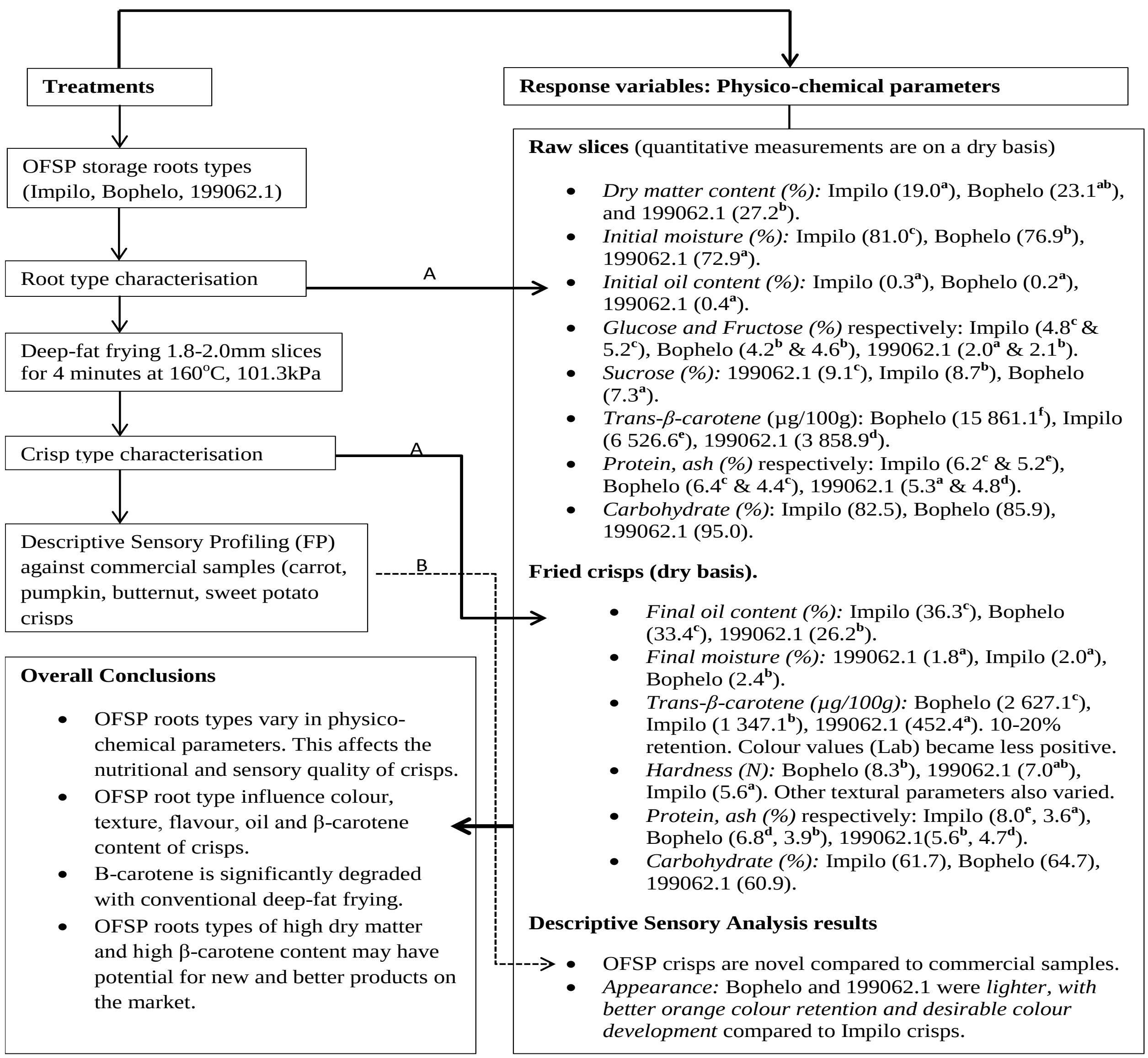


Figure 5.1 *Summary: The influence of OFSP root type on sensory and nutritional quality of deep-fat fried crisps.*

Arrows A and B indicate physico-chemical and sensory analyses respectively.

5.1 OFSP roots physico-chemistry

The OFSP root structure and chemical composition is influenced by the genotype and environmental growth conditions (Laurie, 2010). Night air temperatures below 15°C suppress tuber formation, soil temperatures between 20 and 30°C promote root formation and growth while those at 15°C favours fibrous root formation (Truong et al., 2010). The roots used in this study were obviously affected by these complex influences. High dry matter content storage roots are associated with good eating quality in crisps, long shelf life and processing efficiency (Lebot, 2010). In this study, high dry matter content roots resulted in low oil content crisps, but the crisps were unexpectedly oily relative to those from lower dry matter tubers. This could suggest differences in the distribution patterns of oil within the crisps from different root types.

Regarding colour development, the inclusion of amino acid type and content in explaining the chemistry of fried crisp colour may give a better prediction, because both glucose and asparagine are involved in the reaction that leads to colour development as suggested by Abong (2011). Bophelo, Impilo and 199062.1 roots should be studied over different environmental conditions and several seasons for better understanding of the stability of their physico-chemical variables and hence processing suitability. This is because in sweet potato the genotype (G) x environment (E) interactions (G × E) are so high (Lebot, 2010). Drought, for example, may affect sink-source relationship by exposing the ability of a genotype to translocate reserves to the sink (Kivuvu et al., 2014). While extensive experimentation may be necessary, significant human and financial resources involved in such studies may be restrictive.

5.2 Oil content analysis review

Although fat content determination is a common analysis in foodstuffs laboratories, the extraction and analysis is not straightforward due to difficulty in selecting an appropriate method (Eller and King, 1996). The Soxtec™ method was used in this study without a hydrolysis step. This is often criticised because of the potential to under-extract bound lipids. In foods that have undergone some processing, fat is bound to proteins and carbohydrates. Boiling a sample with hydrochloric acid is thought to be necessary to “free” the fat by breaking inter-molecular bonds and disrupting plant cell walls to make fat available for solvent extraction. Acid hydrolysis however may lead to high fat (gravimetric) values due to the extraction of sugar or sugar by-products.

The Soxtec™ Randall modification of fat analysis is an accelerated technique typically requiring only 20-25 % of the time needed for traditional Soxhlet extraction (Anderson, 2004). Pre-drying was done to remove water from the sample which would decrease solvent extraction efficiency resulting in low fat recoveries (AOAC, 2012). The extraction efficiency of Soxtec™ is influenced by the specific solvent used (Anderson, 2004). Petroleum ether does not extract starches, protein, or water (Carpenter et al., 1993), which justifies its choice in the present study. However, its limitation is that recycling during the Soxtec™ extraction may change its properties through loss of its more volatile components, causing a drift in fat results. Hence diethyl ether is sometimes preferred, although it is known to have the serious limitation of absorbing water and its tendency to form peroxides (AOAC, 2012). Consequently, many laboratories insist on using petroleum ether (Anderson, 2004).

5.3 Trans-β-carotene content analysis review

It is often difficult to select an appropriate carotenoid analysis protocol for standardization because of the reactive nature of carotenoids in different foods. None the less, the chosen method should extract most of carotenoids from the food matrix without compromising their properties. The method used (Van Jaarsveld *et al.*, 2006; Nzamwita, 2012) was reasonably reliable in the extraction and quantification of OFSP carotenoids, and gave fine chromatographic resolution with no peak broadening.

Peak broadening in fatty samples is thought to result from chromatographic interference of the excessive oil, leading to poor separation of *cis*- and *trans*-β-carotene (Howe and Tanumihardjo, 2006). Better resolution resulted from using the auto-sampler temperature of 25 ^{o}C which improved sample viscosity and prevented partitioning in vials. Partitioning causes apparently high extraction efficiencies and quantification errors (Rodriguez-Amaya and Kimura, 2004). Although saponification of samples is recommended to eliminate fat interference with β-carotene determination (Xu et al, 2012), this was not done because some β-carotene would be lost with the fat leading to underestimation upon quantification.

To minimize carotenoid isomerization and degradation during analysis, homogenized freeze-dried OFSP samples were vacuum-sealed to exclude oxygen, stored in the dark at -20 ^{o}C to control photo-degradation of trans-β-carotenoid prior to analysis. During preparation, BHT was added as an antioxidant to the extraction solvent and the mobile phase. Extraction was performed under subdued light using aluminum foil wrapped flasks to protect trans-β-carotene from light-induced *trans-cis* isomerization. Rotary evaporation was done at 35 ^{o}C to minimize destruction of β-carotene at higher temperature. Analytical glassware was thoroughly cleaned with extraction solvent (acetone) before use to eliminate potential residues of acids or bases. These procedures gave satisfactory carotenoid quantification results in the OFSP samples.

5.4 Sensory analysis review

FP is one of the new sensory profiling methods developed to obtain sensory information about products. It is a less time-consuming, more cost-effective method compared to quantitative descriptive analysis due to absence of a training phase (The Society of Sensory Professionals, 2014). FP allows diversity of points of view among assessors (Valentin et al., 2012), providing a product map in a very short time space since the steps of product familiarization, attribute generation and ranking are combined (Chollet et al., 2011). This technique was applied in this study as it was the most suited to the limited samples available.

However, FP has often been criticised of low repeatability and low discriminant ability amongst assessors due to the absence of training (Varela and Ares, 2012). Samples were compared simultaneously to enhance product discrimination as proposed by Delarue & Sieffermann, (2004). There is often a challenge in the interpretation of discriminant terms because of their diversity and lack of consensus on meanings (Chollet et al., 2011). This was particularly so for the terms “light” (which could mean colour or texture) and “burnt” (which could mean aroma, taste or appearance). None the less, in spite of these challenges it is important to make the best of any method chosen and FP was able to meet the objectives of the study.

5.5 Statistical analysis review

MFA is one of the few techniques adapted for FP data (Naes et al., 2010). However, the potential statistical limitations of MFA analysis include loss of variance in the descriptions and the samples through formation of the compromise space. As Revell *et al* (2008) noted with GPA, variance may also be lost during data normalization of each table upon scaling and rotation, followed by averaging of each panelist's space, and from generation of the global PCA. None the less, a straightforward analysis by merging all variables would be dominated with the strongest structure, or by variables with the largest variance and hence balancing the influences of these sets was and is an absolute requirement.

Chapter 6 Conclusions and Recommendations

OFSP root type affects the nutritional and sensory quality of crisps. Agro-processors are encouraged to use sufficient insight in selecting cultivars with roots that produce acceptably low oil content, nutritious crisps of good sensory quality. Although oiliness is often linked to high oil content in crisps, it was unique that OFSP cultivar 199062.1 crisps were perceived as the oiliest in spite of them having the lowest measured oil content. This may be explained by the distribution patterns of oil in the food microstructure, suggesting the potential for different OFSP roots types to follow non-uniform moisture loss and oil uptake mechanisms.

Roots from Bophelo and 199062.1 cultivars gave crisps with better orange/yellow colour retention and appearance. Roots from 199062.1 cultivar can be recommended for high crisp yield, cost-efficient processing to produce healthier low-oil crisps (≈ 26 %), resulting from its high dry matter content. Although Impilo retains trans-β-carotene better than cultivar 199062.1, it is more prone to higher oil content, Maillard darkening and caramelization because of the high sugar content. This may compromise its appearance and acceptability rating. OFSPs, especially processed through methods less destructive to nutrients and natural pigments than conventional deep-frying (e.g. vacuum frying; vacuum-belt drying), may yield high quality crisps and their utilization for crisping should be promoted.

OFSP storage root type is a critical factor in crisping because of the attractive colours and good flavors of high β-carotene tubers with potential to influence consumer preference. Flash Profiling revealed that Bophelo and Impilo were more similar and distinct from 199062.1 crisps, suggesting that appearance (orange/yellow colour due to β-carotene content) was more relevant. OFSP roots with lower reducing sugars, high dry matter and high β-carotene content are preferable for crisping to obtain a desirable colour due to a lower extent of Maillard browning. Therefore, the breeding of cultivars improved in these physico-chemical parameters for desirable sensory effects and good nutrition is encouraged.

OFSP can be recommended for crisping as a way of incorporating carotenoids in diet, yet of much concern for further studies is to determine the bioavailability of *all-trans*-β-carotene from these cultivars when consumed, especially Bophelo with significantly higher all-trans-β-carotene content among the roots studied. Carotenoids could have important roles in human health as anti-oxidants and more insight into this potential role is required. Further texture profile studies on OFSP crisp are needed for relating cultivars to processing specifications. Consumer taste, preference and acceptance are critical in determining the degree of suitability of OFSP types for different markets, highlighting the need for future research.

It is crucial that subsequent research focuses on elucidating the origin and nature of OFSP crisps flavour character notes like pumpkin flavours reported in this study and previously (Leighton, 2007, Laurie et al., 2012) with a view to optimize their occurrence and controlled release from crisps during eating. Flavour is a key element of food acceptability. A more complete understanding of the flavour kinetics in OFSP based products like crisps can help in meeting consumers' need for flavour-rich foods.

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