Sensory quality of deep fat fried potato chips manufactured from potatoes with different physico-chemical characteristics

By

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DECLARATION

I declare that the dissertation herewith submitted for the degree of MSc Food Science at the University of Pretoria, has not previously been submitted by me for a degree at any other university or institution of higher education.

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DEDICATION

Dedicated to my family.

When nothing seems to help, I go and look at a stone-cutter hammering away at his rock perhaps a hundred times without as much as a crack showing in it. Yet at the hundred and first blow it would split in two, and I know it was not that blow that did it, but all that had gone before together. -Jacob A. Riis, (1849-1914)

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A South African potato chip manufacturer for funding this study and the personnel, for their assistance in sample acquisition within the processing line.

ABSTRACT

Sensory quality of deep fat fried potato chips manufactured from potatoes with different physico-chemical characteristics

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Department: Food Science

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Studies generally agree on the critical influence of physico-chemical characteristics of raw potatoes on the physico-chemical and sensory characteristics of potato chips. However, the actual magnitude of differences in sensory quality and consumer acceptance of potato chips as a result of differences in the physico-chemical characteristics of raw potatoes are scarcely reported in most studies. This research was conducted to determine the effect of different physico-chemical characteristics of potato samples on the sensory quality and acceptance of potato chips.

The potato samples which represented typical variations in physico-chemical characteristics that a potato chip manufacturer experiences were sourced over a six month period. The samples comprised of four potato varieties (A, B, C, D) sourced from five regions (V, W, X, Y, Z). The samples were coded *AV*, BW_1, *BW2*, *CW, CX, DY, DW* and *DZ*. *BW1* and *BW2* were of the same variety and grown in the same region but harvested at different time periods. The sourcing of potatoes and potato chips were done at the manufacturer's processing line during regular production. The potatoes were analyzed for physico-chemical characteristics generally reported to influence potato chip sensory quality, i.e. specific gravity (solids contents), starch content and reducing sugars content. After processing, the physico-chemical characteristics i.e. moisture content, colour and oil content of the respective unflavoured potato chip samples were analysed. The sensory qualities of both

unflavoured and flavoured (sour cream and onion) potato chips of the respective potato samples were also determined.

There were significant differences ($p<0.05$) in the specific gravity/solids content of the potato samples. The specific gravity and solids content ranged from 1.073 to 1.098g/cm^3 and 19.2 to 24.9% respectively. Reducing sugars were not detected in any of the potato samples at a minimum detection level of 0.05 %. The potato chip samples differed significantly ($p<0.05$) in moisture content, oil content and colour (a^* and b^* values, chroma, hue angle) with ranges of 1.2 to 1.9 % (moisture), 33.1 to 40.8 % d.b (oil content), 0.39 to 3.69 (a^*), 15.88 to 21.26 (b^*), 15.93 to 21.37 (chroma) and 79.92 to 88.96 ^{o} (hue angle).

Descriptive sensory evaluation showed that 6 and 8 of the attributes identified in the unflavoured and flavoured potato chip samples, respectively, differed significantly ($p<0.05$). Consumer sensory evaluation indicated that there was no clear preference of one chip sample over the others despite of differences observed through descriptive sensory analysis and physico-chemical characteristics. All the chip samples were generally liked.

To the manufacturer this research could be regarded as of a quality control nature since the potato chip samples used in this study were of chipping varieties actually used by the manufacturer. The value of this research to the chip manufacturer was the fact that despite of slight differences in the physico-chemical characteristics (specific gravity/solids content and starch content) of potato samples, potato chips of acceptable sensory quality to the consumers were produced.

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CHAPTER 1: INTRODUCTION

The potato tuber (*Solanum tuberosum* L.) is an enlarged portion of an underground stem or stolon of the potato plant (Miranda & Aguilera, 2006) and generally regarded as a storage organ. The potato is the world's root and tuber crop grown in the greatest quantities (FAO, 1999). It is one of the world's major agricultural crops with worldwide production in excess of 300 million tons/year, a figure exceeded only by wheat, maize and rice (Pedreschi, Moyano, Kaack & Granby, 2005). Potatoes are the single most important vegetable product in South Africa with a total production of 1,655,000 tons per annum (Anonymous, 2003). Potato chips (crisps) represent 50.2% of the total processed potato products in South Africa, and continue to hold the largest share, in both volume and value terms, of the sweet and savoury snacks sector (Ntloedibe, 2006).

Potato chips are described as thin potato slices (thickness less than 2 mm) that are dehydrated by deep fat frying to a moisture content of 2% or less (Baumann & Escher, 1995). Frying in hot oil at temperatures between 160 and 180 °C is characterized by very high drying rates that ensure favourable structural and textural properties (Baumann & Escher, 1995). This is coupled with colour and flavour formation as a result of non-enzymatic browning that takes place at these high temperatures (Pedreschi *et al*., 2005; Krokida, Oreopoulou, Maroulis & Marinos-Kouris, 2001a). The attainment of uniform optimal potato chip quality depends primarily on premium quality potatoes and the control of the various processing operations during manufacture (Bennett, 2001). The desirability of the potato chip is based on its "all-crust" structure (crispy texture), light yellow colour and desirable 'potato chip' flavour.

1.1 PROBLEM STATEMENT

One of the factors affecting the quality of potato chips is the physico-chemical characteristics of the potato from which it is made. Not all potato varieties will produce high quality chips (Miranda & Aguilera, 2006; Bennett, 2001). Studies have shown significant differences in chip quality as a result of varying chemical composition of the potato tuber (Kumar, Singh & Kumar, 2004; Kita, 2002). The physical and chemical characteristics of potato tubers vary from one variety to another and within the same variety depending on the growth (e.g. soil temperature and soil moisture), harvesting and handling conditions (Sengul, Keles & Keles, 2004; Kumar *et al*., 2004). Storage of potatoes after harvest also results in changes in the chemical composition (Kumar *et al*., 2004; Blenkinsop, Copp, Yada, & Marangoni, 2002). Among these changes the reducing sugar content is of concern to the potato chip manufacturer since higher levels of reducing sugars affect the chip colour negatively. According to Blenkinsop *et al*. (2002), this effect is increased when potatoes are stored at low temperatures (< 9 ^{o}C to 10 ^{o}C) resulting in accumulation of starch breakdown products, primarily sucrose and the reducing sugars, fructose and glucose.

In spite of the magnitude of potato chips manufactured and its economic importance, potato chip manufacturers have to contend with potato tubers with varying physico-chemical characteristics which may impact on chip quality. Studies on the impact of physico-chemical characteristics of raw potatoes on the sensory quality and consumer acceptance of potato chip may not reflect practical commercial chip production. This is because studies are carried out on a laboratory scale, and may include potatoes considered not of chip processing quality leading to large variations in chip quality. Information is limited on how the variation in composition of raw potatoes as experienced practically by a chip manufacturer influences the final sensory quality and acceptance of potato chips. Therefore this study, requested by a commercial chip processor in South Africa, aims at determining the effect of different physico-chemical characteristics of potatoes on the sensory quality of potato chips as processed under the practical processing conditions within this manufacturer's processing plant.

CHAPTER 2: LITERATURE REVIEW

The sensory attributes of potato chips develop as a result of structural changes, chemical reactions, moisture loss and oil absorption in the raw potato during chip processing. Therefore, the dry matter constituents (e.g. starch, reducing sugars) of raw potatoes are of the utmost importance as the sensory quality is largely dependent on the transformations of these constituents during the frying process. The processing parameters such as slice thickness and frying conditions are also set depending on the physico-chemical characteristics of the potato to cater for slight variations among potato lots. In this literature review, the approach taken was to review the role of raw potato constituents on the sensory quality of potato chips while also highlighting how these constituents (solids content/specific gravity, starch, reducing sugars) could impact on the selection of processing parameters subsequently influencing sensory quality (Fig. 2.1).

2.1 SENSORY QUALITY OF POTATO CHIPS

Quality can be described as the requirements necessary to satisfy the needs and expectations of the consumer (Claudio, 2006). Bourne according to Moreira, Castell-Perez & Barrufet (1999) states that the four principal quality factors in foods are: (1) appearance, including colour, shape, gloss; (2) flavour including taste and odour; (3) texture; and (4) nutrition. Safety is also an important factor. Sensory quality of a food product relates directly to product quality as it is an important aspect of the total product quality as perceived by the human senses of sight, taste, smell, hearing and touch (Meilgaard, Civille & Carr, 1991). Appearance, flavour and texture refer to sensory acceptability factors because they are directly perceived by the senses (Moreira *et al.,* 1999). Bennett (2001) describes a quality chip as one having a saddle-shaped curl, light golden colour, and having no blemishes. When placed in the mouth, it is crisp, has a slight potato flavour, is properly salted or seasoned and leaves a pleasant aftertaste in the mouth (Bennett, 2001). The sensory quality of potato chips is dependent on the composition of the potatoes, the frying oil and the processing parameters during chip manufacture (Gillat, 2001).

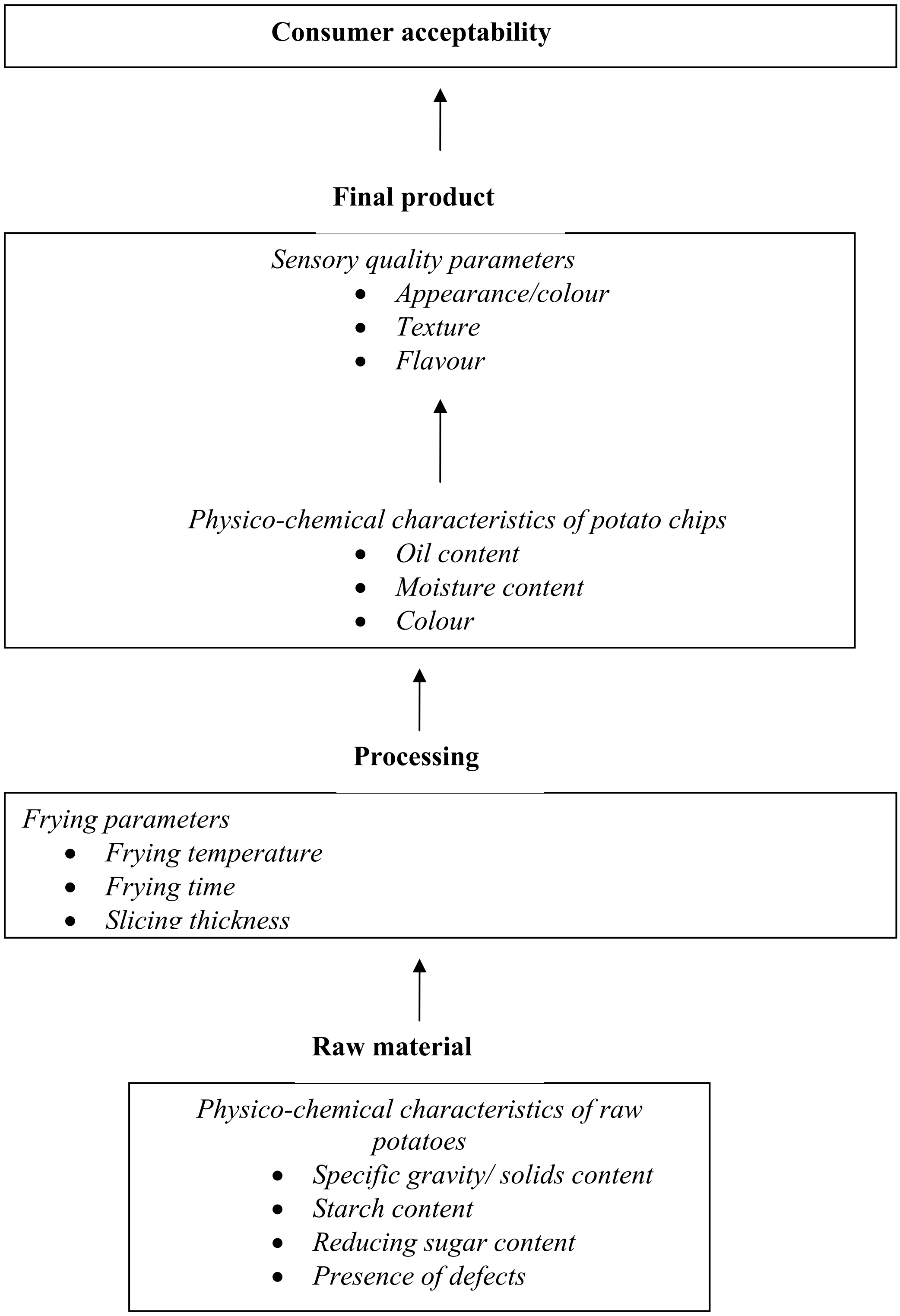

Fig. 2.1 Schematic diagram of the influence of physico-chemical characteristics of potatoes on potato chip processing parameters, potato chip characteristics and acceptability

2.1.1 COLOUR

Colour is probably the most important visual attribute in the perception of product quality among the different classes of physical properties of foods (Pedreschi, León, Mery & Moyano, 2006). Colour is an important visual appearance attribute among the major factors influencing consumer acceptability of fried products as it is the first quality parameter evaluated by consumers (Nouriana, Ramaswamya & Kushalappa, 2003; Segnini, Dejmek & Öste, 1999). Colour generally influences subjective sensory impression as it is regarded as a predictor of other quality characteristics such as flavour (Nouriana *et al*., 2003). Colour is thus critical in the acceptance of the product even before it is consumed (Pedreschi *et al*., 2005; Krokida *et al*., 2001a).

The golden yellow colour of a potato chip indicates a high quality potato chip (Moreira *et al*., 1999). Potato chips with a dark/brown colour are undesirable and unacceptable to the consumer (Blenkisop *et al*., 2002; Pritchard & Adam, 1994).

2.1.2 TEXTURE

Texture is also a key parameter in the development and acceptance of food products and an important attribute in determining consumer acceptability of fried foods (Krokida, Oreopoulou, Maroulis & Marinos-Kouris, 2001b; Miranda, Aguilera, & Beriestain, 2005). Texture can be defined as 'all the rheological and structural (geometric and surface) attributes of the product perceptible by means of mechanical, tactile and where appropriate, visual and auditory receptors (Lawless & Heymann, 1988). Szczesniak (1990) observed that it is how the food feels in the mouth on manipulation and mastication, and how it handles during transport, preparation and on the plate. In terms of consumer acceptability each food has its specific textural characteristics that are desirable and undesirable. Crispness is one of the textural characteristics that are universally liked (Szczesniak, 1990).

One of the desirable textural attributes of potato chip is often described as crispness (Kita, 2002; Segnini *et al*., 1999). In foods described to be crispy, crispness is the most important quality attribute and its absence implies poor quality and loss of consumer acceptance (Roudaut, Dacremont, Pamies, Colas & Lemeste, 2002; Szczesniak, 1990). A universal definition of crispness still needs to be developed as only moderate amount of agreement exists among the current definitions, what influences its perception and its quantification (Roudaut *et al*., 2002; Vincent, 1998). Crispness is associated with the textural experience of eating a food item which fails in a brittle manner (i.e. very suddenly and with relatively little deformation) at a low load (Vincent, 2004). Vincent (2004) observed that crisp materials could generally be described as brittle, stiff cellular materials derived either from expanded starch or from starch-containing cellular materials such as potatoes. Davies (2005) observed that due to their texture, potato chips are known as "crisps" in Britain. They are usually made brittle by structural changes resulting from transformation of potato cell contents during frying and the removal of moisture making them glassy (Vincent, 1998; Vincent, 2004). Luyten, Plijter & Van Vliet (2004) suggests that crispness is associated with the glassy state as loss of crispiness is perceived with increases in water content causing plasticization.

2.1.3 FLAVOUR

The flavour of potato chips is more complex than that of boiled, baked or mashed potatoes, since the cooking temperatures are higher, and the absorbed oil contributes to the overall flavour profile of the product (Scanlon, 2003). In fried potato products, flavour compounds are not only inherent in the raw potato but also from the frying oil, Maillard reaction products and from the interaction of Maillard reaction products with lipid oxidation products (Stier, 2000; Maga, 1994; Whitfield, 1992). The complete composition and understanding of fried potato flavour has not been fully established (Gillat, 2001). Variations in flavour exist between varieties although there is little published research (Dale & Mackay, 1994). Ereifej, Shibli, Ajlouni & Hussein, (1997) reported sensory differences in the aroma and taste of potato chips made from different cultivars that varied in levels of dry matter, sugars, amino acids and lipids.

It is generally understood that the bulk of flavour-producing compounds in raw potato are volatile (Gillat, 2001). The major classes of volatile compounds released by raw potatoes are acids, aldehydes, alcohols, amines, esters, furans, hydrocarbons, ketones, pyrazines, pyridines and thiazoles (Gillat, 2001). However, Maga (1994) suggested that potato flavour might be influenced by non-volatile compounds such as amino acids and sugars. Browning becomes very rapid at temperatures higher than 150°C and volatile flavour compounds are produced as secondary products (Miranda & Aguilera, 2006). Lisiñska (1989) reported that the desirable flavour of potato chips is limited by the high dry matter content as well as the low sugar concentration. The flavour and odour of light coloured chips are less intense than those of dark coloured chips (Lisiñska, 1989). Glycoalkaloids found in potatoes could contribute to bitter off-flavours or burning sensations at elevated concentrations (Maga, 1994).

2.1.4 ROLE OF MOISTURE AND OIL CONTENT OF CHIPS ON SENSORY QUALITY

Moisture content

During frying, the water content of the raw potato slices is reduced from about 80 % to a final moisture content in the range of 1 to 2 % (Miranda & Aguilera, 2006; Gamble, Rice & Selman, 1987). The final moisture content of the chips is critical as it not only influences the chip stability from microbial spoilage but also contributes to the final crisp texture (Miranda & Aguilera, 2006). Final moisture content of above 2% lead to a loss in crispness whereas a moisture content of less than 1 % is associated with excessive oiliness, dark colour, and scorched flavour (Mottur,1989). Potato chips of moisture levels of below 1% would mean excessive frying which leads to more oil absorption and even lead to chip burning yielding a dark colour and burnt flavour. The final moisture content is a critical factor to the quality of the potato chips because it affects the texture, which should not only be crispy immediately after frying but also during months of storage (Lisiñska, 1989).

Oil content

Potato chips have an oil content that ranges from 30% to 40% (wet basis) that gives the product the unique texture-flavour combination that makes them so desirable (Mellema, 2003; Garayo & Moreira, 2002; Stier, 2000; Baumann & Escher, 1995; Gamble *et al*., 1987). The raw potato contains only 0.1 % fat (Miranda & Aguilera, 2006); therefore, all of the oil in the finished chip is due to absorption during frying. The oil content in the potato chips needs to be optimised since not only is the frying oil costly to the processor but it also affects the texture and appearance of the potato chips (Dobarganes, Marquez-Ruiz & Velasco, 2000). The final oil content of the chips is affected by the potato physico-chemical characteristics and the processing conditions.

Mellema (2003) and Saguy & Dana (2003) observed that consumers' preference for low fat and fat-free products were driving the food industry to lower oil content in fried foods. Lisiñska (1989) reported that potato chips high in oil content appear greasy/oily while those of very low oil content are of a hard texture and lack flavour.

2.2 POTATO TUBER

The potato tuber being the main raw material in the manufacture of potato chips plays a significant role in the sensory quality of potato chips. The potato tuber is the storage organ for the nutrients manufactured during the growth cycle of the plant. A longitudinal section of the potato tuber is shown in Fig. 2.2.

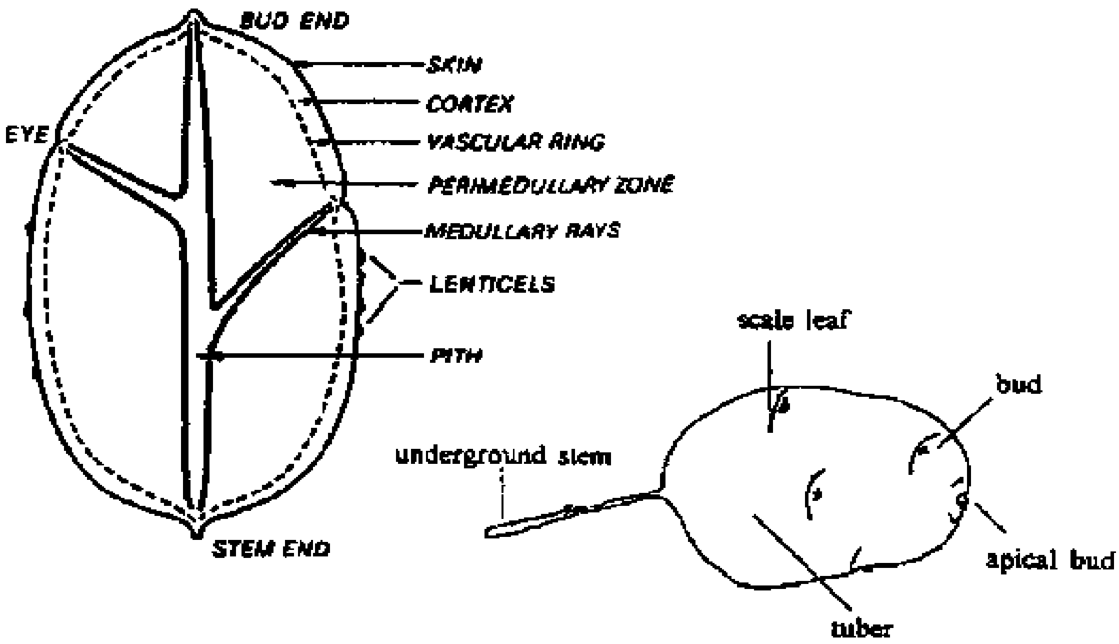

Fig. 2.2 Longitudinal section of a potato tuber (Van Es & Hartmans, 1981)

Potato varieties vary in appearance, season of maturity, internal composition, yield and tuber quality, pest and disease resistance and adaptability (Stark, Olsen, Kleinkopf & Love, 2005). Not all varieties of potatoes will produce high quality chips thus the challenge to the potato processor is to obtain potatoes with good characteristics. The desirable characteristics for potato chip manufacture are: uniform size and shape, shallow eyes, firm, smooth surfaced potatoes with few external and internal defects (Stark *et al*., 2005) and of the proper starch and sugar content (Kumar *et al*. 2004).

The composition of the tuber is of particular interest and concern to the chip manufacturer as it ultimately affects the yield and quality of the chips made thereof (Stark *et al*., 2005; Kaaber, Bråthen, Martinsen & Shomer, 2001). The potato characteristics are dependent to a large extent on the variety and conditions during growth and harvesting (Kumar *et al*., 2004; Kaaber *et al*. 2001). Among the potato varieties available worldwide there are specific varieties which have been identified for chipping purposes and through plant breeding. Specific cultivars with the desired composition have also been developed (Hassanpanah, Shahriari & Khorshidi, 2006; Dale & Bradshaw, 2003). These potato varieties vary regionally as the prevailing environmental factors that affect tuber composition such as temperature, moisture, light, soil type and nutrients differ (Kumar *et al*. 2004). The cultivars most commonly used for chip manufacture in South Africa are Hertha, Pimpernel, Lady Rosetta, Fiana, Crebella and Ernstestoltz (Anonymous, 2005). Potato characteristics are different among varieties but tubers of the same variety or of the same plant can also vary in specific components.

2.3 POTATO CHEMICAL COMPOSITION

The choice of potato as raw material is critical as the desired chemical and physical characteristics desirable for chipping must be present (Bennett, 2001). Potato varieties destined for chip production should generally be of a high dry matter content, high starch content, and have a low susceptibility to accumulation of sugars during storage (Hassanpanah *et al*., 2006; Stark *et al*., 2005). A summary of the chemical composition of potato tubers is given in Table 2.1.

Table 2.1 Chemical composition of potato tubers (Leszcyñski, 1989)

Substance	Content (%)
	Range
Dry matter	13.1 - 36.8
Starch	8.0 - 29.4
Reducing sugars	0.0 - 5.0
Total sugar	0.05 - 8.00
Crude fibre	0.17 - 3.48
Total nitrogen	0.11- 0.74
Crude protein (total nitrogen ×6.25)	0.69 - 4.63
Lipids	0.02 – 0.2
Ash	0.44 - 1.87
Organic acids	0.4 - 1.0
Glycoalkaloids[a]	0.2 - 41
Ascorbic acid & dehydroascorbic acid[a]	1 - 54

[a] in mg/100g.

2.3.1 SPECIFIC GRAVITY AND DRY MATTER

An important characteristic of potatoes for chip manufacture is a high dry matter content, which is measured as specific gravity or percent solids. The dry matter content of potato tubers determines suitability for chip processing purposes by influencing the chip yield, texture, flavour, final oil content and process efficiency (Kumlay, Kaya, Olgun, Dursun, Pehluvan & Dizikisa, 2002; Kaaber *et al*., 2001). The dry matter/specific gravity variation in potato varieties is heritable and varies with location, year and growing conditions (Stark *et al*., 2005; Kumlay *et al*., 2002). The specific gravity of potatoes has been shown to differ among different varieties grown under the same conditions and also within varieties when grown under different conditions (Love & Pavek, 1991). Love & Pavek (1991) have gone a step further demonstrating variations within a field and even among tubers growing on the same plant.

Specific gravity is the weight per volume of a substance (Pavlista, 1997).Water is given a value of 1.000 i.e. one gram of water occupies one millilitre of volume (Pavlista, 1997). Therefore there is an increase in specific gravity with a decrease in the water content of potatoes. The terms tuber dry matter content, tuber solids content, and tuber specific gravity are used interchangeably when related to tuber processing quality (Stark *et al*., 2005; Baumann & Escher, 1995). This is due to high positive correlations among them (Kaaber *et al*., 2001; Wannamaker, Collins & Wolters, 1992).

The choice of specific gravity determination as a practical measure for predicting frying qualities of potatoes is based on its rapid test procedure and is used as a basis for the determination of dry matter content in the potato processing industry (Kaaber *et al*., 2001; Wannamaker *et al*., 1992; Jaswal, 1991). The dry matter content and specific gravity reflect the amount of starch present and are used as crude indicators of the processing quality (Miranda & Aguilera, 2006). The total solids of potatoes destined for chip manufacture should be in the range of 20% to 22%, which equates to specific gravities of 1.08 to 1.09, respectively (Adams, 2004).

The dry matter content and its constituents such as starch and reducing sugars influences the final sensory characteristics of potato chips. Therefore tuber specific gravity influences the sensory quality characteristics of potato chips. There is a strong link between texture of potato chips and dry matter content of the potatoes (Lisiñska, 1989; Faulks & Griffiths, 1983). Potato chips from potatoes of a high dry matter content (above 25%) can exhibit hard textures, whereas those of a low dry matter contain much oil, are greasy and sticky (Lisiñska, 1989).

Potatoes of higher solids contents/specific gravity and thus low moisture contents are desirable since processing efficiency (shorter frying time) and yield are dependent on the amount of water to be lost during frying (Stark *et al*., 2005; Haase, 2003; Kumlay *et al*., 2002). The potato chip manufacturer is interested in maximising yields. Potatoes with a high specific gravity produce a greater yield of chips than potatoes with low specific gravity as the former implies more dry matter (Haase, 2003). It has been found that potatoes of the *Russet* variety with 1.0916 (specific gravity) led to chips yield of 24.32 % of potato while those with 1.0777 (specific gravity) yielded only 21.41 % (Smith, 1975). The specific gravity of potato tubers is used as a determinant of how processing conditions should be set up so that product yield and texture are optimized (Haase, 2003). For instance, at low specific gravity the moisture content is high and thus the frying duration need to be longer compared to when processing potatoes of a high dry matter for the same final moisture content to be attained (Pedreschi & Moyano, 2005; Saguy, Ufheil & Livings, 1998; Baumann & Escher, 1995).

Studies have shown that among the physico-chemical characteristics that affect the oil content of potato chips, the specific gravity has a major influence (Baumann & Escher, 1995; Lulai & Orr, 1979). Baumann & Escher (1995) and Lulai & Orr (1979) found that potato tubers of a high specific gravity/dry matter and starch content produced chips of a low oil content. Lulai & Orr (1979) found that the oil content decreased linearly as the specific gravity increased from 1.060 to 1.110 for the *Norchip* variety tubers fried under the same conditions. This also indicates that the initial solids content of tubers influences oil uptake during chip production (Gamble & Rice, 1988a; Dobarganes *et al.,* 2000). Tubers with high solids content will yield chips of low final oil content (Gamble & Rice, 1988a). Low specific gravity (high moisture) potatoes would therefore yield chips of high oil content giving an oily appearance and oily flavour. Gamble *et al*. (1987) observed that there was a direct relationship between increased oil content of the potato chip and high moisture content of the raw potato. This could be explained by the moisture replacement mechanism in which there is formation of pores due to water evaporation allowing oil to penetrate in the voids created (Pedreschi, Aguilera, & Pyle, 2001) during frying and on cooling. It is thus observed that higher moisture content results in high internal volume of the potato chip that could be occupied by the oil (Ufheil & Escher, 1996; Baumann & Escher, 1995; Gamble *et al*., 1987). However the oil uptake mechanism is a dynamic and complex process and the moisture replacement mechanism only offers a partial explanation for the phenomenon (Saguy & Dana, 2003).

2.3.2 STARCH CONTENT

Starch contributes up to 75 % of the potato dry matter and therefore is the primary determinant of the specific gravity (Leszcyñski, 1989). Starch is the major carbohydrate in potato tubers (Kita, 2002). According to Stark *et al*. (2005) potato varieties vary widely in their ability to accumulate starch in the tubers making the choice of variety to be probably the most critical decision with respect to matching tuber quality with intended market. According to Miranda & Aguilera (2006) and Kita (2002) the crisp texture of potato chips depends mainly on starch content of the potato tubers. The fact that the potato tubers are of a high starch content suggests that the most important contribution to the texture of processed potatoes is due to the gelatinization of starch during heating (Miranda & Aguilera, 2006; Verlinden, Nicolai & De Baerdemaeker, 1995). Dupont, Kirby & Smith (1992) observed that the crust of french fries processed from potatoes of a high starch content were described as crispy. The textural changes that take place during frying are suggested to be associated with chemical and physical changes such as starch gelatinisation and consequent dehydration (Bouchon, Hollins, Pearson, Pyle & Tobin, 2001).

2.3.3 SUGAR CONTENT

The main sugars found in potatoes are sucrose and the reducing sugars, glucose and fructose. The reducing sugar content is critical in the quality of processing potatoes, as studies have shown that it negatively influences the colour and flavour of the finished product due to Maillard reactions that take place during frying (Brierley, Bonner & Cobb, 1996; Roe, Faulks & Belsten, 1990; Marquez & Anõn, 1986). The Maillard reaction, is initiated at high temperatures (> 120 ^{o}C) due to the condensation of free amino acids and reducing sugars (Ames, 1990). It is thus dependent on the content of reducing sugars and amino acids content in the raw potato, the temperature and time of frying (Marquez & Anõn, 1986; Khanabari & Thompson, 1993). Among the sugars, the reducing sugars (glucose and fructose) are of most concern, as they are chemically reactive and involved in the non-enzymatic browning reaction thus determining the eventual fry colour of the potatoes (Rodriguez-Saona & Wrolstad, 1997; Roe *et al*., 1990; Califano & Calvelo, 1987; Marquez & Anõn, 1986).

Sucrose content is critical during harvesting and storage as it is the substrate of the reducing sugars and thus could be hydrolysed in suitable environmental conditions leading to the increase of these sugars (Kumar *et al*., 2004). Reducing sugars (glucose and fructose) have been used to predict the suitability of potatoes for potato chip processing (Rodriguez-Saona & Wrolstad, 1997). This is because studies have shown that reducing sugar ccontent is the limiting factor in browning development in fried potato products (Roe & Faulks, 1991; Marquez & Anõn, 1986). The other constituents of the potato tuber such as amino acids, which must be present before colour formation can occur, are found to be naturally sufficient in the potato tuber (Marquez & Anõn, 1986). Blenkinsop *et al*. (2002) found that the reducing sugar concentration explained most of the variation in chip colour. Kumar *et al.* (2004) and Blenkinsop *et al*. (2002), state that excessive amounts of reducing sugars in potatoes results in dark coloured chips that are unacceptable to the consumer due to their appearance and bitter taste.

Studies generally agree on the very low levels of reducing sugars desirable for chip processing potatoes though agreement on the practical minimum levels differ. Kita (2002) states that the content of total sugars in potatoes destined for chip manufacture should be less than 0.23% and reducing sugars less than 0.12%. Hassanpanah *et al*. (2006) have observed that reducing sugars content in excess of 0.3% fresh weight yields chips of unacceptable dark colour on frying. Dahlenburg, Maier & Williams (1990) reported that even within the ranges of 0.1 to 0.2% fresh weight unacceptably dark coloured chips could be produced. According to Stark *et al.* (2005) the maximum allowable levels of reducing sugars in potatoes for chip manufacture is 0.035% fresh weight. The tendency to contain a high or low content of total sugars or of a particular sugar is a heritable trait (Rodriguez-Saona & Wrolstad, 1997; Dale & Mackay, 1994) and thus the potato variety has a strong influence on the initial reducing sugar levels in a mature tuber. The sugar content is also influenced by the growing environment, cultural practices and handling and storage conditions (Kumar *et al*. 2004).

2.4 POTATO CHIP PROCESSING

In addition to the raw potato characteristics, the potato chip processing steps are major factors influencing the potato chip quality. From the receipt of potatoes at the processing plant and subsequent processing steps, the chip manufacturer ensures set specifications are maintained to yield chips of uniform quality. Potato chip processing is a dynamic system of interdependent steps linked together to convert a potato into a chip (Bennett, 2001). The processing procedures vary from processor to processor but generally the technological scheme of chip manufacturing in South Africa is as summarised in Fig. 2.3

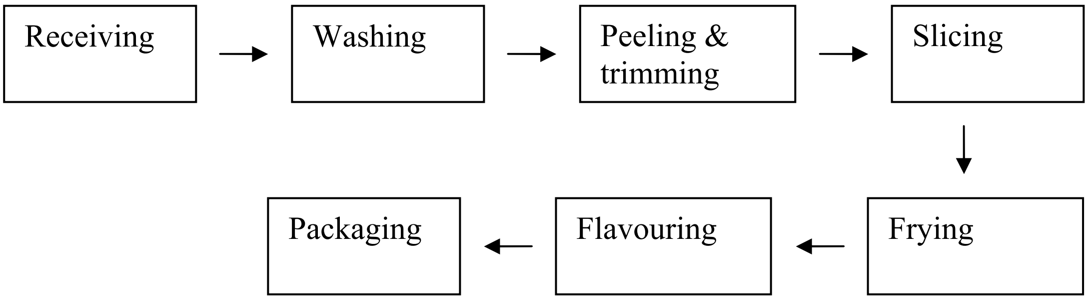

Fig. 2.3 Schematic diagram of potato chip processing

Adjustments of processing parameters in some of the processing steps can be made based on the raw potato physico-chemical characteristics (Kaaber *et al*., 2001). This ensures production of potato chips of uniform quality and that meet the processor's set quality specifications. However, adjustments in processing parameters can only cater for slight variations and thus potatoes considered to be of poor processing quality (e.g. low specific gravity) cannot yield good quality chips based on processing parameter manipulation.

2.4.1 RECEIVING

This is one of the critical steps as the decision to accept or reject a lot of potatoes for processing is made during this step. The suitability of potatoes for chip processing is established by carrying out raw potato quality assessments on a representative sample of the lot immediately on receipt of the potatoes at the processing plant. These assessments include the determination of size and shape, presence of defects (external and internal) and specific gravity (solids content) (Bennett, 2001). It was observed at the potato chip manufacturer that, a representative sample of the potatoes was peeled, sliced and fried to visually inspect the appearance of the chips against set standards of colour and after-fry defects. The manufacturer has a specified range for these assessments which must be met before the potatoes are accepted for processing.

2.4.2 CLEANING, PEELING AND TRIMMING

The peeling duration is dependent on the surface characteristics of the potatoes such as eye depth, cortex thickness and surface injuries (Lisiñska, 1989). The control of the peeling operation is essential as insufficient peeling may result in poor appearance of the chip (Bennett, 2001). Peeled potatoes are passed on the inspection belts where defects are trimmed off (Bennett, 2001; Lisiñska, 1989). Presence of defects such as bruises, green and dark spots, decayed portions and eyes give a poor appearance to chips (Lisiñska, 1989).

2.4.3 SLICING

The slicing operation is of fundamental importance and among the most important steps to the manufacture of high quality potato chips (Bennett 2001; Lisiñska, 1989; Gamble & Rice 1988b). The slicing step is known to impact upon chip appearance, colour, texture, slice contour, breakage, oil absorption, moisture content and frying time (Miranda & Aguilera, 2006; Baumann & Escher, 1995; Gamble & Rice 1988b). Slice thickness ranges from 0.7 to 1.8 mm; with optimal thickness at 1.0 to 1.2 mm (Lisiñska, 1989). According to Bennett (2001), slices that are very thin have a negative impact on colour and tend to be oil soaked and easily broken, whereas, thick slices tend to have a high final moisture content and are less crispy. Johnson according to Gamble & Rice (1988b) reported that increasing the slicing thickness from l.04 to 2.11 mm altered the final oil content of the chips from 49.93 to 43.85%. Gamble & Rice (1988b) found a large variation in thickness of potato slices cut with an *Urschel* industrial slicer with the mean value being always less than the set value (approximately by 10%). These lead to discrepancies in moisture content after frying, particularly for short frying times and for thicker slices (Gamble & Rice, 1988b). Therefore, uniformity between slices is extremely important as it may create undesirable characteristics of both thin and thick chips (Bennett, 2001) affecting the sensory quality.

Slice thickness setting is varied by the potato chip manufacturer according to the specific gravity or solids content of the potato being processed by controlling the slicer blade gap (Bennett, 2001). Potatoes with lower solids contents are thickly sliced in comparison to those of higher solids content (Bennett, 2001) to ensure chips of lower oil content. For instance, the slicer blade gap for potatoes with a solids content of 14% is set at about 1.40 mm and for a potato with a solids content of 18% about 1.27 mm (Bennett, 2001). This explains the practice of processing potato lots with similar solids content (Bennett, 2001). Overused and blunt slicing blades are known to produce chips with rough or torn surfaces leading to increased oil content (Bennet, 2001; Lisiñska, 1989). Washing of slices to remove surface starch ensures that the slices do not adhere together during frying leading to unfried sections within the chip (Bennett, 2001; Lisiñska, 1989).

2.4.4 Potato chip frying

During deep fat frying, heat and mass transfer takes place simultaneously; heat is transferred from the oil to the food, water is evaporated from the food material and oil is absorbed (Krokida *et al*., 2001b; Sahin, Sastry, & Bayindirili, 1999). At these high temperatures the food material undergoes intense dehydration coupled with structural changes (i.e. formation of pores and crust, curling, expansion or shrinkage), physico-chemical transformations (colour and flavour formation) and microbiological inactivation (Rimac-Brnčić, Lelas, Rade, & Šimundić, 2004; Vitrac, Trystram, & Raoult-Wack, 2000; Farkas, Singh & Rumsey, 1996).

The desirable sensory properties of potato chips are developed during frying and thus apart from the quality of the raw potatoes the conditions during frying will affect the final product quality (Hubbard & Farkas, 1999; Lolos, Oreopoulou & Tzia, 1999). In commercial potato chip production raw potato slices are fried in a continuous fryer for about 2 to 4 min (Baumann & Escher, 1995).

2.4.4.1 Frying temperature and time

Frying time and temperature are processing variables that the manufacturer manipulates in order to produce optimum quality chips and depends on the raw potato composition and slice thickness (Moreira *et al*., 1999; Gamble & Rice, 1988b). These frying variables influence the texture (Miranda *et al*., 2005), final oil content (Baumann & Escher, 1995), colour and flavour (Pedreschi *et al*., 2005). It is reported that higher temperatures yield chips with less oil than lower temperatures since hotter oil has a lower density and is not adsorbed as easily whereas lower frying temperatures require longer frying times, allowing the chip surface to adsorb more oil (Saguy *et al.,* 1998).

2.4.4.2 Frying oil

The frying oil is the heat transfer medium and contributes to the final characteristics of the fried food (Stier, 2004; Vitrac *et al.,* 2000). As the food fries it absorbs part of the frying oil and thus it contributes to the overall quality of the fried food (Stier, 2004; Blumenthal, 1991). Frying continuously at elevated temperatures leads to oil breakdown (Blumenthal, 1991). Basic deterioration reactions during frying are hydrolysis caused by steam from the food, oxidation caused by air (oxygen) and thermal alterations caused by heat (Blumenthal, 1991). Oil degradation leads to changes in the physical and thermal properties (Miller, Singh, Farkas, 1994) of the oil whereas decomposition products formed affect the products' flavour and its keeping quality (Stier, 2000).

An ideal frying oil is described as one with a long frying life (stable), inexpensive, good flavour characteristics, low in saturated fatty acids and trans fatty acids (Mehta & Swinburn, 2001). From a processing perspective, the resistance towards degradation (stability) during frying is the main technical criterion for the selection of a frying oil (Gertz, Klostermann & Kochar, 2000). The suitability of an oil for frying is largely dependent on its fatty acid composition. For instance, sunflower oil has a poor frying stability due to high linoleic acid in comparison to palm olein whereas oils such as canola oil with about 8 % linolenic acid are of very low frying stability (Gupta, 2005; Mehta & Swinburn, 2001). Commonly used frying oils are sunflower oil, soy bean oil, canola oil, animal tallow, cotton seed oil, palm oil, palm olein and maize oil (Kita & Lisiñska, 2005; Blumenthal & Stier, 1991). Sunflower oil and palm olein are commonly used industrial frying oils in South Africa.

Palm olein

Palm olein is one of the oils increasingly being used in most industrial frying settings due to its stability. Palm olein is the liquid fraction obtained during the fractionation of palm oil (Pangoli, Melton, Collins, Penfield & Saxton, 2002). Palm olein has a high proportion of saturated fatty acids and is therefore more stable to oxidation in comparison to oils such as sunflower and maize oil (Rossell, 2001). However its level of saturation is relatively high from a nutrition perspective. Palm olein is reported to be rich in natural antioxidants; tocopherols and tocotrienols which act against autoxidation during frying giving it a good frying stability (Gupta, 2005). Although palm olein darkens as frying proceeds (Rossell, 2001) it is reported not to affect the fried food colour (Masashi, Takashashi & Sonehara, 1985).

2.4.4.3 Role of frying oil in flavour development

According to Stier (2000) most frying oils used in industrial frying are bland and flavour of these oils develop during the frying operation. Desirable and undesirable frying oil flavours generally result from the secondary and tertiary breakdown products of degradative reactions during frying (Stier, 2000). Oxidation is the main degradative reaction known to contribute the most flavour compounds during frying (Chi-Tang Ho & Shahidi, 2005).

Hydroperoxides (primary oxidation products) formed during autoxidation of unsaturated fatty acids are unstable at the frying temperature and are decomposed into volatile compounds (Martin & Ames, 2001). Aldehydes are the most significant flavour compounds of the hydroperoxide decomposition (Chi-Tang Ho & Shahidi, 2005). Pleasant fried food flavours are associated with the breakdown products of linoleic acid at high temperatures (Gupta, 2005). Hexanal and 2, 4-decadienal are the secondary oxidation products of linoleic acid. According to Porkony (1988), oxidation products of linoleic acid, such as 2-*trans* decadienal and 4-*trans* decadienal, have been found to be part of the rich flavour of fried potato chips. Hexanal is associated with off flavours such as rancid flavour in fried foods (Gupta & Warner, 2005). Most snack products such as potato chips are fried and packaged for consumption within 2 to 3 months after preparation. Therefore, the susceptibility of the frying oil to rancidity should be taken into account (Saguy & Dana, 2003). Oxidative rancidity during storage of potato chips has been linked to degraded frying oil. This is due to frying oil oxidation products (free fatty acids) present in the food that act as catalysts causing further degradation of the absorbed oil (Saguy & Dana, 2003; Pangoli *et al.*, 2002).

2.4.5 Seasoning (flavouring) and packaging

To enhance potato chip flavour, flavouring substances (seasoning) are added. The flavourings can be applied through electrostatic coating or traditional coating by dusting on chip surface (Ratanatriwong, Barringer & Delwiche, 2003). Typical seasonings applied on potato chips include sour cream onion, barbeque and salt and vinegar.

Proper packaging is essential to ensure that potato chips reach the consumer with acceptable quality. Mechanical damage (breakage), absorption of moisture, and oil oxidation in packaged chips leads to a decline in consumer acceptability (Matz, 1993). Potato chips are susceptible to oxidation due to the high oil content leading to rancidity during storage and moisture pickup which would lead to loss in crispness (Matz, 1993). The chip packaging material used, generally consists of composites of plastic film, paper and metalised foil, resist moisture-vapour transfer and reflect light (Bennett, 2001; Matz 1993).

2.5 CONCLUSIONS

The physico-chemical characteristics of the raw potatoes and the conditions during potato chip manufacture affect the sensory quality of potato chip. The specific gravity, starch content and reducing content are the potato constituents of most importance to potato chip sensory quality. The processing conditions are varied to cater for slight variations in raw potato constituents of chipping quality potatoes. The most important processing parameters influencing sensory quality of potato chips are the frying oil, frying temperature, frying time and slice thickness.

There are numerous publications on the influence of the physico-chemical characteristics of raw potatoes on the physico-chemical characteristics of potato chips. However, the actual magnitude of differences in sensory quality and consumer acceptance of potato chips as a result of differences in the physico-chemical characteristics of raw potatoes are scarcely reported in most studies. Most observations linking the two aspects are based on generalisations rather than on actual experimental work.

2.6 HYPOTHESES

Potatoes with a higher reducing sugar content will yield chips of a darker colour (Roe & Faulks, 1991) and more Maillard flavour (*probably bitter*) (Maga, 1994) as these are mainly due to Maillard reactions involving the reducing sugars and the amino acids. In these reactions the reducing sugars content is the limiting factor (Marquez & Anõn, 1986).

Potatoes of a low specific gravity/solids content and starch content will yield potato chips of a higher oil content since there will be more moisture to be lost and therefore more absorption of the frying oil by the chips (Baumann & Escher, 1995; Ufheil & Escher, 1996). The crisp texture of potato chips depends mainly on the dry matter content of the potatoes thus those of a low dry matter content will be less crispy.

Flavouring (sour cream & onion) perception of potato chips of higher oil content will be lower compared to those of relatively lower oil content because higher oil content will decrease the rate of flavour release due to a higher oil/water partition coefficient.

It is hypothesised that consumer acceptability of potato chips manufactured from potatoes of different physico- chemical characteristics will differ. This is because of differences in the physico-chemical characteristics of the potatoes which will lead to differences in colour, oiliness, appearance, texture and flavour of potato chips.

2.7 OBJECTIVES

To correlate the effect of reducing sugars content of potatoes with colour and flavour of potato chips.

To correlate the effect of starch content/dry matter content of potatoes with the oil content of potato chips.

To correlate the effect of oil content on the flavour perception of the potato chips.

To correlate the physico-chemical characteristics and sensory quality of potato chips with consumer acceptance.

CHAPTER 3: RESEARCH

The objective of this study was to determine the effect of the physico-chemical characteristics of potato samples on sensory quality of potato chips and subsequent influence on consumer acceptance. The experimental design is shown in Fig. 3.1 and Fig. 3.2.

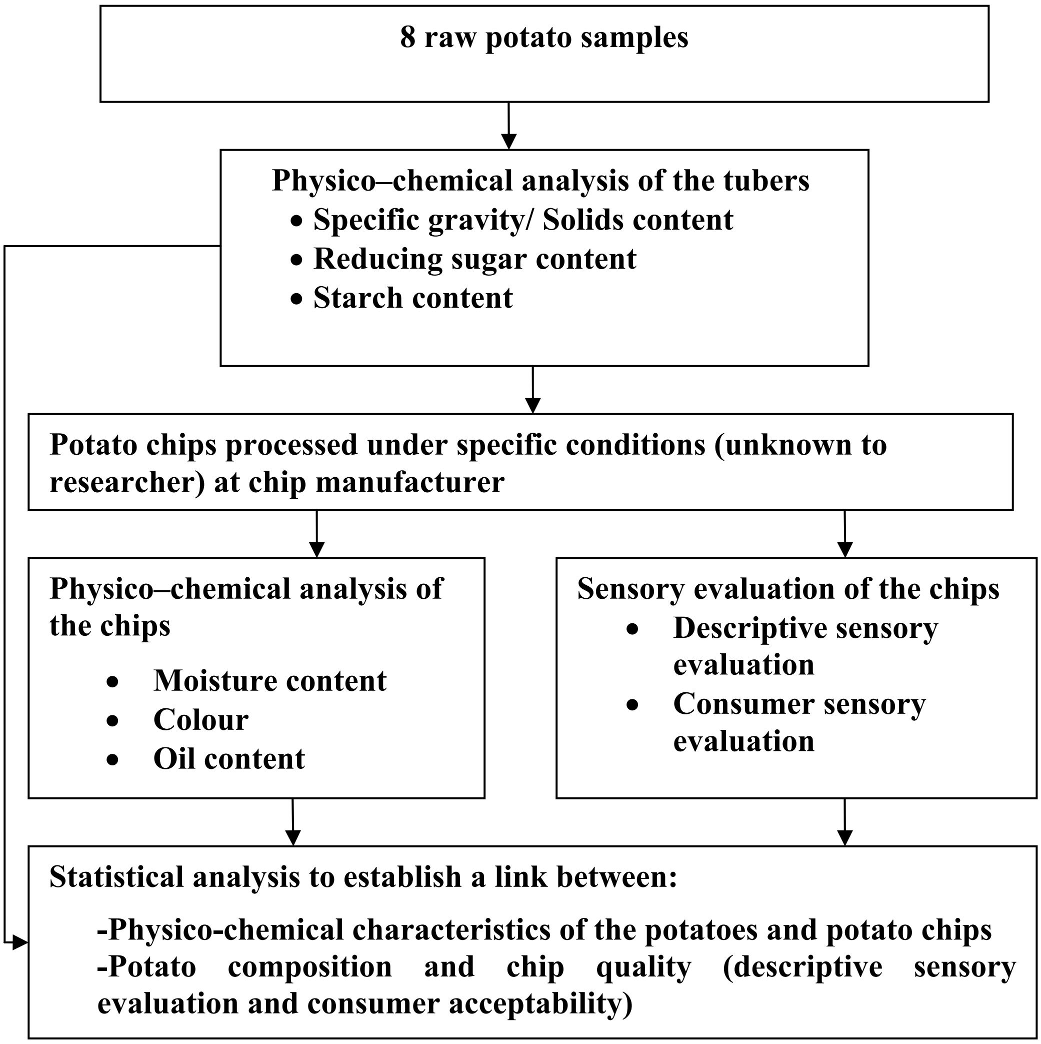

Fig. 3.1 Experimental design to determine the effect of physico-chemical characteristics of raw potatoes on the physico-chemical, sensory characteristics and consumer acceptance of potato chips

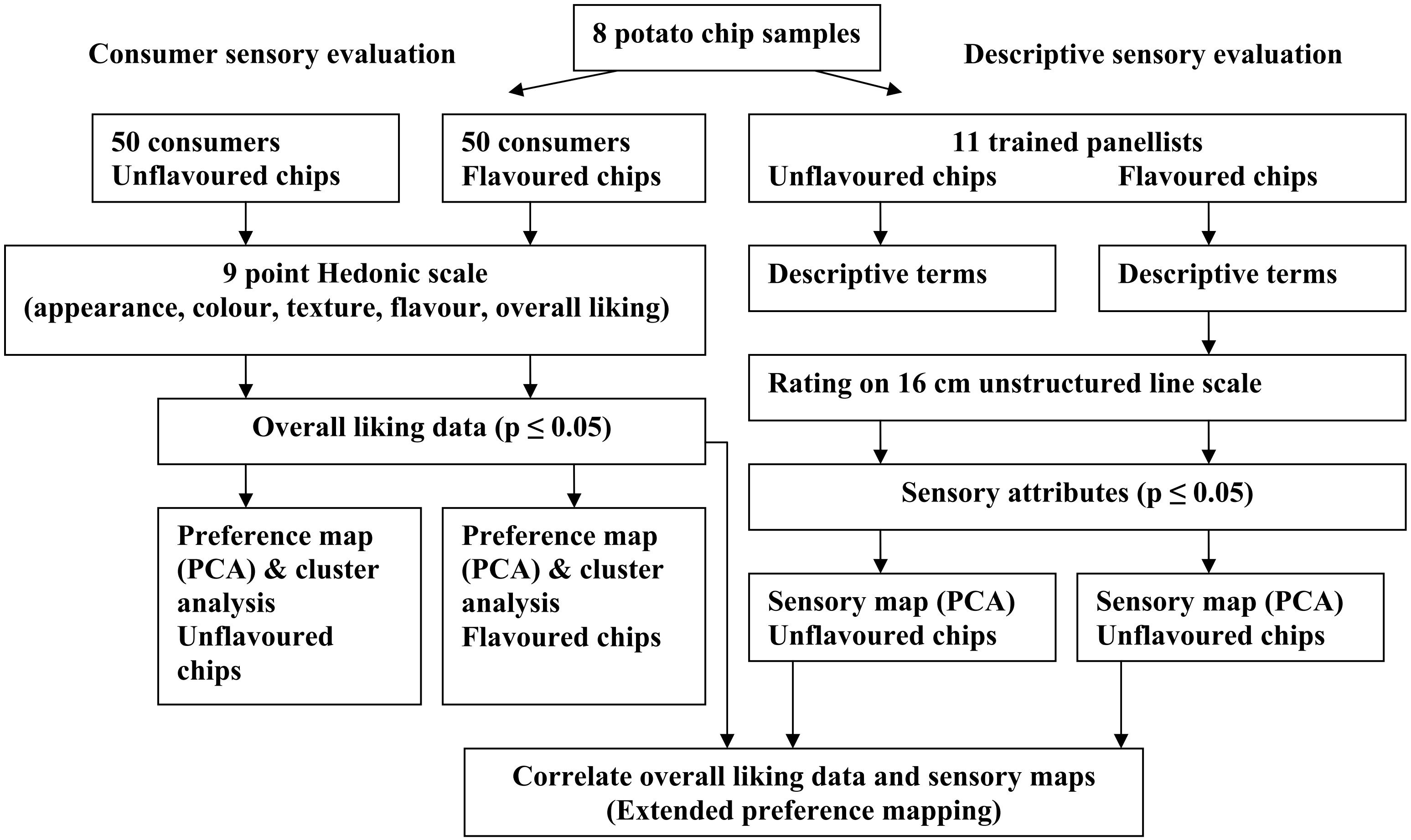

Fig. 3.2 Experimental design of Sensory evaluation

3.1 SENSORY QUALITY OF DEEP FAT FRIED POTATO CHIPS MANUFACTURED FROM POTATOES WITH DIFFERENT PHYSICO-CHEMICAL CHARACTERISTICS

Abstract

Potato chips manufacturers may encounter substantial variability in physico-chemical characteristics of potatoes that could affect the final chip quality. The aim was to investigate the extent of variation in the sensory quality of potato chips practically experienced by a chip manufacturer over a six months period. Eight raw potato samples and their subsequent unflavoured and flavoured potato chips were sourced over a six months period from a chip manufacturer. There were significant differences ($p < 0.05$) in the specific gravity/solids content and starch content of the potato samples. Reducing sugars were not detected in any of the raw potato samples at 0.05 % minimum level of detection. The potato chips differed significantly ($p \leq 0.05$) in moisture content, oil content and colour (a^*, b^*, chroma and hue angle). Significant differences in important sensory attributes such as colour and flavour were observed using descriptive sensory evaluation. However, these did not lead to clear differences in consumer preferences for the various flavoured and unflavoured chips.

3.1.1 INTRODUCTION

Potatoes selected for potato chip processing should yield chips with desirable sensory characteristics to consumers and profit to the processor (Bennet, 2001). In the manufacture of potato chips, the final chip quality is mainly determined by the processing quality of the raw potato. The processing quality characteristics of potatoes are based on the physico-chemical characteristics, shape, size, eye depth and defects of the raw potato (Bennet, 2001; Lisiñska, 1989). These characteristics influence the processing parameters (e.g. peeling operation, slice thickness, frying temperature and duration) and the sensory characteristics of chips (appearance, flavour and texture).

The desirable sensory characteristics of potato chips such as golden yellow colour, crispiness and potato flavour are to a large extent dependent on the physico-chemical characteristics of the raw potato (Miranda & Aguillera, 2006; Bennet, 2001). The desirable physico-chemical characteristics of potatoes include a high specific gravity and solids content, high starch content and low reducing sugars content. These characteristics are found in certain potatoes and not in others (Miranda & Aguillera, 2006). The total solids of potatoes destined for chip manufacture should be in the range of 20 % to 22%, which equates to specific gravities of 1.08 to 1.09, respectively (Adams, 2004; Mehta & Swinburn, 2001).

Potatoes vary in their physico-chemical characteristics as a result of the genetic make-up of a variety and interactions with the growth environment (Kumar *et al*.., 2004). Studies have reported physico-chemical variations in potatoes of the same variety grown in different locations and seasons as a result of environmental factors and agronomic practices (Lærke & Christiansen, 2005; Sengul *et al*., 2004; Dale & Mackay, 1994). Soil temperature, soil moisture, fertilization, and post-harvest factors such as storage temperature are some of the factors known to affect the physico-chemical composition of potatoes (Kumar *et al*., 2004; Leszcyñski, 1989).

During potato chip manufacture, processing parameters have a significant influence on the final chip quality. The processing parameters such as slice thickness, frying temperature, frying duration can be manipulated to cater for slight variations in the chemical composition of the potatoes to yield chips of uniform quality (Bennet, 2001). Potato chips manufacturers source potatoes from different locations during different seasons and thus may encounter substantial variability in the physico-chemical characteristics of the raw potatoes that could affect the final chip quality. The objective of this study was to evaluate the impact of physico-chemical characteristics of a selection of potato samples, representing typical variation experienced commercially by a manufacturer, on the sensory quality and consumer acceptability of the manufactured potato chips.

3.1.2 MATERIALS AND METHODS

3.1.2.1 Potato tubers

In order to obtain potato tubers (*Solanum tuberosum* L.) of different physico-chemical characteristics, potatoes were sampled from different regions in South Africa and at different time periods. These were freshly harvested tubers sourced from contracted commercial growers and sampling was done at a commercial potato chip processor. Sampling of the tubers was done during potato chip processing at the feeding hopper. In this study eight potato samples comprising four potato varieties (A, B, C, D) sourced from five growing regions (V, W, X, Y, Z) were used . The samples were coded *AV*, BW_1, *BW2*, *CW, CX, DY, DW* and *DZ*. *BW1* and *BW2* were of the same variety and grown in the same region but harvested two weeks apart. The potato samples represented the typical variation in source material that a processor experienced over a period of six months. During sampling the specific gravity & solids content of the potato tubers, which had been determined prior to processing, were recorded. For each sample, 30, average - sized, injury free tubers were randomly selected from the feeding hopper. The tubers were cleaned with tap water and peeled using a hand potato peeler. The chips were then sliced to about 2 mm thick slices using a manual chip slicer (Böner slicer, Germany) and placed on stainless steel freeze drying plates. The slices were frozen at -20 ^{o}C and freeze dried in a Instruvac 13 KL (Vacuum technologies, South Africa). The freeze dried potato samples were ground using a coffee grinder (Moulinex, France), vacuum packaged and stored at -20 oC until further analyses.

3.1.2.2 Potato chip

During chip processing of each potato sample, 12 kg of unflavoured flat cut potato chips (Fig. 3.3) were sampled into plastic bags after frying and re-packaged into 125 g foil laminate bags (Nampak, South Africa). Similarly flavoured chips (Fig. 3.3), flavoured with sour cream and onion flavour (a popular flavour with consumers), packed in 125 g foil laminate bags (Nampak, South Africa) were sampled at the packaging section. The chips were stored frozen at -20 ^{o}C until analyses were carried out. The physico-chemical analyses were conducted on the unflavoured potato chips.

3.1.2.3 Reducing sugars

Five grams of raw freeze-dried potato tissue were boiled for 15 min in 50 ml 80 % ethanol, quenched in an ice water bath, washed with 80 % ethanol through Whatman no. 1 filter paper, and the filtrate brought up to 100 ml. The extract was centrifuged for 15 min at 15,000 rpm (ambient) and the supernatant injected immediately. Twenty ml aliquots were injected through an auto injector into an Agilent carbohydrate liquid chromatography column (Zorbax carbohydrate (NH2) 5 µm, 25 cm x 4.6 mm i.d. using 75% acetonitrite: 25% water as mobile phase). An Agilent model 1100 pump produced a flow rate of 1.5 ml.min^{-1}. Operating temperature was 25 ^{o}C. An Agilent 1100 differential refractometer (Agilent Technologies, Waldbron, Germany) and an HP Compaq PC loaded with the appropriate Chemetrix software was used to calculate the peak area for individual sugars. The percentage of the sugars (sucrose, glucose, fructose and maltose) in each sample was calculated using peak areas against a linear regression curve with three concentration levels for each sugar standard solutions ranging from 0.05% to1.0%.

3.1.2.4 Total starch

Total starch content of the potato samples was determined in triplicate using 100 mg of ground, freeze-dried peeled potato by the amyloglucosidase/α-amylase method 996.11 (AOAC, 2002) using the Megazyme Total Starch Assay Kit (Megazyme Ltd, Bray, Ireland).

3.1.2.5 Colour

Colour of the unflavoured potato chips was measured using a CR210 Minolta chromameter (Model CR-400, Minolta Camera Co. Ltd, Osaka, Japan), calibrated with a white plate (CIE L^*=97.91, a* = -0.68, b^* = 2.45). Five readings of the L^*, a^*

and b^* values were taken on each side of 5 potato chips randomly selected per sample and the mean value recorded. The hue angle was determined by calculating the arctangent of b^*/a^*, and $[(a^*)^2 + (b^*)^2]^{1/2}$ yielded chroma (McGuire, 1992).

3.1.2.6 Moisture content

The moisture content of the unflavoured potato chip samples was determined in triplicate by the AOAC method 934.06 (AOAC, 2002). Five grams of crushed potato chips were dried in a convection oven at 105 °C for 20 h.

3.1.2.7 Oil content

Oil content of the unflavoured potato chips was determined in triplicate using the Soxhlet extraction method 920.39 (AOAC, 2002). Five grams of ground chips were weighed into an extraction thimble and fat extraction was done using the Soxtest apparatus (Raypa, U.S.A). Extraction was done for 8 h using petroleum ether (40 – 60 °C). The extracted oil was then dried in an oven at 105 °C for 30 min and weighed.

3.1.2.8 Descriptive sensory evaluation

Descriptive sensory evaluation of both flavoured and unflavoured potato chips was conducted using the generic descriptive evaluation method (Einstein according to Lawless & Heymann, 1998). The potato chips were evaluated by a trained panel consisting of 11 panellists (7 women and 4 men) aged between 19 and 33 years. The panellists were selected from 30 people using 4 screening tests: a basic taste recognition test, odour recognition and description test, an intensity ranking test and a triangle test. The training and descriptive terms development were done in 9 days, 1 h per day. Prior to training, panellists completed a consent form (Appendix A) explaining their willingness to participate in the test. During training the panellists were exposed to potato chip samples included in the study, assessment procedure in the sensory laboratory and the use of sensory evaluation software (Compusense® Five release 4.6 [1986-2003] Guelph, Ontario Canada). After the descriptive terms development, training sessions focused on reaching agreement on the definition of descriptive terms, scale end anchors and the use of the line scales. The descriptive terms were developed with the aid of term lists in literature (Campbell, 1997). The descriptive terms developed and used by the panellists were based on appearance, aroma, flavour, texture after taste and mouthfeel of the flavoured and unflavoured chips (Table 3.1).

For each descriptor, the scoring of the perceived intensity (between 0 and 10) was made on a 16 cm unstructured line-scale anchored at the extreme ends, with verbal expressions (Table 3.1). All eight unflavoured potato chip samples were evaluated per session in a randomized complete block design. The evaluations were repeated three times, each evaluation on a different day. The same procedure was applied for the eight flavoured potato chip samples but on different days. Frozen potato chips (flavoured and unflavoured) were thawed for 3 h prior to sensory evaluation. About 15 g of potato chips of each sample were presented to each panellist in ziplock bags (120 mm × 180 mm) and were labelled with randomly selected three-digit codes. The order of presentation of samples to panellists was randomised within and between sessions. Evaluation was carried out in sensory booths at the sensory evaluation laboratory of the Department of Food Science, University of Pretoria using automated data collection (Compusense® Five release 4.6 [1986-2003] Guelph, Ontario Canada). The sensory evaluation booth area was held at 20 ^{o}C. A glass of water and carrot slices were provided to each panellist for cleansing the palate before and in between tasting each sample.

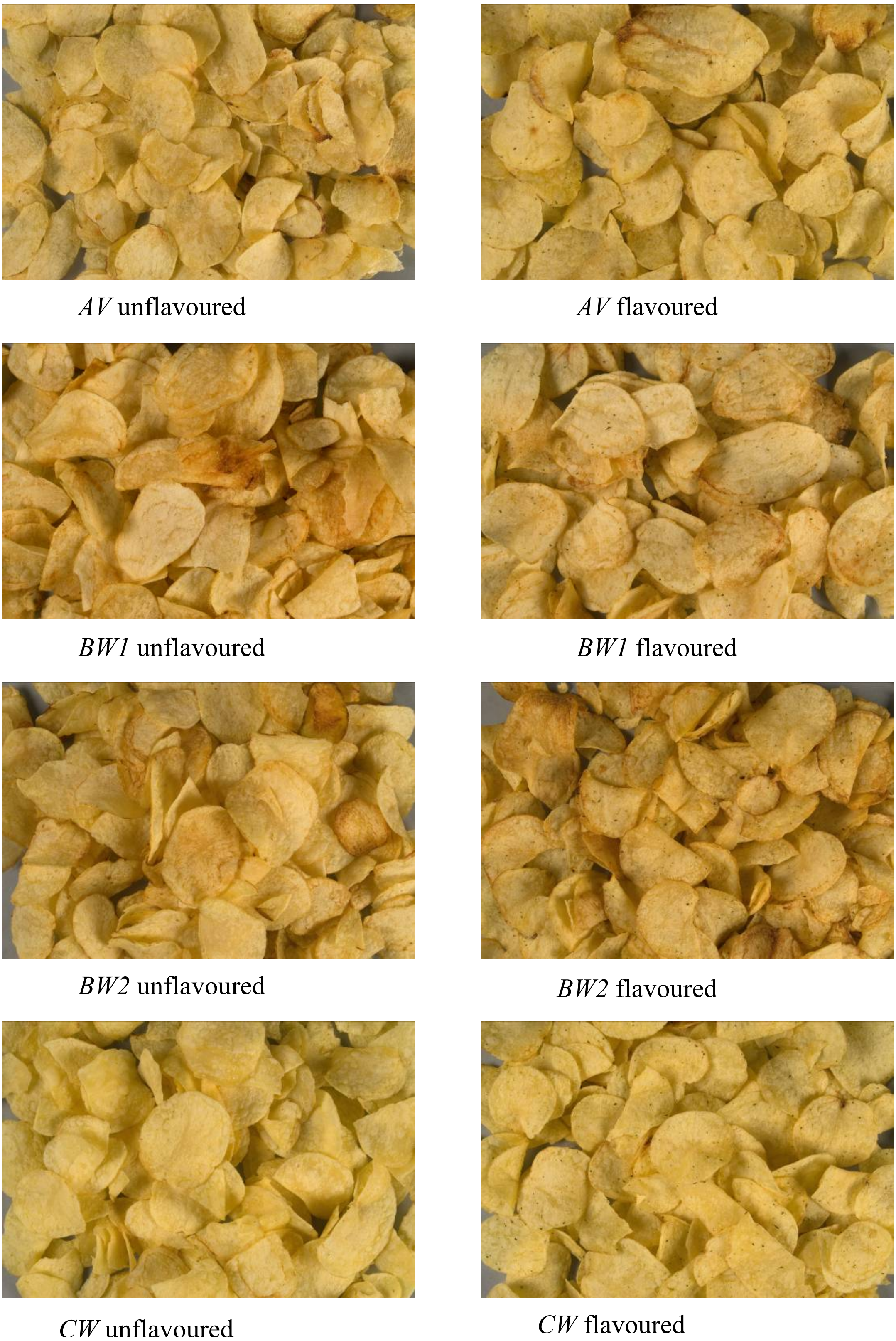

Fig. 3.3 Photographic images of potato chip samples

CX unflavoured

CX flavoured

DW unflavoured

DW flavoured

DY unflavoured

DY flavoured

DZ unflavoured

DZ flavoured

Fig. 3.3 Photographic images of potato chip samples (continued)

Table 3.1 Descriptors, definitions and word anchors used by the trained sensory panel to describe the sensory properties of the unflavoured and flavoured potato chip samples

Descriptors	Definition	Anchors
Appearance		
Colour	Intensity of the golden yellow colour	Light golden yellow….Brown
Thickness	Thickness of chip along the edge, ignoring bubbles	Thin…..Thick
Roughness	Amount of irregularity, protrusions or bumps which can be seen on the surface of the chips.	Smooth…..Rough
Oily	Amount of surface area with oily spots	None…..Much
Blisters/Air bubbles	Number of blisters or air bubbles on the chip surface	None…..Many
Translucency	Degree of translucency (amount of light coming through) of the chip	Not translucent.....Very translucent
Brown specks	Number of brown specks within the surface of the chip	None…..Many
Aroma		
Raw potato	Intensity of aroma associated with raw potato	None…..High
Fried potato	Intensity of aroma associated with fried potato	None…..High
Burnt	Intensity of aroma associated with burnt food.	None…..High
Onion	Intensity of aroma associated with onion	None…..High
Sour	Intensity of aroma associated with vinegar.	None…..High
Oily	Intensity of aroma associated with of frying oil	None…..High
Rancid oil	Intensity of aroma associated with old oil	None…..High
Texture		
Ease of breaking	Ease of breaking a chip in half using both hands	Easy to break…..Difficult to break
Crispness	A combination of the type of sound (i.e., short snapping and longer cracking sounds) and the force to bite and chew as perceived on first bite.	Not crispy…..Very crispy
Fracturability	The number of pieces into which the chip breaks on biting with the incisors	Few…..Many
Hardness(incisors)	The force required to bite through the chips with the incisors.	Not hard…..Very hard
Hardness(molars)	The force required to bite through the chips with the molars.	Not hard…..Very hard
Crunchiness	Perception of crushing sounds transmitted through the jaws while chewing	Not crunchy…..Very crunchy
Tooth packing	Degree to which chip particles sticks to molars and palate while chewing	Not sticky…..Very sticky
Grittiness/Graininess	Feeling of individual particles in the mouth or across the tongue while chewing	Not gritty…..Very gritty
Rate of breakdown	The rate at which the chips breaks down during chewing so that it can be swallowed	Slowly ….. Quickly
Flavour/taste		
Salty	Intensity of taste associated with salt (NaCl)	None…..High
Sour	Intensity of taste associated with vinegar	None…..High
Sweet	Intensity of taste associated with sucrose	None…..High
Bitter	Intensity of bitter taste associated with caffeine	None…..High
Burnt	Intensity of burnt flavour	None…..High
Oily	Intensity of frying oil flavour	None…..High
Fried potato	Intensity of fried potato flavour	None…..High
Onion	Intensity of onion flavour	None…..High
Raw potato	Intensity of raw potato flavour	None…..High
Rancid oil	Intensity of rancid oil flavour	None…..High
Aftertaste/mouthfeel		
Bitter	Degree to which bitter aftertaste could be perceived	None…..High
Residual particles	Number of particles remaining in the mouth	None…..Many
Tooth packing	Extent to which after swallowing, remaining particles stick to the teeth	Not much…..Very much

3.1.2.9 Consumer sensory evaluation

Fifty consumers from the University of Pretoria community were recruited to evaluate the acceptability of each category (unflavoured and flavoured chips). Consumers were selected after responding to advertisement posters (Appendix B) inviting potato chip consumers to participate in consumer sensory evaluation. The consumers for the unflavoured chips included 27 females and 23 males between 18 and 46 years. At least 64 % of the participants consumed chips at least once per week while the rest consumed chips occasionally but at least once a month. The consumers for the flavoured chips included 35 females and 15 males between 18 and 46 years. At least 70 % of the participants consumed chips at least once per week while the rest consumed chips occasionally but at least once a month. The consumers completed consent forms (Appendix C) before evaluation. Sensory evaluation was conducted in a sensory laboratory. About 15 g of potato chips of each of the 8 potato types were presented to each panellist in ziplock bags (120 mm × 180 mm) and were labelled with three-digit random codes. The order of presentation of samples to consumers was randomized. Consumers were asked to take a compulsory five minute break between the fourth and fifth sample and were requested to take a sip of water and eat a slice of carrot before and in between tasting each of the samples. Evaluations were carried out in sensory booths at the sensory evaluation laboratory, Department of Food Science, University of Pretoria using automated data collection (Compusense® Five release 4.6 [1986-2003] Guelph, Ontario Canada). The sensory evaluation booth area was held at 20 °C. The consumers expressed their overall liking, liking of appearance, colour, taste ("Taste" is the word consumers normally use which implies flavour) and texture of each sample using a 9-point hedonic scale (Peryam & Pilgrim, 1957) ranging from 1-dislike extremely to 9-like extremely.

3.1.2.10 Statistical analysis

The effects of different potato samples on physico-chemical properties and on sensory descriptors (data averaged across the 11 trained panellists) were determined using analysis of variance (ANOVA) and where appropriate Fischer's least significant difference test (LSD, $p \leq 0.05$) using Statistica 7.0 (Statsoft Inc., Tulsa, OK). The univariate analysis of the descriptive sensory data showed significant differences among the unflavoured samples for 6 of the 32 attributes and 8 of the 35 attributes among the flavoured samples ($p < 0.05$) (Table 3). Principal component analysis (PCA) of the sensory descriptors that showed significant differences (data for each descriptor averaged across the 11 trained panellists per evaluation session and then averaged across the triplicate sessions) was performed using a correlation matrix with potato chip sample means in rows and descriptors in columns. PCA and Pearson correlation were applied to the descriptive data and physico-chemical analyses of the unflavoured chips to determine relationships among sensory attributes and the physico-chemical characteristics.

The consumer data (overall degree of liking, degree of liking of appearance, degree of liking of colour, degree of liking of taste and degree of liking of texture) were analysed by two way ANOVA using Statistica 7.0 (Statsoft Inc., Tulsa, OK) to test for sample and consumer effects. Where appropriate Fischer's least significance difference test (LSD) ($p \leq 0.05$) was used. To identify the preferences of consumers for the different potato chip samples, PCA of the matrix of overall degree of liking data (as rows) and the potato chip samples (as columns) was performed (internal preference mapping). To understand consumers' responses further, the preference data was analysed by *k*-means cluster analysis using Ward's method with Euclidean distances (an agglomerative hierarchical cluster analysis method) using XL-stat 7.5.3 (Addinsoft, New York). This method assigns rows (in this case consumer) with similar preference for the different potato chip samples to the same cluster. Visual investigation of the dendograms generated was used to select the most suitable number of clusters to select for further analysis. To understand the sensory attributes driving overall liking, external preference mapping was used to regress the overall liking for individual consumers onto the descriptive sensory data space derived from the PCA of descriptive sensory ratings using XL-Stat 7.5.3 (Addinsoft, New York). The different models used to regress were the vectorial, circular, elliptical and quadratic models.

3.1.3 RESULTS

3.1.3.1 Physico-chemical analyses

The specific gravity and solids content of the different potato samples differed significantly ($p < 0.05$). The specific gravity and solids content ranged from 1.073 g/cm^3 to 1.098 g/cm^3 and 19.2% to 24.9% respectively (Table 3.2).

Table 3.2 Means[1] ± standard deviations. of the physico-chemical properties of raw potatoes and of potato chips

Physico-chemical properties		Potato samples								F- value	P-value
		AV	BW_1	BW2	CW	CX	DY	DW	DZ		
Raw potatoes											
Specific gravity (g/cm^3)		1.073^{a}±0.004	1.078^{b}±0.002	1.079^{b}±0.001	1.093^{e}±0.001	1.098^{f}±0.001	1.090^{d}±0.007	1.084^{c}± 0.0004	1.084^{c}±0.001	92.874	<0.001
Solids content (%)		19.2^{a}±0.8	20.5^{b}±0.4	20.5^{b}±0.3	23.7^{e}±0.2	24.9^{f}±0.0	22.9^{d}±0.1	21.6^{c}±0.1	21.7^{c}±0.1	119.504	<0.001
Reducing sugars (%)		< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05		
Starch (% dry basis)		67^{ab}±2.33	71^{c}±2.18	71^{c}±2.51	71^{c}±3.28	65^{a}±3.26	70^{c}±3.61	69^{bc}±2.26	69^{bc}±3.72	4.722	0.001
Potato chips											
Chip oil content	**as is %**	32.7^{a}±1.1	40.1^{e}±0.1	39.3^{e}±0.3	33.6^{b}±0.2	36.1^{d}±0.1	34.8^{c}±0.2	32.8^{ab} ±0.6	35.2±0.3	65.181	<0.001
	dry basis %	33.1^{a} ±1.1	40.8^{e}±0.1	39.9^{e} ±0.3	34.3^{b}±0.2	36.7^{d}±0.1	35.3^{c}±0.2	33.4^{ab} ±0.6	35.8^{cd} ±0.3	65.181	<0.001
Chip moisture (%)		1.16^{a} ±0.06	1.67^{cd}±0.03	1.54^{bc}±0.01	1.93^{e}±0.12	1.52^{b}±0.21	1.50^{b}±0.00	1.89^{e}±0.06	1.72^{d}±0.06	44.096	<0.001
Colour											
L^*		60.77^{a}±2.77	59.12^{a}±3.37	59.56^{a}±2.52	58.18^{a}±1.59	59.88^{a}±2.58	57.11^{a}±1.83	60.73^{a}±0.74	61.53^{a}±2.39	1.830	0.117
a^*		1.68^{bc}±0.21	1.23^{b}±0.47	3.69^{d}±1.38	0.39^{a}±0.18	2.17^{c}±0.39	1.01^{ab}±0.24	1.28^{b}±0.20	1.2^{b}±0.18	15.444	<0.001
b^*		18.24^{bc}±0.71	15.88^{a}±1.94	20.35^{cd}±1.95	21.21^{d}±1.78	21.26^{d}±2.08	17.05^{ab}±0.89	18.63^{bc}±1.93	18.12^{abc}±1.36	6.850	<0.001
Hue angle		84.75^{bc} ±0.51	85.59^{bcd} ±1.36	79.92^{a} ±2.93	88.96^{e}±0.45	84.21^{b} ±0.67	86.59^{d} ±0.90	86.05^{cd} ±0.78	86.17^{cd} ±0.86	19.438	<0.001
Chroma		18.31^{b} ±0.72	15.93^{a} ±1.95	20.70^{cd} ±2.13	21.22^{d} ±1.78	21.37^{d} ±2.10	17.08^{ab} ±0.88	18.67^{bc} ±1.92	18.16^{ab} ±1.35	6.861	<0.001

[1]Means in a row with different letters (abcdef) are significantly different ($p < 0.05$)

There were significant differences within and among varieties. Potatoes of the same variety grown in different locations differed significantly for the *C* and *D* varieties. The specific gravity and solids content of *DY* differed significantly ($p<0.05$) from *DW* and *DZ*. The specific gravity of the latter two samples were similar ($p>0.05$). *CW* and *CX* of the same variety but grown in different locations differed significantly ($p< 0.05$). The highest specific gravity values were those of *CW* and *CX* (1.093 g/cm^3 and 1.098 g/cm^3 respectively). The specific gravity of *BW1* and *BW2*, same variety and growing location, harvested at different time periods did not differ significantly.

Overall the starch content varied significantly ($p <0.01$) among the different potato samples (Table 3.2). The starch content of potatoes of the same variety did not vary significantly except for *C* variety. The starch content ranged from 65% to 71% of the potato dry matter. It is interesting to note that *CX* had the lowest starch content (65%) although it had the highest specific gravity (1.098 g/cm^3). *BW* samples had similar starch content as *CW* but had significant differences in specific gravity. The correlation between starch content and specific gravity (Table 3.3) was very low ($r = 0.09$, $p> 0.05$).

The final oil and moisture content of the chips differed significantly among the potato samples ($p<0.001$). The moisture content of potato chips ranged from 1.2 to 1.9 % while that of oil ranged from 33.1 to 40.8% (dry basis). The oil content was highest in variety *B* potatoes which did not differ significantly in moisture and oil content ($p > 0.05$). There was a very low insignificant correlation between the oil content and the specific gravity (Table 3.3) of the potatoes ($r =0.11$, $p>0.05$).

Table 3.3 Correlations between physico- chemical characteristics of potato samples, physico- chemical characteristics and descriptive sensory attributes of unflavoured potato chips

	Burnt	Oily	Colour	Brown specks	Hardness (molars)	Burnt	Specific gravity	Solids content	Starch	Chip oil content	Chip moisture	L*	a*	b*	Hue angle	Chroma
Burnt	1.00	-0.04	**0.43***	**0.62***	0.18	**0.85***	0.26	0.25	-0.05	0.22	-0.12	-0.11	0.25	0.13	-0.26	0.14
Oily		1.00	0.14	0.20	-0.31	0.11	0.06	0.07	-0.14	-0.10	-0.14	-0.19	-0.02	0.05	0.03	0.04
Colour			1.00	**0.63***	**-0.49***	0.55*	-0.16	-0.15	-0.17	0.16	**-0.45***	0.27	**0.62***	0.02	**-0.66***	0.05
Brown specks				1.00	-0.17	**0.70***	0.22	0.24	0.04	0.32	-0.19	0.14	**0.44***	0.17	**-0.45***	0.18
Hardness(molars)					1.00	0.10	**0.44***	**0.43***	0.07	-0.24	0.29	**-0.45***	-0.23	**0.41***	0.31	**0.39***
Burnt						1.00	0.23	0.23	-0.08	0.33	-0.13	-0.08	**0.54***	0.19	**-0.53***	0.22
Specific gravity							1.00	1.00*	0.09	0.11	**0.45***	-0.28	-0.22	**0.41***	0.30	**0.39***
Solids content									0.07	0.11	**0.43***	-0.27	-0.20	**0.42***	0.28	**0.40***
Starch									1.00	**0.42***	**0.42***	-0.16	-0.06	-0.21	0.03	-0.20
Chip oil content										1.00	0.17	-0.11	0.36	-0.17	-0.39	-0.14
Chip moisture											1.00	-0.04	-0.35	0.26	**0.41***	0.24
L*												1.00	0.09	-0.10	-0.11	-0.10
a*													1.00	0.21	**-0.98***	0.27
b*														1.00	-0.06	**1.00***
Hue angle															1.00	-0.12
Chroma																1.00

*numbers in bold represent significant correlations ($p<0.05$)

The potato chips' colour were described by L*, a* and b* values. Where L* represented lightness, a* red and b* yellow chromacity (Frydecka-Mazurczyk & Zgórska, 2003). There were significant differences in a* and b* values between the potato samples but not for the L* value (Table 3.2). The a* values ranged from 0.39 to 3.69. The a* values of *BW2* and *CX* did not differ significantly from each other and were also the highest, 3.69 and 2.17 respectively. Visually, these two potato samples appeared darker compared to the other potato types (Fig 3.3). The b* values ranged from 15.88 to 21.26. The b* values of the darker samples (*BW2* and *CX*) did not differ significantly. The hue angle ranged from 79.92 to 88.96 with *BW2* and *CX* having the lowest values (Table 3.2).

There were no reducing sugars (glucose, fructose, maltose) detected in the potato samples at a minimum detection level of 0.05 %.

3.1.3.2 Descriptive sensory evaluation

The univariate analysis of the descriptive sensory data showed significant differences ($p < 0.05$) among the unflavoured samples for 6 of the 32 attributes (Table 3.4) and 8 of the 35 attributes among the flavoured samples (Table 3.5). Among the attributes that differed significantly, the most discriminating attributes based on *F*-values ($p<0.05$) for the unflavoured chips were brown specks and burnt flavour followed by colour intensity and burnt aroma (Table 3.44). Darker yellow colour intensity, brown specks, burnt flavour and burnt aroma were associated with *BW2* and to a lesser extent *CX*. These two samples were rated significantly higher than the other samples in these attributes. Oily aroma and hardness (molars) also differed significantly ($p \leq 0.05$). The range of average values for oily aroma intensity was small (2.4 to 4.1) with *DW* receiving the highest rating. The average hardness (molars) intensity ranged from 2.4 to 4.6 with *CW* receiving the highest rating and *BW* samples receiving the lowest ratings.

For the flavoured chips, the most discriminating attributes were similar to that identified in unflavoured chips i.e. brown specks and burnt flavour. It was noted that the rancid flavour and aroma of the chips differed significantly among the flavoured chip samples but it was not the case for the unflavoured chips. *DW* appeared to be associated with rancid aroma and flavour. The other flavoured chips attributes that

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differed significantly ($p < 0.05$) were, ease of breaking, hardness (incisors), hardness (molars) and rate of breakdown. Although the differences in these texture attributes were significant ($p \leq 0.05$) the scalar differences were relatively small. These texture attributes had similar rating ranges: ease of breaking (2.8 to 4.3), hardness (incisors) (2.5 to 4.7), hardness (molars) (2.3 to 4.6) and rate of breakdown (2.5 to 4.8). *CW* chip samples were not always significantly different though rated highest for these texture attributes compared to the other chip samples.

PCA of the six attributes which discriminated significantly ($p \leq 0.05$) among the unflavoured potato chip samples showed that 98.68% of the variance could be explained by the first three principal components (Fig. 3.4 and Fig. 3.5). PC 1 explained 67.53% of the total variance, separating potato chip samples (Fig. 3.4b) based on the attributes burnt aroma, burnt flavour, presence of brown specks and colour intensity (Fig. 3.4a). These attributes distinguished *BW2* and to a lesser extent *CX,* from the other potato samples. PC 2 (Fig. 3.5) described an additional 17.88 % of the variation and separated chip samples based on oily aroma intensity. *DY*, *DW, AV* and *CX* chips (Fig. 3.5b) were associated with a more oily aroma (Fig. 3.5a). PC 3 (13.27%) distinguished chips based on hardness (molars) (Fig. 3.5b).

PCA of the physico-chemical characteristics of raw potatoes, unflavoured potato chips and descriptive sensory descriptors of the unflavoured chips are shown in Fig. 3.6 and Fig. 3.7. PC1 (Fig. 3.6a) accounted for 42.87% of the variation and explained the colour differences in the potato chip samples. Colour, burnt flavour, burnt aroma and brown specks were positively correlated with a^* value of the potato chips. The significant correlations between colour, burnt flavour and brown specks with a^* value were $r = 0.62$, $r = 0.54$, and $r = 0.44$, respectively (Table 3.3). The hue angle was negatively correlated with these sensory attributes. PC2 (23.90%) separated samples based on hardness (molars), specific gravity, b^* value and chroma. Hardness (molars) was positively correlated with specific gravity ($r = 0.44$, $p<0.05$) but not correlated with starch content ($r = 0.07$, $p> 0.05$). PC3 (Fig. 3.7a) (15.4%) separated samples based on oily aroma and L^* value at the top and starch content, chip moisture and chip oil content. It appeared that there was no relation between the oily aroma and the chip oil content shown by the insignificant, low correlation ($r = -0.10$, $p> 0.05$).

Table 3.4 Mean (± standard deviation) ratings for the descriptive sensory attributes of unflavoured potato chips

Attribute[1,2,3]	**Potato samples**								**F-Value**	**P-value**
	AV	**BW_1**	**BW_2**	**CW**	**CX**	**DY**	**DW**	**DZ**		
Raw potato aroma	2.4±0.7	2.4±0.4	2.5±0.5	1.5±0.3	2.3±0.5	2.0±0.2	1.5±0.6	2.6±1.0	0.908	0.500
Fried potato aroma	4.2±0.4	4.3±0.2	4.4±0.2	3.4±0.3	4.0±0.7	4.4±0.1	3.7±0.2	3.9±0.4	0.531	0.810
Burnt aroma	**$0.5^{ab}\pm0.3$**	**$0.4^{ab}\pm0.2$**	**$2.9^{c}\pm0.1$**	**$0.3^{a}\pm0.1$**	**$1.2^{b}\pm0.5$**	**$0.3^{a}\pm0.1$**	**$0.5^{ab}\pm0.2$**	**$0.7^{ab}\pm0.4$**	**8.473**	**< 0.001**
Oily aroma	**$3.7^{bcd}\pm0.3$**	**$3.0^{abc}\pm0.5$**	**$2.9^{abc}\pm0.4$**	**$2.4^{a}\pm0.4$**	**$3.9^{cd}\pm0.4$**	**$4.0^{d}\pm0.7$**	**$4.1^{d}\pm0.8$**	**$2.8^{ab}\pm0.5$**	**3.170**	**0.003**
Rancid oil aroma	2.1±0.3	1.4±0.3	1.9±0.5	0.7±0.6	2.3±0.6	1.7±0.4	2.3±0.7	1.4±0.5	1.717	0.105
Colour	**$4.0^{c}\pm0.6$**	**$3.1^{abc}\pm0.5$**	**$6.1^{d}\pm0.7$**	**$2.3^{a}\pm0.2$**	**$5.1^{d}\pm0.4$**	**$2.8^{ab}\pm0.1$**	**$3.5^{bc}\pm0.4$**	**$3.6^{bc}\pm0.4$**	**11.541**	**< 0.001**
Thickness	4.5±0.3	4.0±0.2	4.2±0.2	4.3±0.6	4.4±0.3	4.1±0.4	4.3±0.4	4.7±0.3	0.349	0.931
Roughness	5.3±0.1	4.9±0.5	5.7±0.4	5.5±0.5	5.7±0.5	5.3±0.5	5.1±0.2	4.7±0.3	0.902	0.505
Oily appearance	4.8±0.4	5.3±0.8	5.0±0.7	5.5±0.3	4.7±0.8	5.4±1.2	4.9±0.3	4.9±0.5	0.562	0.786
Blisters	4.1±0.4	4.3±0.9	4.9±0.4	4.7±0.1	4.6±0.7	4.3±0.5	4.2±0.7	3.6±0.2	1.006	0.428
Translucency	4.9±1.4	6.1±0.5	4.6±0.6	5.1±0.3	4.6±0.6	5.2±0.7	5.2±0.7	4.9±0.5	1.452	0.185
Brown specks	**$1.9^{bc}\pm0.5$**	**$1.3^{ab}\pm0.3$**	**$5.5^{e}\pm0.6$**	**$0.7^{a}\pm0.5$**	**$3.7^{d}\pm0.3$**	**$0.8^{a}\pm0.3$**	**$1.9^{bc}\pm0.4$**	**$2.3^{c}\pm0.4$**	**22.563**	**< 0.001**
Ease of breaking	3.3±0.7	2.6±0.4	3.1±0.2	3.9±0.6	3.9±0.6	3.1±0.8	3.4±0.2	3.8±0.2	1.572	0.144
Crispness	6.4±0.4	6.8±0.3	5.8±1.1	6.3±0.3	6.3±0.3	6.3±0.6	5.8±0.6	5.9±0.8	1.120	0.351
Fracturability	4.8±0.8	5.7±0.6	5.1±0.7	5.4±0.8	5.4±0.8	5.3±0.3	4.7±0.8	5.0±0.2	0.539	0.805
Hardness (incissors)	3.7±0.4	2.7±0.5	2.7±0.2	4.3±0.2	3.9±0.3	3.8±0.3	3.4±0.3	3.9±0.8	1.885	0.072
Hardness(molars)	**$3.7^{bc}\pm0.7$**	**$2.4^{a}\pm0.4$**	**$3.0^{ab}\pm0.2$**	**$4.6^{c}\pm0.2$**	**$3.7^{bc}\pm0.3$**	**$3.8^{bc}\pm0.3$**	**$3.5^{b}\pm0.4$**	**$3.7^{bc}\pm0.7$**	**2.841**	**0.007**
Crunchiness	6.0±0.7	6.0±0.3	5.7±0.6	6.4±0.3	6.1±0.1	6.7±0.3	5.9±0.5	6.1±0.8	0.817	0.574
Gritiness/graininess	4.1±0.2	4.3±0.7	4.2±0.4	4.6±0.2	4.5±0.4	4.0±0.4	4.2±0.5	4.1±0.3	0.331	0.940
Rate of breakdown	3.5±0.6	3.0±0.1	2.9±0.5	4.4±0.2	3.8±0.3	3.3±0.2	3.8±0.3	4.1±0.7	2.000	0.056
Toothpacking	4.4±0.3	4.1±0.2	4.0±0.2	5.0±0.3	4.6±0.3	4.5±0.2	4.4±0.2	4.4±0.6	0.683	0.687
Raw potato flavour	3.5±0.4	3.1±0.5	2.8±0.3	1.8±0.4	2.9±0.3	3.1±0.2	2.3±1.2	3.2±0.7	1.227	0.288
Fried potato flavour	4.8±0.4	4.6±0.4	4.9±0.1	4.5±0.2	4.8±0.2	4.9±0.4	4.4±0.4	4.7±0.5	0.153	0.994
Burnt flavour	**$0.7^{ab}\pm0.3$**	**$1.2^{b}\pm0.4$**	**$4.7^{d}\pm0.7$**	**$0.3^{ab}\pm0.3$**	**$2.5^{c}\pm0.9$**	**$0.2^{a}\pm0.1$**	**$0.8^{ab}\pm0.2$**	**$1.0^{ab}\pm0.6$**	**20.265**	**< 0.001**
Salty taste	1.4±0.1	1.2±0.2	0.8±0.2	1.2±0.3	1.3±0.2	1.7±0.6	1.2±0.1	1.0±0.1	0.694	0.677
Rancid oil flavour	1.4±0.4	1.3±0.3	2.0±0.4	0.7±0.8	1.6±0.2	0.9±0.4	1.6±0.5	1.5±0.2	1.126	0.347
Oily flavour	3.9±0.4	3.5±0.2	2.9±0.4	3.6±0.0	3.7±0.6	3.2±0.3	4.0±0.5	3.4±0.1	0.682	0.687
Bitter taste	2.2±0.0	2.1±0.2	2.8±0.7	1.4±0.2	2.5±0.4	1.8±0.2	2.0±0.6	2.0±0.1	0.544	0.801
Bitter aftertaste	2.4±0.1	2.2±0.1	3.0±0.3	1.3±0.2	2.6±0.4	1.9±0.2	1.9±0.4	2.0±0.4	0.885	0.519
Residual particles	3.2±0.3	2.9±0.3	3.3±0.2	3.0±0.4	2.8±0.1	3.0±0.5	2.9±0.1	3.0±0.2	0.173	0.990
Tooth packing	3.9±0.6	3.9±0.2	4.2±0.4	4.2±0.1	3.5±0.3	4.1±0.1	3.6±0.1	3.8±0.2	0.364	0.922
Oily aftertaste	3.4±0.6	3.1±0.8	2.6±0.0	2.9±0.3	3.0±0.2	3.2±0.3	3.4±0.2	3.0±0.2	0.267	0.966

[1] Means in a row with different letters (abcde) are significantly different (p<0.05)
[2] Refer to Table 1. for attributes definitions
[3] Ratings are based on unstructured line scales ranging from 0 to 10.

Table 3.5 Mean (± standard deviation) ratings for the descriptive sensory attributes of sour cream and onion flavoured potato chips

Attribute[1,2]	Potato samples								F-Value	P-value
	AV	BW_1	BW_2	CW	CX	DY	DW	DZ		
Raw potato aroma	2.7±2.8	2.5±2.8	2.1±2.7	1.7±2.3	1.7±2.5	2.2±2.9	1.7±2.4	2.1±2.6	0.648	0.716
Fried potato aroma	2.7±2.6	3.2±2.8	3.5±2.9	3.1±2.8	3.3±3.0	2.6±2.6	3.0±2.7	3.2±2.5	0.376	0.916
Burnt aroma	0.8±1.9	0.7±1.6	1.4±2.3	1.1±2.3	1.9±2.8	0.7±1.7	0.5±1.4	0.7±1.9	1.834	0.081
Onion aroma	2.0±2.2	2.0±2.1	1.9±2.0	2.1±2.2	2.2±2.3	2.4±2.3	1.2±1.5	1.8±2.1	0.975	0.450
Oily aroma	2.1±1.8	2.5±2.3	1.9±2.0	2.0±1.8	2.4±2.3	1.9±1.8	3.2±2.3	1.7±1.9	1.753	0.097
Sour aroma	4.2±2.7	4.2±2.8	4.3±2.9	3.7±2.5	3.9±3.0	4.1±2.8	3.2±2.4	3.7±2.8	0.598	0.757
Rancid oil aroma	**1.5^{a}±2.3**	**2.4^{a}±2.9**	**1.3^{a}±1.8**	**1.4^{a}±2.4**	**2.0^{a}±2.9**	**1.9^{a}±2.7**	**4.0^{b}±3.5**	**1.3^{a}±2.4**	**3.801**	**0.001**
Thickness	4.6±1.7	3.9±2.1	4.4±1.8	4.6±1.6	4.9±1.8	3.7±1.9	4.4±1.9	4.1±1.9	1.545	0.152
Roughness	4.9±2.3	5.1±2.5	5.1±2.3	5.5±2.0	4.8±2.2	5.3±1.9	4.5±2.1	3.9±2.2	1.831	0.082
Oily/greasy	4.1±2.4	4.0±2.6	3.7±2.4	3.8±2.0	4.3±2.6	4.2±2.1	3.9±2.6	3.7±2.1	0.308	0.950
Blisters	3.5±2.2	4.5±2.8	4.4±2.4	4.6±2.1	4.1±2.1	3.8±2.2	3.8±2.6	2.9±2.2	1.967	0.060
Brown specks	**1.8^{a}±1.5**	**1.5^{a}±1.9**	**3.8^{c}±2.8**	**2.0^{ab}±2.6**	**3.0^{bc}±2.9**	**1.0^{a}±1.2**	**1.5^{a}±1.7**	**1.7^{a}±1.8**	**6.213**	**< 0.001**
Ease of breaking	**3.6^{ab}±1.9**	**2.8^{a}±2.1**	**3.7^{ab}±2.3**	**4.3^{b}±2.1**	**3.5^{ab}±2.3**	**3.1^{a}±1.8**	**3.0^{a}±1.9**	**3.0^{a}±1.7**	**2.097**	**0.044**
Crispness	6.9±1.5	6.3±1.9	6.8±2.0	6.0±2.1	6.2±1.8	6.0±1.9	6.4±1.9	6.0±1.8	1.142	0.337
Fracturability	5.1±2.2	5.1±2.2	5.5±2.1	4.5±2.3	5.1±2.2	5.0±2.1	5.2±2.3	4.3±2.3	0.955	0.465
Hardness (incisors)	**3.2^{ab}±2.1**	**2.5^{a}±2.0**	**3.6^{b}±2.2**	**4.7^{c}±2.5**	**3.8^{bc}±1.7**	**3.2^{ab}±1.8**	**3.2^{ab}±2.1**	**3.7^{bc}±2.1**	**3.122**	**0.004**
Hardness (molars)	**3.5^{b}±2.2**	**2.3^{a}±1.9**	**3.3^{b}±2.0**	**4.6^{c}±2.4**	**3.8^{bc}±2.0**	**3.3^{b}±2.1**	**3.3^{b}±1.8**	**3.9^{bc}±2.0**	**3.600**	**0.001**
Crunchiness	6.1±1.6	5.5±2.4	6.3±1.9	6.0±2.2	6.3±2.0	6.2±1.7	5.9±1.8	5.7±1.9	0.708	0.666
Gritiness/graininess	4.3±1.9	4.5±2.3	4.2±1.8	4.5±1.7	4.3±2.0	4.1±2.0	4.2±1.9	4.3±2.0	0.194	0.987
Rate of breakdown	**3.6^{b}±1.7**	**2.5^{a}±1.7**	**3.5^{b}±2.0**	**4.8^{c}±2.0**	**3.9^{bc}±2.2**	**3.6^{b}±2.0**	**3.4^{b}±1.7**	**3.7^{b}±1.8**	**3.757**	**0.001**
Toothpacking	3.9±1.8	3.4±1.8	3.7±2.1	4.5±2.2	4.0±2.3	3.6±1.8	3.8±2.0	4.4±2.1	1.101	0.363
Raw potato flavour	1.9±2.4	1.3±1.7	0.9±1.5	1.0±1.6	1.1±1.9	1.0±1.6	0.9±1.5	1.7±2.2	1.532	0.157
Fried potato flavour	3.4±2.7	3.3±2.8	3.3±2.9	3.6±2.9	4.3±2.7	2.8±2.9	3.3±2.8	3.6±2.6	0.751	0.629
Burnt flavour	**0.7^{a}±1.4**	**0.8^{a}±1.2**	**2.4^{b}±2.6**	**1.2^{a}±2.1**	**2.3^{b}±3.1**	**0.4^{a}±1.2**	**0.4^{a}±1.0**	**0.6^{a}±1.4**	**6.428**	**< 0.001**
Salty taste	2.6±2.0	3.1±2.2	3.6±2.5	3.0±2.1	3.1±2.3	2.7±2.3	2.6±2.0	2.2±1.8	1.177	0.316
Sour taste	4.2±2.9	4.4±2.9	4.7±3.1	4.4±3.0	4.3±3.2	4.6±3.2	3.3±2.7	3.4±2.9	1.027	0.412
Rancid oil flavour	**1.0^{a}±1.9**	**1.3^{a}±1.9**	**0.6^{a}±1.1**	**0.7^{a}±1.2**	**0.8^{a}±1.1**	**0.8^{a}±1.4**	**2.9^{b}±3.3**	**0.8^{a}±1.6**	**5.801**	**< 0.001**
Oily flavour	1.7±2.0	1.9±1.8	1.1±1.3	1.8±1.7	2.2±2.5	1.7±1.7	2.7±2.1	1.9±2.2	1.851	0.078
Bitter taste	0.7±1.3	1.5±2.5	1.5±2.7	1.3±2.2	1.7±2.3	1.2±2.3	0.9±1.8	1.2±2.1	0.712	0.662
Onion flavour	2.4±2.4	2.9±1.9	2.6±2.3	3.1±2.4	2.5±2.1	2.8±2.2	1.7±1.8	1.8±1.9	1.702	0.109
Sweet taste	1.7±1.7	1.7±1.4	1.8±1.5	1.9±1.8	1.8±1.9	1.5±1.4	1.3±1.3	1.1±1.2	1.291	0.255
Bitter aftertaste	0.6±1.1	1.5±2.6	1.5±2.6	1.5±2.4	1.4±2.1	1.0±1.7	1.1±2.1	1.4±2.6	0.663	0.703
Residual particles	2.8±2.3	2.5±2.1	2.5±1.8	2.6±2.0	2.9±2.1	3.0±2.2	2.7±1.9	2.9±2.3	0.286	0.959
Tooth packing	3.6±2.2	3.1±2.2	3.3±2.2	3.3±2.5	3.1±2.2	3.2±2.0	3.3±2.6	3.3±2.0	0.174	0.990
Oily aftertaste	1.8±2.1	1.6±2.2	1.2±1.6	1.3±1.4	1.7±2.4	1.5±1.7	2.7±2.7	2.0±2.5	1.519	0.161

[1] Means in a row with different letters (abcde) are significantly different (p<0.05)
[2] Refer to Table 1. for attributes definitions
[3] Ratings are based on unstructured line scales ranging from 0 to 10

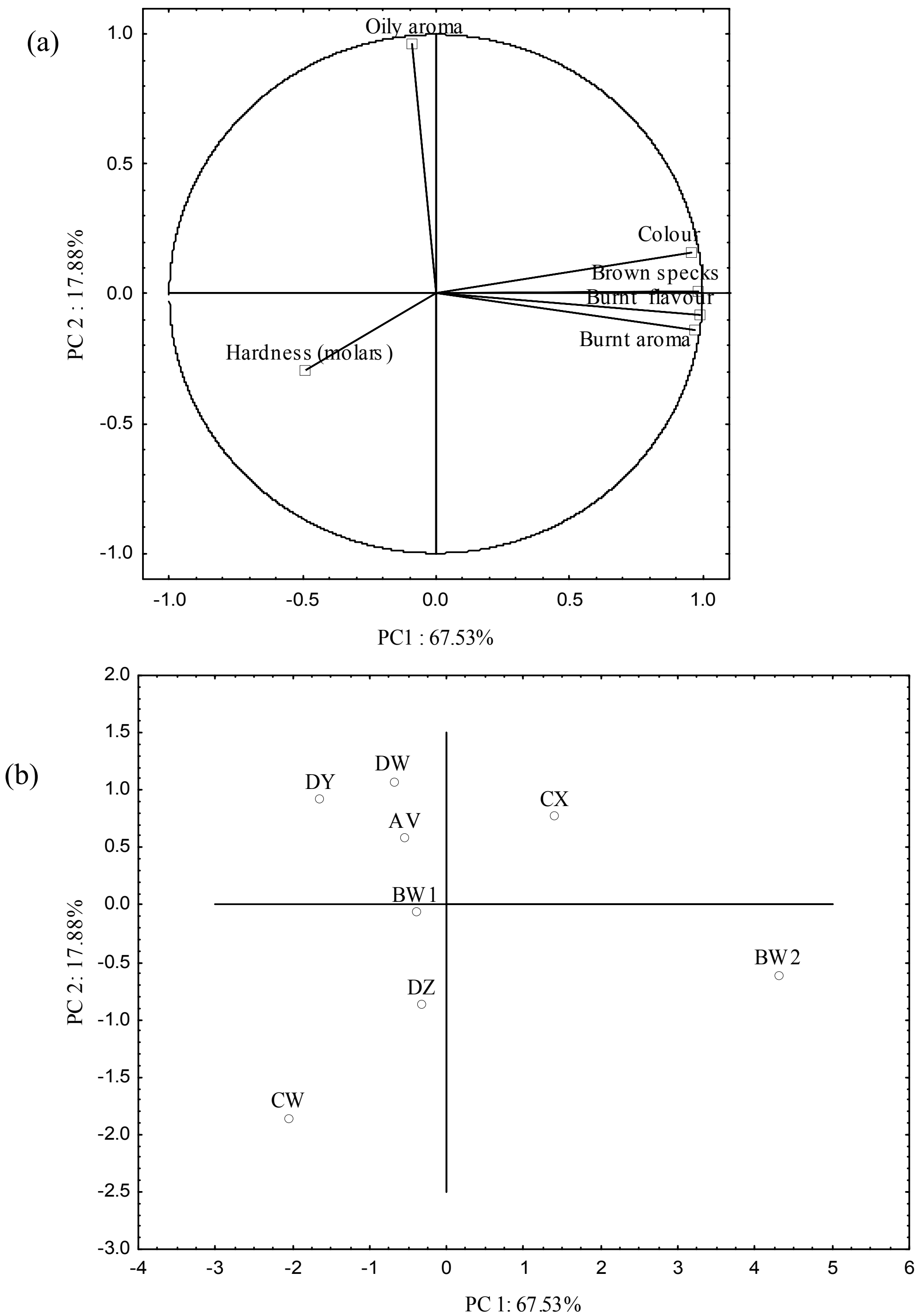
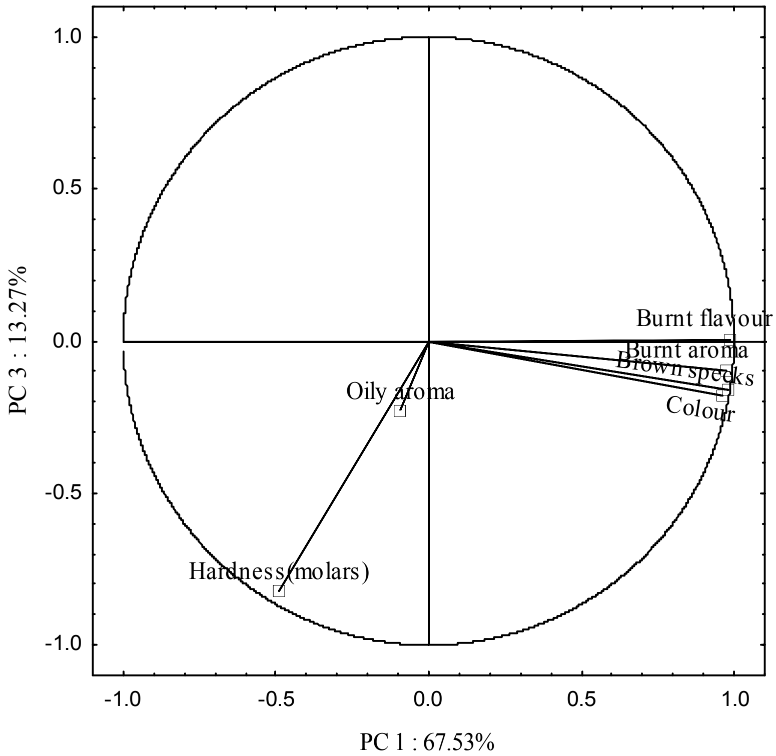


Fig. 3.4 Results of PCA of sensory attributes of unflavoured potato chips. (a) Plot of the loading vectors of the ratings of sensory descriptors for PC1 and PC2; (b) plot of factor scores of the unflavoured potato chips for PC1 and PC2

(a)



(b)

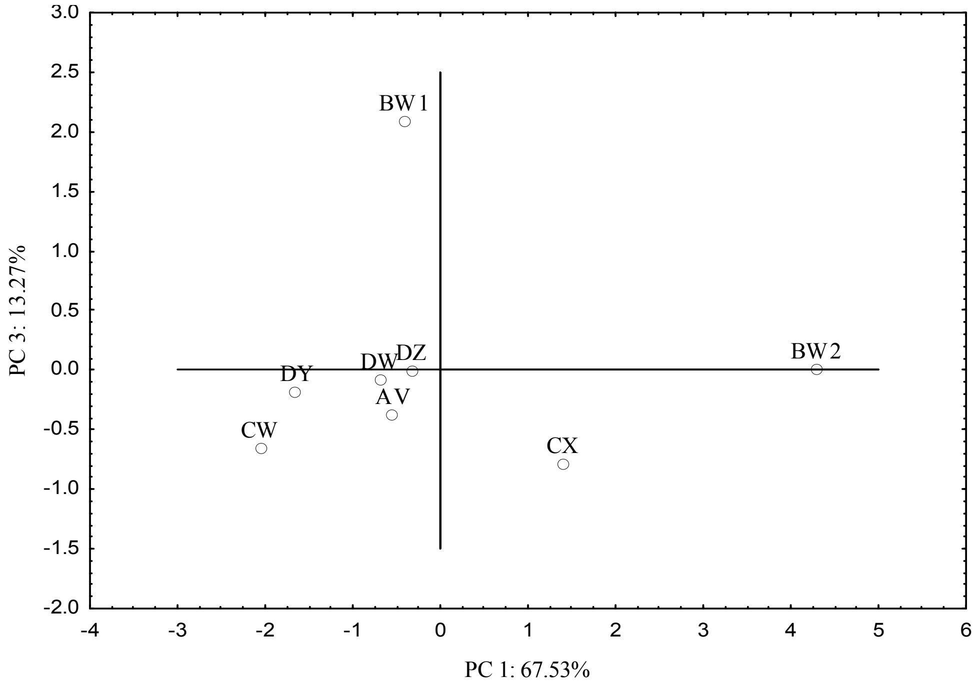


Fig. 3.5 Results of PCA of sensory attributes of unflavoured potato chips. (a) Plot of the loading vectors of the ratings of sensory descriptors for PC1 and PC3; (b) plot of factor scores of the unflavoured potato chips for PC1 and PC3

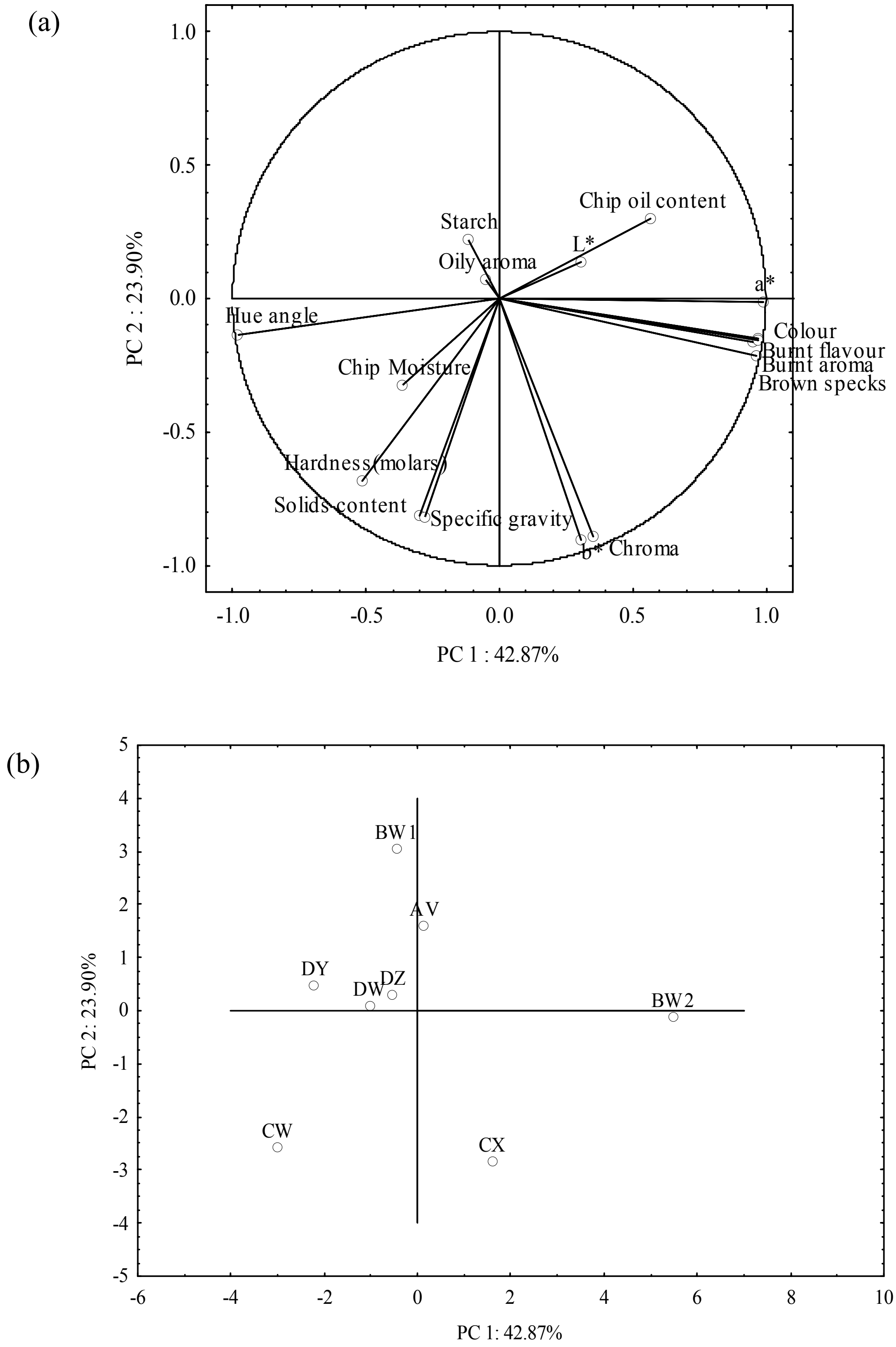


Fig. 3.6 Results of principal components analysis of sensory attributes of unflavoured potato chips, physico-chemical characteristics of the raw potatoes and unflavoured potato chips. PC1 and PC2

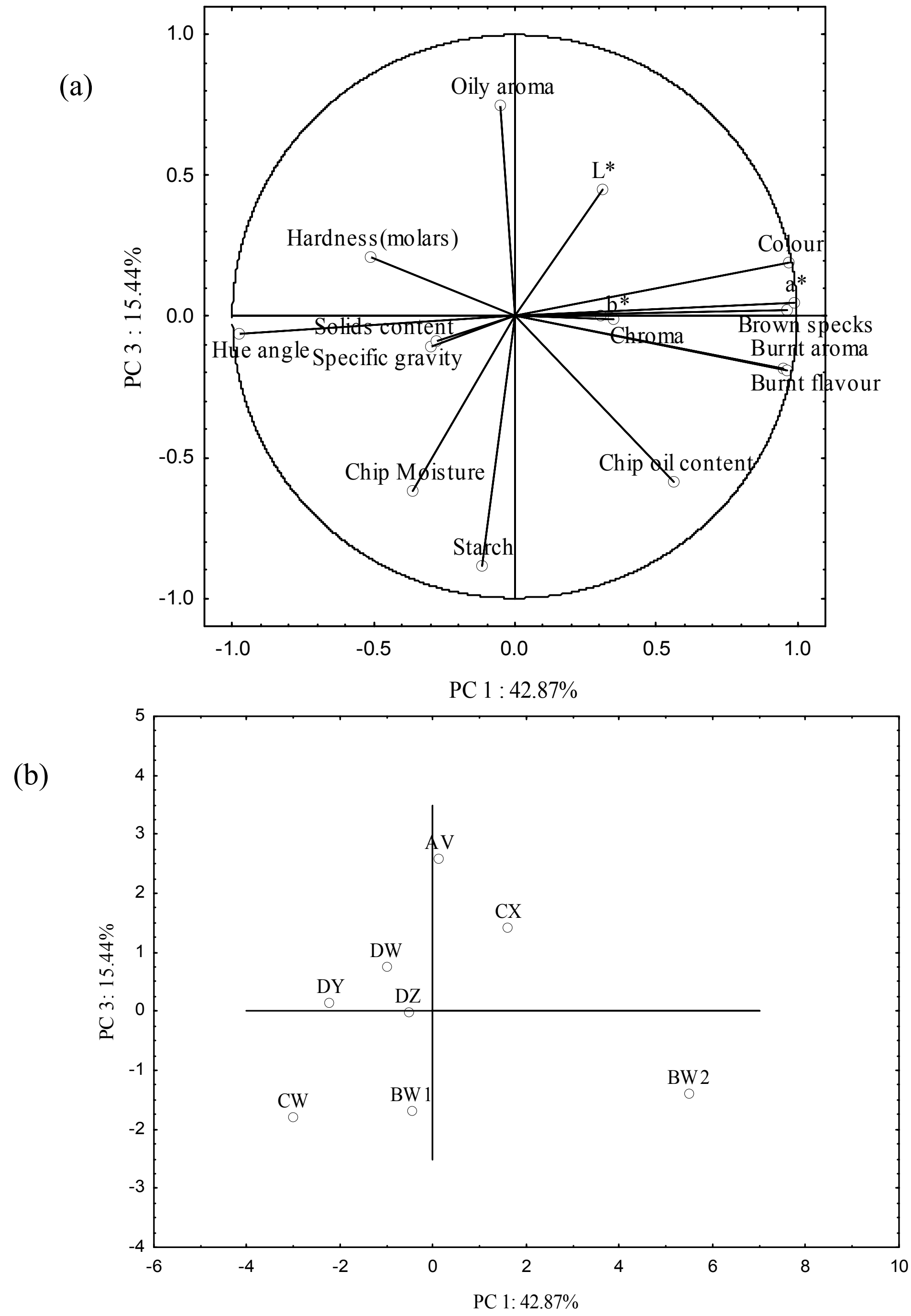


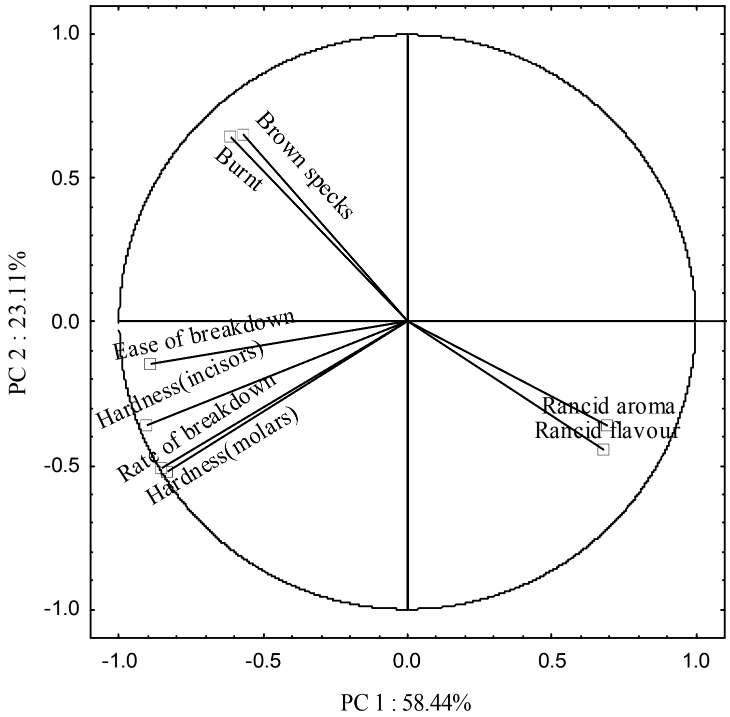
Fig. 3.7 Results of principal components analysis of sensory attributes of unflavoured potato chips, physico-chemical characteristics of the raw potatoes and unflavoured potato chips. PC1 and PC3

PCA of the eight attributes which discriminated significantly ($p \leq 0.05$) among the flavoured potato chips samples showed that 95.59% of the variance could be explained by the first three principal components (Fig. 3.8 and Fig. 3.9). PC 1 accounted for 58.44% of the total variance, whereas PC 2 and PC 3 explained 23.11% and 14.04%, respectively. PC 1 (Fig. 3.8a) distinguished samples on the basis of textural attributes (ease of breaking, hardness (incisors), hardness (molars), and rate of breakdown) and rancid attributes (rancid aroma and rancid flavour). On the left of PC 1 *CW* was separated from the other samples as being harder (incisors & molars), less easy to break and with a lower rate of breakdown during chewing. On the right of PC 1 *DW* was distinguished for rancid aroma and rancid flavour. PC 2 separated samples based on the presence of brown specks and burnt flavour. *BW2* and to a lesser extent *CX* had a more burnt flavour and more brown specks (Fig. 3.8a). PC 3 (Fig. 3.9) clearly separated *DW* from the other samples on the basis of rancid aroma and rancid flavour.

3.1.3.3 Consumer sensory evaluation

There were significant differences in acceptability of the unflavoured chip samples with regards to the overall liking, and liking of appearance, colour, texture and flavour (Table 3.6). The average overall liking ratings for the unflavoured chips ranged from 5.4 to 6.8 on the 9-point hedonic scale. As expected the average ratings of flavoured chips were higher than the unflavoured chips. The flavoured chip samples were on average all rated above 5.9. Although there were statistically significant differences in the hedonic ratings for different samples in both chip categories (unflavoured and flavoured) the differences in ratings across potato samples were relatively small. The range of differences were less than 1.1 units for liking of appearance, colour and texture; 1.4 units for overall liking; and 1.8 units for taste for both chip categories. Relative to other attributes rating of the flavour of chips in both categories received the lowest rating values.

(a)



(b)

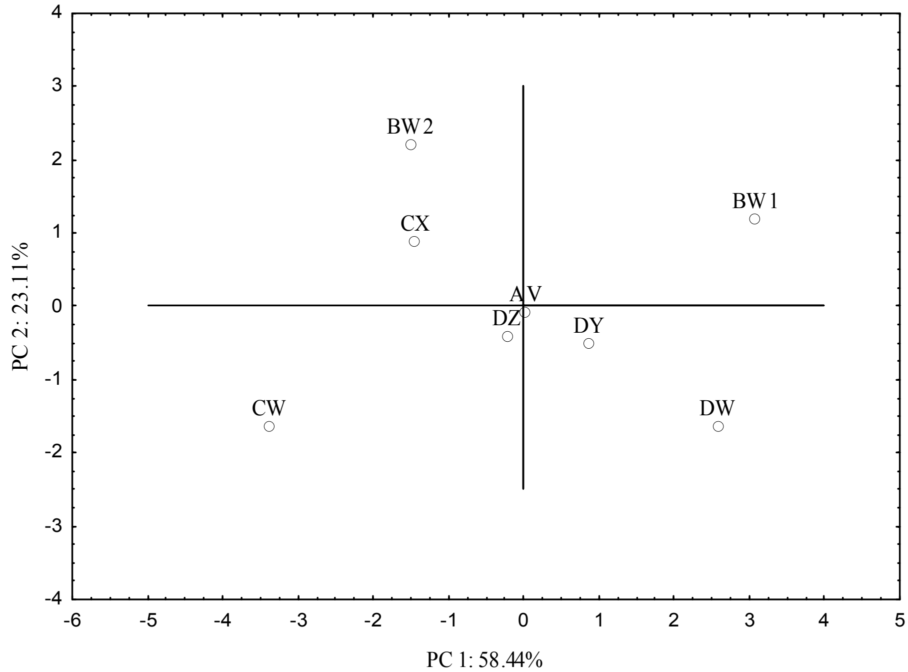
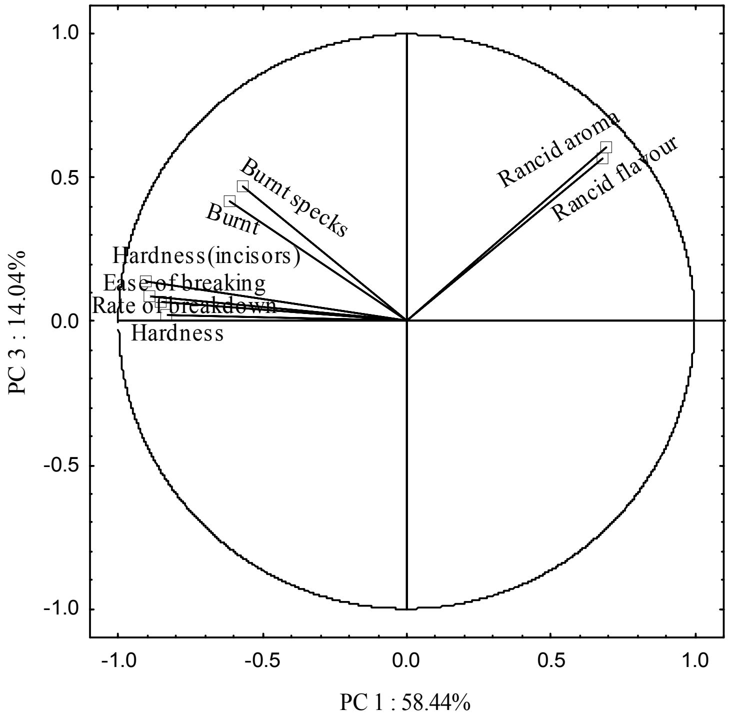


Fig. 3.8 Results of PCA of sensory attributes of flavoured potato chips. (a) Plot of the loading vectors of the ratings of sensory descriptors for PC1 and PC2; (b) plot of factor scores of the flavoured potato chips for PC1 and PC2

(a)



(b)

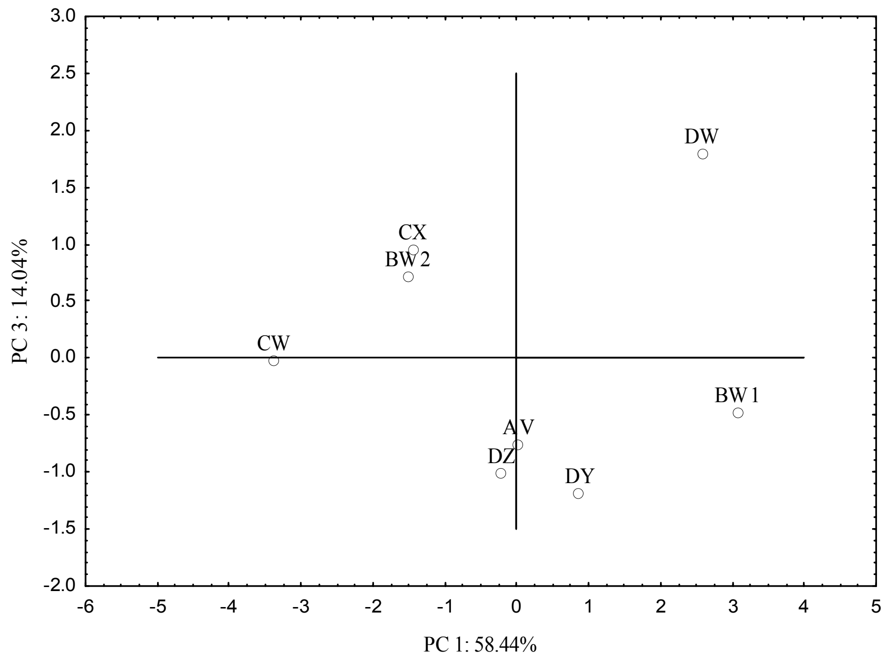


Fig. 3.9 Results of PCA of sensory attributes of flavoured potato chips. (a) Plot of the loading vectors of the ratings of sensory descriptors for PC1 and PC3; (b) plot of factor scores of the flavoured potato chips for PC1 and PC3

Table 3.6 Consumer acceptance (mean ± standard deviation) of the sensory attributes of unflavoured and flavoured potato chip samples

	Potato samples								F-value	P-value
Attribute[1,2]	**AV**	**BW_1**	**BW_2**	**CW**	**CX**	**DY**	**DW**	**DZ**		
Unflavoured chips										
Overall	$6.4^{cde}\pm0.2$	$5.6^{ab}\pm0.3$	$6.6^{de}\pm0.2$	$6.8^{e}\pm0.2$	$5.4^{a}\pm0.3$	$6.6^{de}\pm0.2$	$6.1^{bcd}\pm0.2$	$5.9^{abc}\pm0.3$	5.747	< 0.001
Appearance	$6.3^{abc}\pm0.2$	$5.8^{a}\pm0.3$	$6.8^{cd}\pm0.2$	$6.8^{d}\pm0.2$	$6.0^{a}\pm0.3$	$6.6^{bcd}\pm0.2$	$6.6^{bcd}\pm0.2$	$6.1^{ab}\pm0.2$	4.029	< 0.001
Colour	$6.1^{a}\pm0.2$	$6.1^{a}\pm0.3$	$7.0^{b}\pm0.2$	$6.9^{b}\pm0.2$	$6.0^{a}\pm0.2$	$6.7^{b}\pm0.2$	$6.7^{b}\pm0.2$	$6.0^{a}\pm0.2$	5.648	< 0.001
Texture	$6.5^{abc}\pm0.2$	$6.0^{a}\pm0.2$	$6.9^{c}\pm0.2$	$6.6^{bc}\pm0.2$	$6.1^{ab}\pm0.2$	$7.0^{c}\pm0.2$	$6.7^{c}\pm0.2$	$6.1^{ab}\pm0.2$	4.11	< 0.001
Taste	$6.1^{cd}\pm0.3$	$4.9^{a}\pm0.3$	$6.2^{cd}\pm0.3$	$6.4^{cd}\pm0.3$	$5.2^{ab}\pm0.3$	$6.7^{bcd}\pm0.3$	$5.7^{d}\pm0.2$	$5.4^{ab}\pm0.3$	6.963	< 0.001
Flavoured chips										
Overall	$6.6^{ab}\pm0.2$	$7.0^{bc}\pm0.2$	$7.6^{e}\pm0.2$	$7.6^{de}\pm0.2$	$7.0^{bcd}\pm0.2$	$7.2^{cde}\pm0.2$	$6.2^{a}\pm0.2$	$6.6^{ab}\pm0.2$	6.204	< 0.001
Appearance	$6.8^{abc}\pm0.2$	$7.2^{cd}\pm0.1$	$7.2^{cd}\pm0.2$	$7.6^{d}\pm0.2$	$6.3^{a}\pm0.3$	$6.9^{bc}\pm0.3$	$6.7^{ab}\pm0.2$	$6.8^{abc}\pm0.2$	5.270	< 0.001
Colour	$6.9^{ab}\pm0.2$	$7.3^{bc}\pm0.2$	$7.0^{b}\pm0.2$	$7.6^{c}\pm0.2$	$6.5^{a}\pm0.2$	$7.1^{b}\pm0.2$	$7.0^{ab}\pm0.2$	$6.8^{ab}\pm0.2$	3.470	< 0.001
Texture	$6.7^{ab}\pm0.2$	$7.2^{bc}\pm0.2$	$7.2^{b}\pm0.2$	$7.5^{c}\pm0.2$	$7.0^{a}\pm0.2$	$7.1^{b}\pm0.2$	$6.6^{ab}\pm0.2$	$6.8^{ab}\pm0.2$	3.05	0.004
Taste	$6.5^{abc}\pm0.3$	$6.8^{bcd}\pm0.3$	$7.2^{de}\pm0.3$	$7.6^{e}\pm0.2$	$6.9^{cde}\pm0.3$	$7.0^{cde}\pm0.3$	$5.9^{a}\pm0.2$	$6.1^{ab}\pm0.3$	5.121	< 0.001

[1] Means in a row followed by different letters (abcde) represent significant differences ($p\leq0.05$)

[2] Acceptability was measured on 9-point hedonic scale from 1 = 'dislike extremely' to 9 = 'like extremely'

The dendograms generated using hierarchical cluster analysis of hedonic data indicated that two clusters was a reasonable number of clusters to be used in this study (Fig. 3.10 and Fig. 3.11). As shown in Fig. 3.10 and Fig. 3.11, the use of three clusters would result in one cluster having very few consumers (n=5 or 9, respectively) thus the selection of two clusters. The mean ratings for overall liking of each category (flavoured and unflavoured chips) by clusters are shown in Table 3.7.

The internal preference maps of the consumer overall liking data for the unflavoured chips are shown in Fig. 3.12 and Fig. 3.13. Each individual consumer is represented as a + or * (Fig. 3.12a and Fig. 3.13a). For the unflavoured chips 65% of the variance in the data could be explained by the first 3 principal components. PC 1 separated consumers on the right that generally liked all the chip samples from those on the left who liked the chips less (Fig. 3.12a). PC 2 separated consumers who preferred *AV* and *DY* more from those who preferred *DZ, BW2* and *BW1.* PC 3 (Fig. 3.13a) separated consumers at the top who preferred *CX* and *BW1* from those at the bottom preferring *DW*, *CW* and *BW2*. Cluster 1(*) consumers (46%) generally liked (i.e. gave high ratings) for all the chip samples while cluster 2 (+) consumers (54%) generally gave lower ratings.

The internal preference maps of the consumer overall liking data for the flavoured chips are shown in Fig. 3.14 and Fig. 3.15. The potato chip samples (Fig. 3.14a) were grouped on the right side of PC1, similar to the observation made for the unflavoured potato chips. PC1 (31.71%) separated consumers on the right who generally liked all the chip samples from those on the left who liked the chips less. PC2 (17.13 %) separated consumers who had preference for samples *CW* on the top and to a lesser extent *DY* to those who preferred *BW1* and to a lesser extent *DW* and *DZ.* PC3 separated consumers who had preference for the dark coloured chips *CX* and *BW2* from those who disliked them. From these maps, it appears that there was no clear preference of one chip sample over the other samples. There were more cluster 1(*) consumers (62%) that gave a high rating for the chip samples compared to cluster 2 (+) consumers (38%).

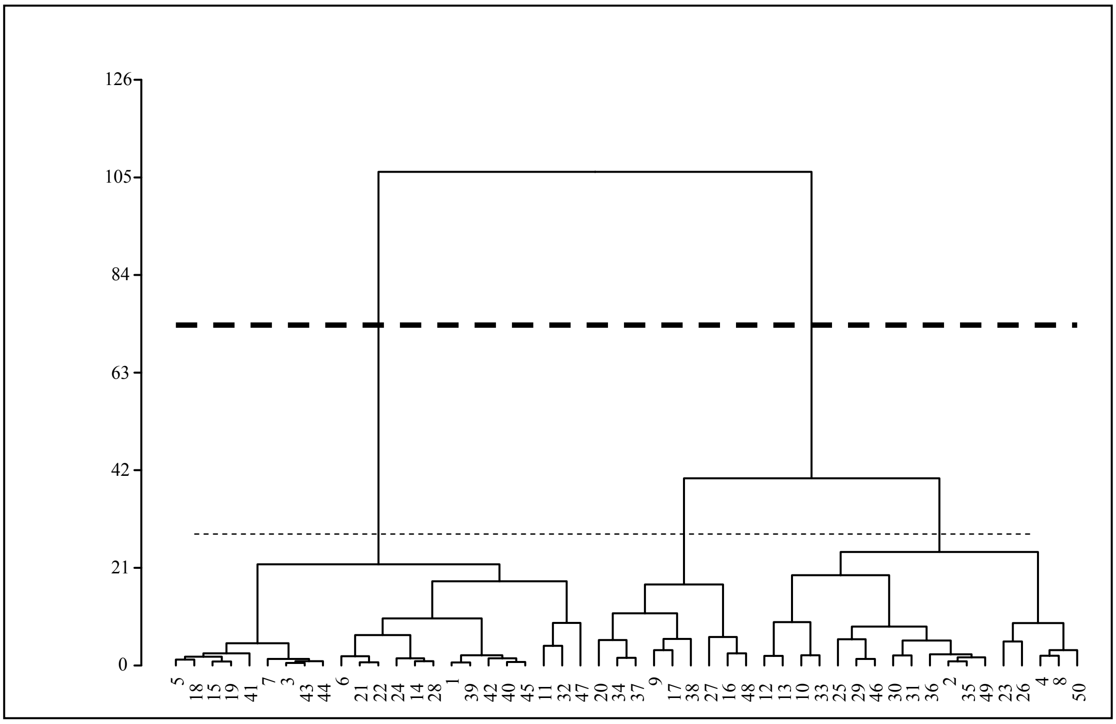


Fig. 3.10 Dendogram for hierarchical cluster analysis using Ward's method showing division of two clusters (**----**) and three clusters (----) of 50 consumers' overall liking scores of unflavoured potato chip samples

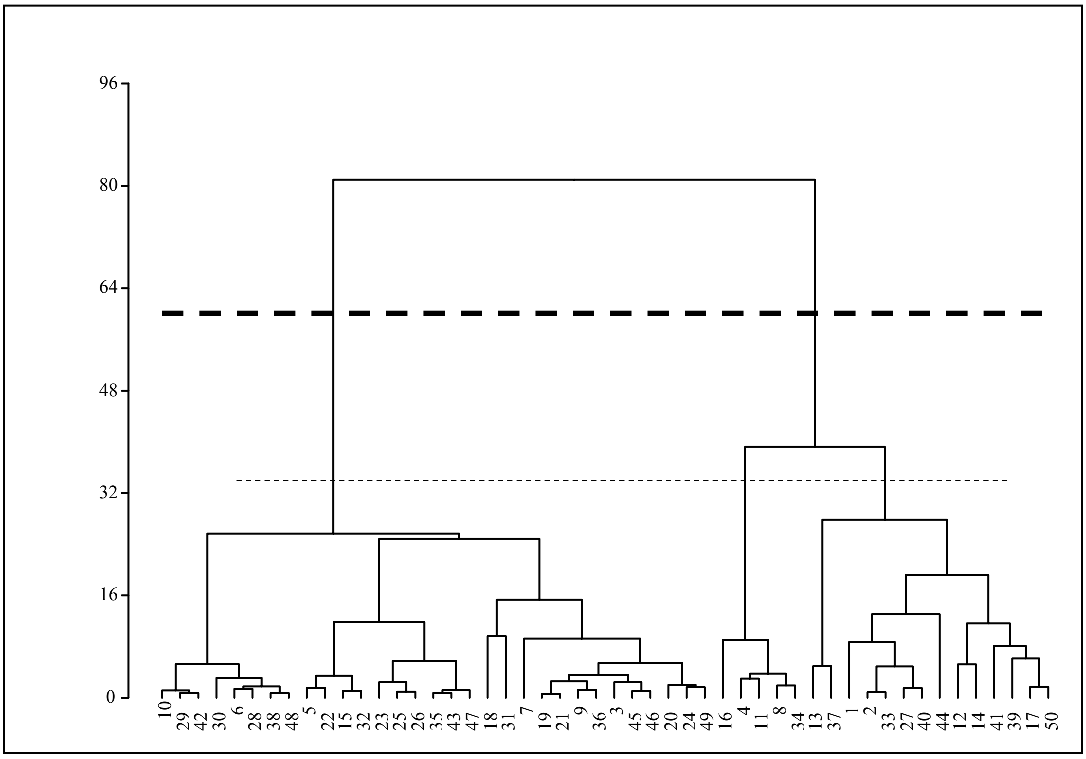


Fig. 3.11 Dendogram for hierarchical cluster analysis using Ward's method showing the division of two clusters (**----**) and three clusters (----) of 50 consumers' overall liking scores of sour cream and onion flavoured chip samples

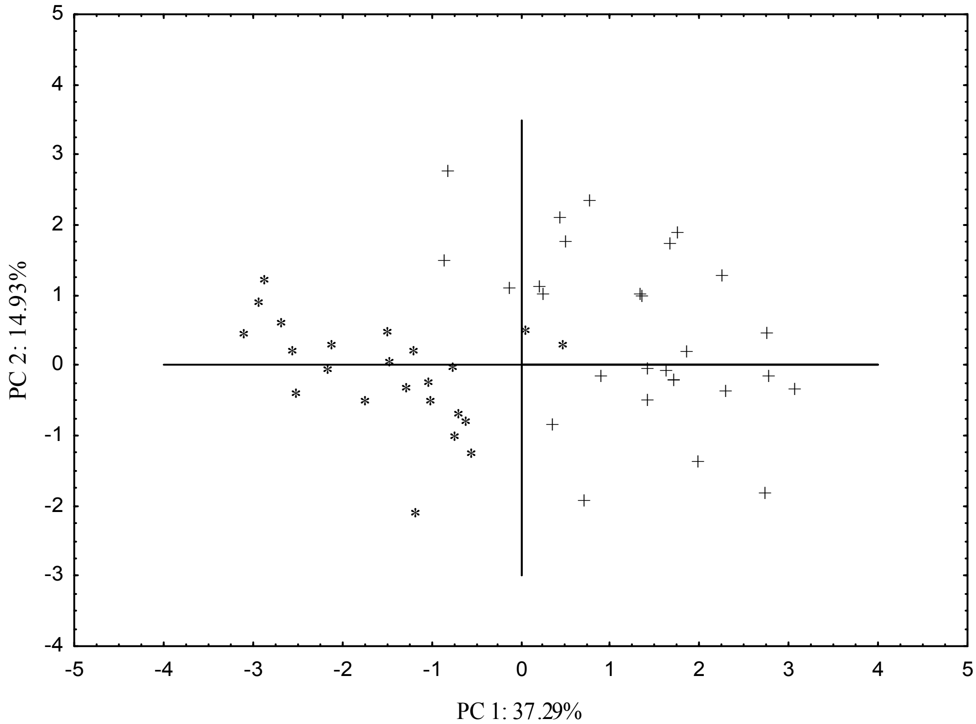
Table 3.7 Mean ratings of the unflavoured and flavoured potato chip samples for 2 clusters of consumers from hierarchical cluster analysis of the overall preferences.

Cluster	*N*(%)	**Potato chip samples**							
		AV	***BW_1***	***BW_2***	***CW***	***CX***	***DY***	***DW***	***DZ***
Unflavoured chips									
1(*)	23 (46%)	$6.7^{a} \pm 1.6$	$6.8^{b} \pm 1.4$	$7.6^{b} \pm 0.7$	$7.6^{b} \pm 1.2$	$6.9^{b} \pm 0.8$	7.0 ± 1.5	$7.0^{b} \pm 1.3$	$7.4^{b} \pm 1.2$
2(+)	27 (54%)	$6.0^{a} \pm 1.6$	$4.6^{a} \pm 1.8$	$5.8^{a} \pm 1.85$	$6.1^{a} \pm 1.6$	$4.1^{a} \pm 1.6$	6.4 ± 1.8	$5.4^{a} \pm 1.4$	$4.6^{a} \pm 1.7$
***p*-value**		**0.129**	**< 0.001**	**< 0.001**	**0.001**	**< 0.001**	**0.228**	**< 0.001**	**< 0.001**
Flavoured chips									
1(*)	31 (62%)	$7.0^{b} \pm 1.7$	$7.6^{b} \pm 0.9$	$8.1^{b} \pm 1.1$	$8.0^{b} \pm 1.1$	$7.5^{b} \pm 1.2$	$7.7^{b} \pm 1.0$	$7.0^{b} \pm 1.1$	$7.1^{b} \pm 1.2$
2(+)	19 (38%)	$5.9^{a} \pm 1.4$	$5.9^{a} \pm 2.2$	$6.9^{a} \pm 1.1$	$6.8^{a} \pm 2.0$	$6.3^{a} \pm 2.0$	$6.4^{a} \pm 1.0$	$4.9^{a} \pm 1.8$	$5.7^{a} \pm 1.8$
***p*- value**		**0.018**	**< 0.001**	**0.001**	**0.010**	**0.017**	**< 0.001**	**< 0.001**	**0.002**

[1]Means in a column for the respective categories (unflavoured or flavoured) followed by different letters (a, b) represent significant differences ($p \leq 0.05$)

[2]Acceptability was measured on 9-point hedonic scale from 1 = 'dislike extremely' to 9 = 'like extremely'

(a)



(b)

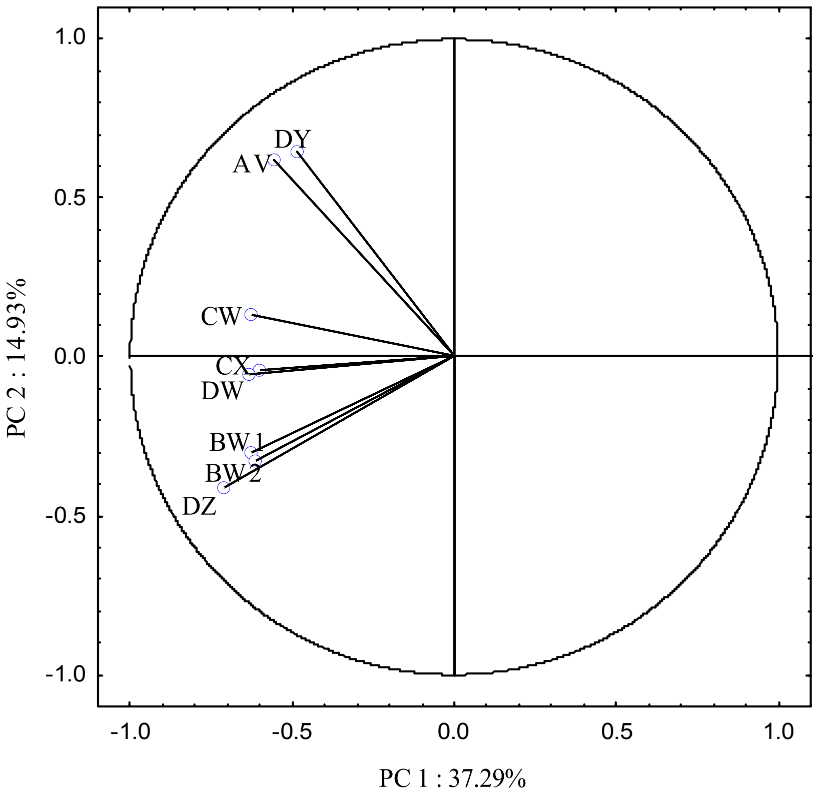
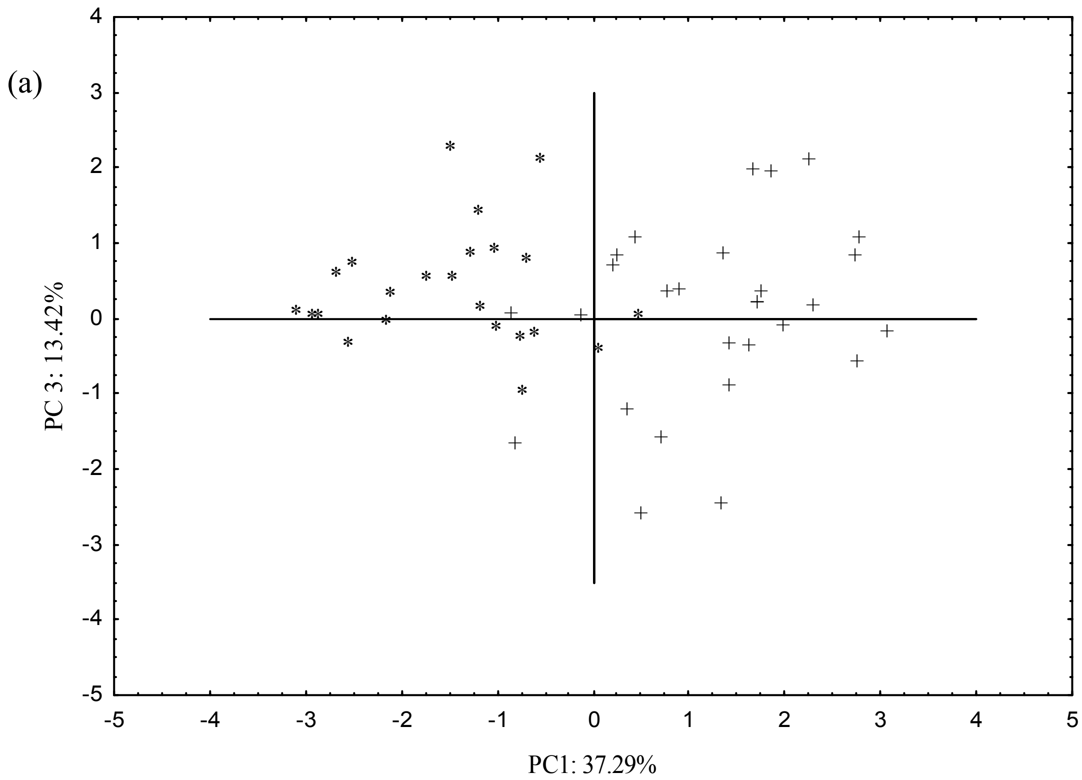


Fig. 3.12 Internal preference mapping (PC1 and PC2) indicating the position of the (a) consumers (n = 50) in two cluster groups (cluster 1= +, cluster 2 = *) and (b) the unflavoured potato chip samples



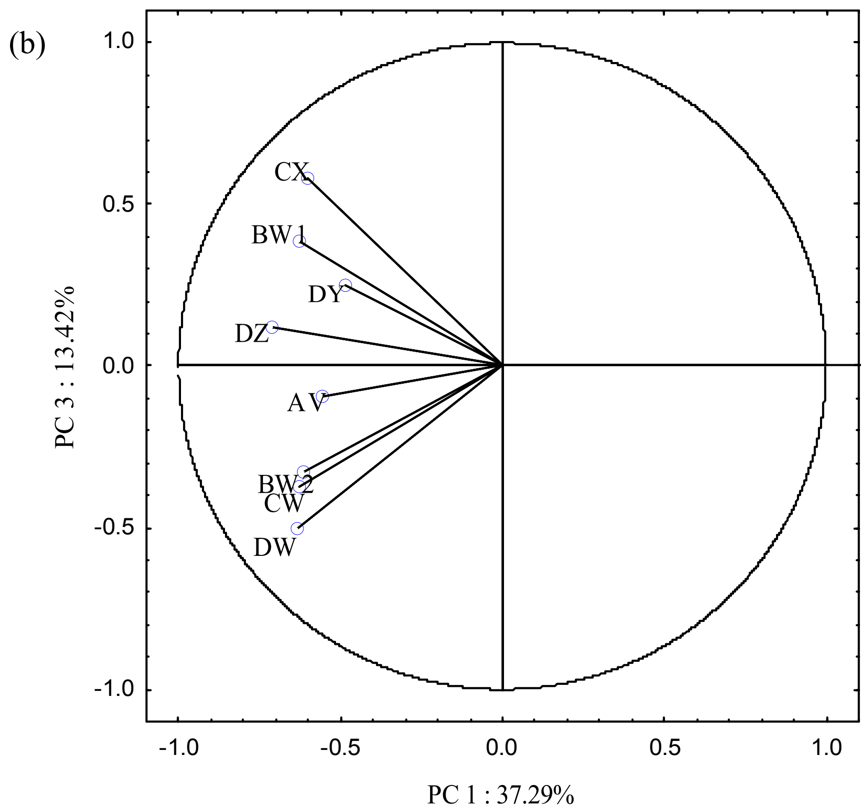
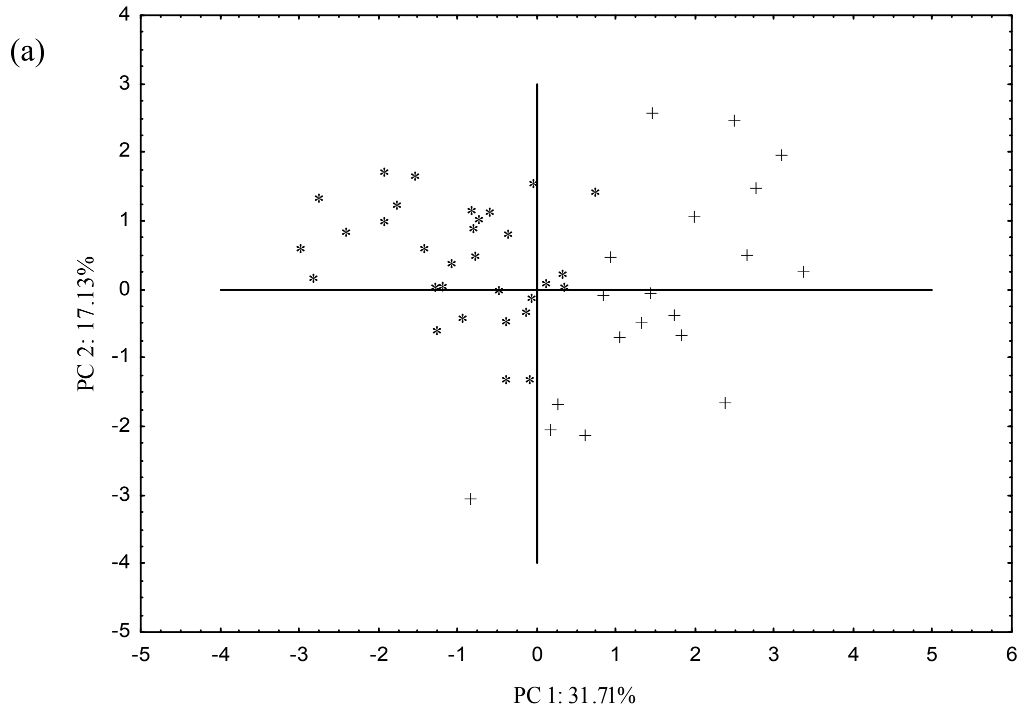


Fig. 3.13 Internal preference mapping (PC1 and PC3) indicating the position of the (a) consumers (n = 50) in two cluster groups (cluster 1= +, cluster 2 = *) and (b) the unflavoured potato chip samples



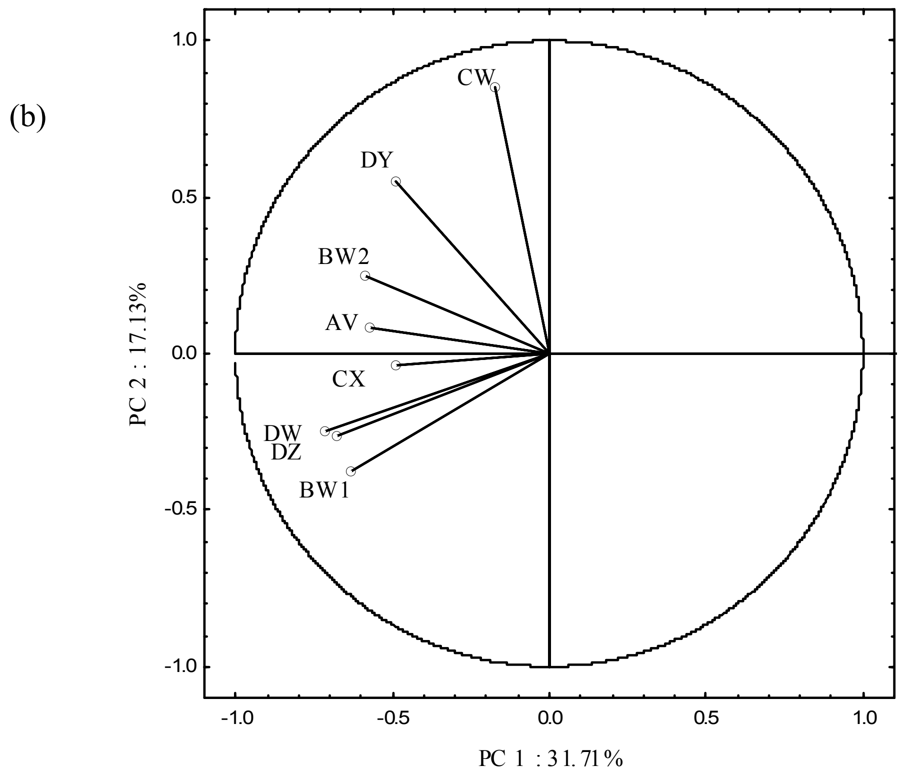
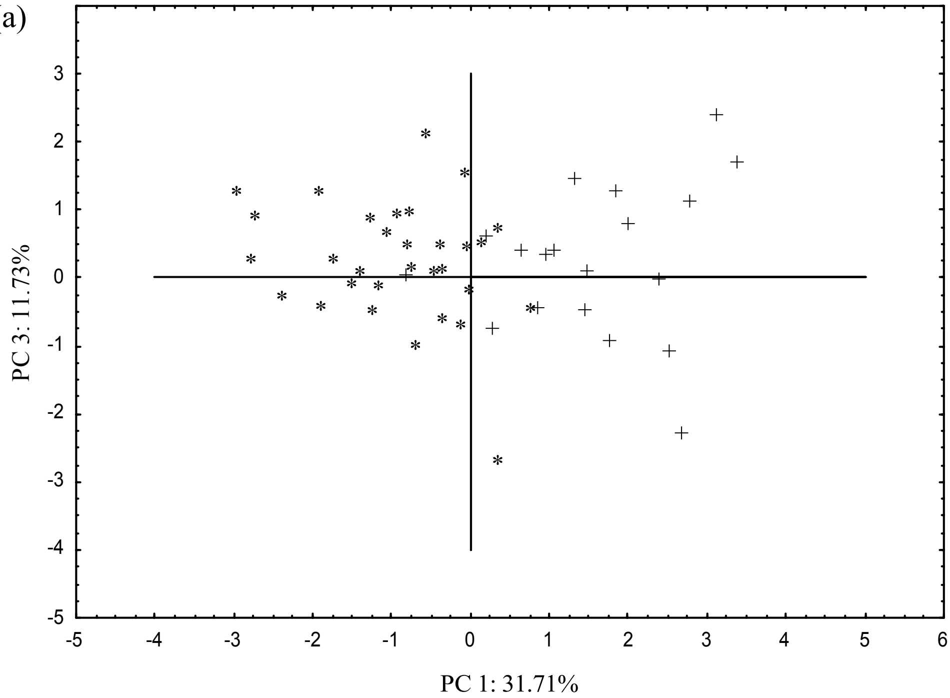


Fig. 3.14 Internal preference mapping (PC1 and PC2) indicating the position of the (a) consumers (n = 50) in two cluster groups (cluster 1= +, cluster 2 = *) and (b) the flavoured potato chip samples

(a)



(b)

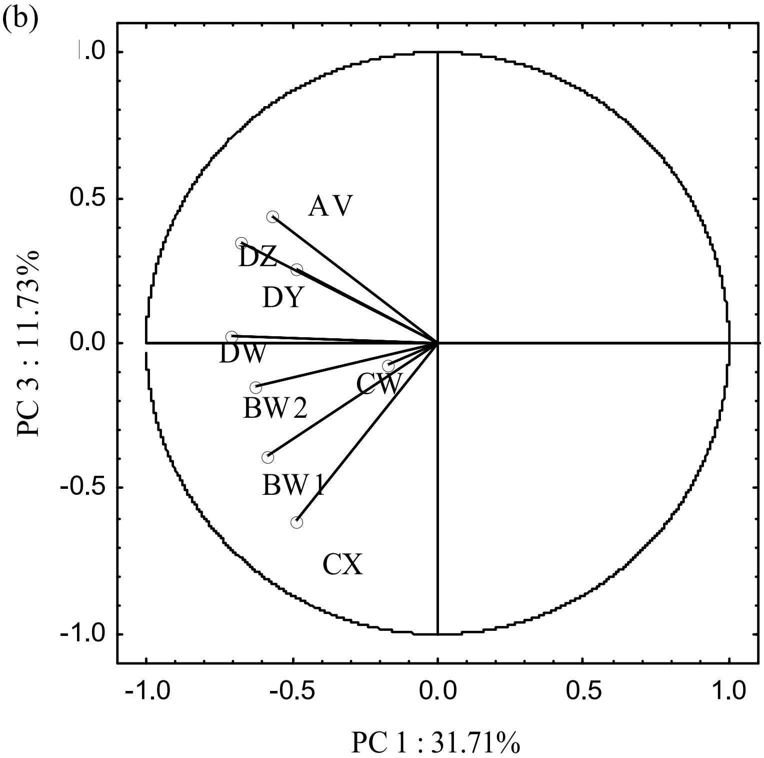


Fig. 3.15 Internal preference mapping (PC1 and PC2) indicating the position of the (a) consumers (n = 50) in two cluster groups (cluster 1= +, cluster 2 = *) and (b) the flavoured potato chip samples

Only a few consumers were significantly ($p< 0.10$) fitted into any of the four models external preference models (Table 3.8 and Table 3.9) i.e. for the unflavoured chips 3 consumers were fitted by the vector model and 10 by the circular model and 7 and 5 consumers were fitted respectively by the vector and circular models for the unflavoured chips. The quadratic and elliptical models did not fit any consumer ($p>0.10$) in both categories of chips.

3.1.4 DISCUSSION

The specific gravity and solids content of the potato samples included in this study differed significantly. However the values were within the range reported to be acceptable for potato chip manufacture, except those for *AV* which were lower. The total solids of potatoes destined for chip manufacture should be in the range of 20% to 22%, which equates to specific gravities of 1.08 to 1.09, respectively (Adams, 2004). The variation in potato samples of different varieties is probably due to genotypic differences that are inherent within a variety (Kumar, *et al*., 2004; Lisiñska, 1989). The higher specific gravity values of *CW* and *CX* (1.093 g/cm^3 and 1.098 g/cm^3) compared to the other potatoes could be due to a variety effect. The specific gravity is dependent on the dry matter components of the potatoes with a contribution of up to 75 % by starch (Leszcyñski, 1989). Factors such as soil moisture, soil temperature and fertilisation affecting the growth and maturation of the potatoes in a particular location will ultimately influence the specific gravity (Kumar, *et al*., 2004). Although the effect of growing season (Kumlay *et al*., 2002) and date of harvest (Liu, Weber, Currie & Yada, 2003) has been reported to affect the dry matter content (specific gravity) of potatoes it was found that the specific gravity of *BW* potatoes grown in the same region but harvested at different time periods (two weeks apart) did not differ significantly.

Table 3.8 Analysis of the most suitable external preference model to explain the sensory rating of the individual consumers for the 8 unflavoured potato chip samples

Consumer	Model	Point type	DF	SS	Mean squares	R^2	F-ratio	p value
1	Vector	-	2	0.691	0.346	0.142	0.413	0.682
2	**Circular**	**Anti-ideal**	**3**	**5.451**	**1.817**	**0.899**	**11.905**	**0.026**
3	Vector	-	2	0.850	0.425	0.425	1.848	0.251
4	Vector	-	2	7.271	3.635	0.338	1.277	0.356
5	Vector	-	2	3.048	1.524	0.508	2.581	0.170
6	Vector	-	2	4.361	2.180	0.168	0.504	0.632
7	Vector	-	2	3.368	1.684	0.421	1.817	0.255
8	Vector	-	2	4.458	2.229	0.451	2.057	0.223
9	Circular	Anti-ideal	3	18.801	6.267	0.730	3.603	0.131
10	Vector	-	2	8.976	4.488	0.392	1.614	0.288
11	Vector	-	2	5.452	2.726	0.214	0.680	0.548
12	**Vector**	**-**	**2**	**9.073**	**4.536**	**0.654**	**4.723**	**0.070**
13	Circular	Anti-ideal	3	21.925	7.308	0.736	3.711	0.126
14	Vector	-	2	4.069	2.035	0.517	2.673	0.162
15	**Circular**	**Anti-ideal**	**3**	**5.145**	**1.715**	**0.970**	**43.550**	**0.003**
16	Circular	Anti-ideal	3	29.016	9.672	0.798	5.266	0.083
17	Circular	Anti-ideal	3	2.498	0.833	0.313	0.608	0.479
18	Circular	Anti-ideal	3	1.312	0.437	0.466	1.164	0.341
19	Circular	Anti-ideal	3	1.075	0.358	0.436	1.032	0.367
20	Vector	-	2	12.246	6.123	0.340	1.289	0.354
21	Vector	-	2	4.328	2.164	0.433	1.907	0.242
22	Circular	Ideal	3	0.656	0.219	0.140	0.217	0.666
23	Circular	Anti-ideal	3	5.679	1.893	0.259	0.467	0.532
24	**Circular**	**Anti-ideal**	**3**	**4.698**	**1.566**	**0.854**	**7.816**	**0.049**
25	Circular	Ideal	3	4.471	1.490	0.268	0.487	0.524
26	Vector	-	2	11.862	5.931	0.411	1.743	0.266
27	**Circular**	**Anti-ideal**	**3**	**50.630**	**16.877**	**0.941**	**21.295**	**0.010**
28	**Circular**	**Anti-ideal**	**3**	**8.547**	**2.849**	**0.889**	**10.674**	**0.031**
29	Vector	-	2	0.802	0.401	0.401	1.674	0.278
30	Vector	-	2	1.743	0.871	0.135	0.391	0.695
31	Vector	-	2	4.089	2.044	0.264	0.896	0.465
32	Vector	-	2	6.082	3.041	0.218	0.698	0.540
33	Vector	-	2	25.668	12.834	0.536	2.890	0.147
34	**Vector**	**-**	**2**	**10.444**	**5.222**	**0.674**	**5.165**	**0.061**
35	**Circular**	**Anti-ideal**	**3**	**5.620**	**1.873**	**0.866**	**8.588**	**0.043**
36	Circular	Anti-ideal	3	4.755	1.585	0.729	3.584	0.131
37	Circular	Anti-ideal	3	9.232	3.077	0.645	2.426	0.194
38	Circular	Anti-ideal	3	19.011	6.337	0.742	3.831	0.122
39	**Vector**	**-**	**2**	**3.764**	**1.882**	**0.772**	**8.470**	**0.025**
40	Circular	Ideal	3	0.314	0.105	0.086	0.126	0.741
41	Circular	Anti-ideal	3	5.428	1.809	0.628	2.249	0.208
42	Vector	-	2	3.360	1.680	0.420	1.810	0.256
43	**Circular**	**Ideal**	**3**	**2.235**	**0.745**	**0.793**	**5.113**	**0.087**
44	**Circular**	**Ideal**	**3**	**3.042**	**1.014**	**0.886**	**10.350**	**0.032**
45	Circular	Ideal	3	1.125	0.375	0.651	2.487	0.190
46	Vector	-	2	3.311	1.655	0.257	0.865	0.476
47	Vector	-	2	4.974	2.487	0.161	0.480	0.645
48	**Circular**	**Anti-ideal**	**3**	**35.889**	**11.963**	**0.882**	**9.965**	**0.034**
49	**Circular**	**Anti-ideal**	**3**	**9.173**	**3.058**	**0.876**	**9.410**	**0.037**
50	Vector	-	2	9.411	4.705	0.286	1.003	0.430

Text in bold show fitness by a model at $p < 0.10$

Table 3.9 Analysis of the most suitable external preference model to explain the sensory rating of the individual consumers for the 8 flavoured potato chip samples

Consumer	Model	Point type	DF	SS	Mean squares	R^2	F-ratio	p value
1	**Circular**	**Ideal**	**3**	**4.959**	**1.653**	**0.816**	**5.899**	**0.072**
2	Circular	Ideal	3	4.694	1.565	0.702	3.141	0.151
3	Vector	-	2	1.180	0.590	0.169	0.507	0.630
4	**Circular**	**Anti-ideal**	**3**	**6.608**	**2.203**	**0.914**	**14.100**	**0.020**
5	**Circular**	**Anti-ideal**	**3**	**5.276**	**1.759**	**0.858**	**8.084**	**0.047**
6	**Vector**	**-**	**2**	**4.470**	**2.235**	**0.639**	**4.418**	**0.079**
7	Circular	Ideal	3	2.036	0.679	0.291	0.546	0.501
8	**Vector**	**-**	**2**	**5.385**	**2.692**	**0.769**	**8.335**	**0.026**
9	Vector	-	2	2.723	1.362	0.389	1.592	0.292
10	Circular	Anti-ideal	3	2.263	0.754	0.507	1.369	0.307
11	**Circular**	**Anti-ideal**	**3**	**6.356**	**2.119**	**0.895**	**11.336**	**0.028**
12	Vector	-	2	3.865	1.932	0.552	3.082	0.134
13	Vector	-	2	2.103	1.051	0.300	1.073	0.409
14	Vector	-	2	2.706	1.353	0.387	1.575	0.295
15	Vector	-	2	3.413	1.706	0.488	2.379	0.188
16	Circular	Ideal	3	4.974	1.658	0.688	2.944	0.161
17	Circular	Anti-ideal	3	3.065	1.022	0.467	1.166	0.341
18	Circular	Anti-ideal	3	3.070	1.023	0.614	2.120	0.219
19	Vector	-	2	3.249	1.624	0.464	2.165	0.210
20	Vector	-	2	2.375	1.187	0.339	1.284	0.355
21	Circular	Anti-ideal	3	2.816	0.939	0.642	2.396	0.197
22	Vector	-	2	3.280	1.640	0.469	2.204	0.206
23	Vector	-	2	1.686	0.843	0.241	0.793	0.502
24	Vector	-	2	2.423	1.211	0.346	1.323	0.346
25	Circular	Anti-ideal	3	2.530	0.843	0.554	1.659	0.267
26	Circular	Anti-ideal	3	1.895	0.632	0.353	0.727	0.442
27	**Vector**	**-**	**2**	**4.381**	**2.191**	**0.626**	**4.183**	**0.086**
28	Vector	-	2	4.192	2.096	0.599	3.733	0.102
29	Vector	-	2	2.858	1.429	0.408	1.725	0.269
30	Vector	-	2	1.270	0.635	0.181	0.554	0.606
31	Circular	Anti-ideal	3	0.301	0.100	0.014	0.019	0.896
32	**Vector**	**-**	**2**	**4.880**	**2.440**	**0.697**	**5.756**	**0.050**
33	**Vector**	**-**	**2**	**5.459**	**2.729**	**0.780**	**8.855**	**0.023**
34	Vector	-	2	2.112	1.056	0.302	1.080	0.407
35	Vector	-	2	3.181	1.591	0.454	2.083	0.220
36	Vector	-	2	1.358	0.679	0.194	0.602	0.583
37	Circular	Anti-ideal	3	2.257	0.752	0.585	1.883	0.242
38	Vector	-	2	2.674	1.337	0.382	1.546	0.300
39	**Circular**	**Anti-ideal**	**3**	**5.490**	**1.830**	**0.915**	**14.419**	**0.019**
40	**Vector**	**-**	**2**	**6.059**	**3.030**	**0.866**	**16.097**	**0.007**
41	Vector	-	2	3.245	1.623	0.464	2.161	0.211
42	Vector	-	2	2.111	1.056	0.302	1.080	0.408
43	Vector	-	2	1.834	0.917	0.262	0.888	0.468
44	**Vector**	**-**	**2**	**5.857**	**2.929**	**0.837**	**12.812**	**0.011**
45	Circular	Anti-ideal	3	0.549	0.183	0.077	0.112	0.755
46	Vector	-	2	0.100	0.050	0.014	0.036	0.965
47	Circular	Anti-ideal	3	4.142	1.381	0.674	2.760	0.172
48	Vector	-	2	1.032	0.516	0.147	0.432	0.671
49	Vector	-	2	0.961	0.481	0.137	0.398	0.691
50	Vector	-	2	1.798	0.899	0.257	0.864	0.476

Text in bold show fitness by a model at $p < 0.10$

It was expected that the potato sample with the highest specific gravity, *CX*, would have a higher starch content relative to the samples with lower specific gravities as up to 75 % of the dry weight of potato is made up of starch (Dale & Mackay, 1994; Leszcyñski, 1989). However, it was found that *CX* had the lowest starch content (65%) though it had the highest specific gravity (1.098 g/cm^3). The correlation between starch content and specific gravity was not found to be strong in this study. Although positive correlations between dry matter content, starch content and specific gravity have been reported (Miranda & Aguilera, 2006, Stark *et al*., 2005), other studies have suggested that the relationship is not exact but predictive (Hassanpanah, *et al*., 2006; Samotus, Leja, Scigalski, Dulinski & Siwanowicz, 2006). For instance Hassanpanah *et al*. (2006) found a potato cultivar (*Agria*) with specific gravity of 1.091 g/cm^3 with 13.8% starch (as is) whereas *Cosima* with a specific gravity of 1.050 g/cm^3 had 14.6% starch (as is). This would suggest that differences in specific gravity were contributed by the other non-starch dry matter components e.g. non-starch polysaccharides, lignin, nitrogen compounds and mineral substances.

The chip oil content varied significantly among the potato samples. It was expected that the chip oil content would be low for potatoes with high solids content. Thus, it was expected that *AV* with low specific gravity/solids content would have the highest oil content. However, in this study *AV* had the lowest oil content whereas *CX* which had a high specific gravity had significantly higher oil content. The negative correlation between specific gravity/solids content and chip oil content previously reported (Dobarganes *et al*., 2000; Ufheil & Escher, 1996; Gamble & Rice, 1988a) was thus not established in this study. Studies reporting a negative correlation between specific gravity and chip oil content (Ufheil & Escher, 1996; Gamble & Rice, 1988a; Lulai & Orr, 1979) dealt with chips which were prepared using standardized frying conditions (temperature and duration). In the current study, frying took place at a commercial processor and the frying conditions could have been adjusted to attain moisture and oil content ranges within company specifications. It is highly likely that the frying temperature and duration were varied depending on the specific gravity to obtain chips within a specified oil content range.

The moisture content of all the chip samples was within the range desired for potato chips i.e. in the range of 1 to 2 % (Baumann & Escher 1994; Gamble *et al*., 1987).

An almost linear relationship between raw potato moisture content and potato chip oil uptake has been reported (Gamble *et al*., 1987). Therefore, greater moisture loss during frying of chips will results in more oil uptake (Gamble & Rice, 1988a). Studies have shown that potatoes of low specific gravity (low solids content) yield chips with higher final oil content compared to those of a high specific gravity (high solids content) when fried to similar final moisture content (Ufheil & Escher, 1996; Gamble & Rice, 1988a; Lulai & Orr, 1979).

For instance, Gamble & Rice (1988a) observed that a potato sample with 20.6% solids yielded chips with an oil content of 43.12% while a potato sample of 23.0% solids yielded chips with an oil content of 39.02%. It was noted that *BW1* and *BW2* yielded chips with no significant difference in the final oil content when fried to similar moisture content. This suggests that potatoes of the same specific gravity fried to similar final moisture content would yield potato chips of similar oil content. The specific gravity of *DW* and *DY* did not differ significantly but the final oil chip content differed significantly as a result of differences ($p \leq 0.05$) in the final moisture content. *DY* chips were fried to a lower final moisture content (1.7 %) thus yielding a higher oil content (35.2%) than *DW* which had a higher final moisture content (1.9 %) and a lower oil content (32.8 %). Although these values were significantly different ($p < 0.05$), the margin of differences was relatively small.

Oil uptake during frying takes place as moisture is released from the food (Kochhar & Gertz, 2004; Farkas *et al*., 1996). However the actual mechanisms of oil uptake are not clearly understood (Saguy & Dana, 2003). It has been suggested that oil penetrates the voids created as the water evaporates during frying (Pedreschi, *et al*., 2001; Moreira, Sun & Chen, 1997). Higher moisture content would increase the internal volume (voids) left in the cellular structure of a frying food (Pedreschi *et al*., 2001). It is also suggested that oil uptake is a result of a decrease in internal vapour pressure due to condensation of steam upon cooling leading to sucking of the adhering oil on the surface of the product (Ufheil & Escher 1996; Baumann & Escher, 1995).

There were no detectable reducing sugars in the potato samples at the minimum detection level of 0.05 %. This would suggest that reducing sugars were probably zero or too low to be detected by the HPLC method employed. Some researchers have reported zero reducing sugars in some potato cultivars that have not undergone storage (Hassanpanah *et al*., 2006). The potatoes samples in this study had not undergone storage and thus it appears they had very little reducing sugars. Some of the potato samples used in the study were from varieties specifically bred for chip processing by breeders. The reduction in the ability of tubers to accumulate reducing sugar content through plant breeding has been reported (Dale & Bradshaw, 2003).

For colour of fried potato chips significant variations in a* values have been related to non-enzymatic browning reactions (Garayo & Moreira, 2002; Pedreschi *et al.,* 2005) with increased a* value indicating a darker and redder chip. The a* value of *BW2* and *CX* did not differ significantly and these chips appeared darker compared to the other potato types. According to McGuire (1992) the hue angle is a more appropriate measure of colour. A hue angle of 0 ^{o} represents red in colour while 90 ^{o} represents yellow in colour (McGuire, 1992). Therefore, potato chip *CW* was the most yellow while *BW2* and *CX* were the lowest in yellow colour. The chroma is related to colour saturation or intensity of the particular colour of a sample (McGuire, 1992). *CX* and *CW* were more saturated in colour. Studies have shown reducing sugars (glucose and fructose) content to explain most of the variation in colour of fried potato chips (Blenkinsop *et al*., 2002; Rodriguez-Saona, Wrolstad & Pereira, 1997; Roe & Faulks, 1991; Roe *et al*., 1990; Marquez & Anõn, 1986).

Although excessive browning of potato chips is mainly associated with higher reducing sugars content, deviations to this observation have been reported in some potato varieties and growing conditions (Blenkinsop *et al*., 2002; Rodriguez –Saona & Wrolstad, 1997). In the current study no reducing sugars were detected suggesting that other raw potato constituents could have contributed to the variations in colour. Rodriguez-Saona & Wrolstad (1997) reported that at low reducing sugar content ($\leq$ 60mg/100g fresh weight), the colour quality of the potato chips could not be predicted by the reducing sugar content and thus other constituents such as amino acids, ascorbic acid and sucrose could play a bigger role in colour formation.

In a later study Rodriguez-Saona *et al.* (1997) showed that at a reducing sugar concentration of $\leq$ 40 mg/100g fresh weight as well as increases in the sucrose and ascorbic acid concentrations resulted in a darker colour. It has been suggested that sucrose could be hydrolysed to fructose and glucose during frying and indirectly influence the colour of fried products (Leszkowiat, Baricello, Yada, Coffin, Lougheed & Stanley, 1990). However, low correlations between chip colour and sucrose content suggest minor contribution to colour by sucrose (Rodriguez –Saona & Wrolstad, 1997; Roe & Faulks, 1991). Brierley *et al*. (1996) and Roe *et al*. (1990) reported that at the same reducing sugar content an increase in free amide correlated with a more darker colour during frying. In model systems, amino acids have been shown to react with ascorbic acid forming brown compounds (Rodriguez –Saona & Wrolstad, 1997) but their quantities in potato tubers have been reported to be insufficient to cause any significant discolouration in potato chips (Lisiñska, 1989; Mazza, 1983). An increase in free amino acid content was observed to occur with increased nitrogen fertilisation during potato growth (Brierley *et al*., 1996; Roe *et al*., 1990). This led to an increase in the degree of browning. It is postulated that with undetectable reducing sugar concentrations in the potato samples, other factors such as amino acids and ascorbic acid content could have played a role in the differences observed in the colour of the potato chips. It could be that there were variations in frying temperature and duration among the chip samples resulting in increased darkening of potato chips as the non-enzymatic browning reactions are highly temperature dependant (Pedreschi *et al*., 2006; Pedreschi *et al*., 2005; Ames, 1990).

The important sensory quality characteristics of potato chips are those of appearance, flavour and texture (Bennet, 2001). The unflavoured potato chip samples differed significantly in colour. *BW2* and *CX* with higher colour intensity than the other potato chips were perceived to be darker and had higher a^* values. The two samples were also characterized as having a higher concentration of brown specks. Studies have shown an association between dark fry colour of potato chips with burnt flavour and burnt aroma (Sahin, 2000, Pritchard & Adam, 1994). These findings were also evident in this study as *BW2* and *CX* chips also displayed significantly higher burnt aroma and burnt flavour. *CW* chips that had the lowest a^* value also had low values for colour (lighter), burnt aroma and burnt flavour intensity. Excessive browning has been reported to yield bitter tasting chips due to melanoidins that are the products of Maillard reaction (Lærke & Christiansen, 2005). However, there were no significant differences in bitter taste and the ratings were generally low indicating that the level of Maillard reaction was low. Although *CX* and *BW2* were considered to be darker in comparison to the other potato chip samples the excessive darkness reported in literature was not associated with these two samples.

Although unflavoured potato chips from the different potato samples differed significantly in hardness (molars), while the flavoured chips differed in hardness (incisor and molars), ease of breaking and rate of breakdown it was noted that there was no significant difference in crispness; a frequently reported important quality attribute of potato chips (Kita, 2002). The mean rating range of 5.8 to 6.8 in crispness indicated that panellists did perceive the chips to be crisp, but suggests that the differences were subtle. Texture properties of potato chips are influenced by the dry matter content of the raw potatoes of which starch is a major contributor (Kita, 2002; Bouchon *et al*., 2001; Pedreschi *et al*., 2001).

Potato chips made from potatoes of a higher specific gravity were expected to be rated high in hardness compared to those of lower specific gravity. Studies have shown potato types of low specific gravity and starch content to require less breaking force compared to those of high specific gravity and starch content using instrumental texture measurement (Lefort, Durance & Upadhyaya, 2003; Segnini *et al*., 1999). However, instrumental texture measurements of chip hardness do not necessarily correlate with human in mouth perception of hardness. Differences in hardness were not consistent with the reports stating that increase in specific gravity would result in an increase in hardness. For instance, *BW* potato samples were found to have significantly higher specific gravity and higher starch content compared to *AV* but yielded unflavoured chips of significantly lower hardness (molars) compared to *AV* chips. However, *CW* chips which were among the potato samples with the highest starch content, and a relatively higher specific gravity yielded chips of the highest hardness (molars). It is suggested that the relative differences in hardness were small.

It was noted that the differences in oily flavour of the unflavoured chips were not significant ($p > 0.05$) and did not correspond to the significant difference in the measured oil content of the chips. *BW2* chips, which had a higher oil content (39.3 %, as is basis), had an oily flavour rating of 2.9 whereas *AV* with an oily flavour rating of 3.9 had the lowest oil content of 32.7 % (as is basis). The oily flavour range (2.9 – 4.0) was small. Therefore, the inability of the panellists to differentiate significantly could be explained by the observation that the chip samples were within the expected oil content range.

It was noted that with flavouring of the chips some of the differences found in unflavoured chips, notably aroma, were no longer perceived after flavouring e.g. burnt aroma and oil aroma, suggesting that the sour cream and onion seasoning had a masking effect on these aroma attributes. Similarly it appeared that flavouring lessened the burnt flavour perception as the ratings for this attribute on flavoured chips were lower than those of unflavoured chips. This observation is particularly exhibited in *BW1* and *CX* chips which received a burnt flavour rating of 4.7 and 2.5 respectively for the unflavoured chips but 2.4 and 2.3 respectively for the flavoured chips. The rancid oil aroma and flavour attributes of the flavoured potato chips differed significantly especially for *DW*, which received a significantly higher rating than the other flavoured potato chip samples. Rancidity has been reported in freshly fried potato chips as a result of absorption of thermally oxidized frying oil (Pangloli *et al*., 2002). However the observation that rancidity was associated with flavoured chips (*DW*) suggests that rancid flavour could have originated from the flavour (sour cream and onion) batch used.

Potato chips are consumed flavoured by the consumers and this would explain the relatively higher mean hedonic rating of flavoured chips in comparison to the unflavoured chips for most of the attributes. Practically the differences in the mean ratings of the attributes between chip samples by the consumers were relatively low although significant differences were shown statistically. It appeared that there was no predictable preference for one chip sample over the other as the ranges in means of attributes were small. Similar observations were made from the internal preference maps as there was no marked preference of a chip sample over the others. Potato samples used in this study were chipping varieties and it appears that significant differences in the intensity of sensory attributes as determined by the descriptive panel did not clearly show differences in terms of overall acceptance of potato chips by the consumers. In understanding the consumers further, cluster analysis was carried out. It was evident from the clustering that consumers responded differently to liking of the potato chip samples. Some consumers used the upper side of the hedonic scale. These consumers gave a high rating for all chips (cluster 1) in comparison to cluster 2 consumers. It appeared that cluster 1 consumers generally liked all chip samples. The observation that there were more cluster 1 consumers in the flavoured chip category was expected as potato chips are normally consumed flavoured.

It has been reported that dark coloured chips and bitter taste, contribute negatively to liking (Kita, 2002; Kumar *et al*., 2004). However samples *BW2* and *CX* which had higher intensity in these attributes were liked by some consumers. Guinard, Uotani & Schlich (2001) reported that consumers respond differently to the sensory attribute of products due to differences in likes and dislikes. Mottur (1989) observed that some consumers preferred darker coloured chips. However the excessive dark colour that could have resulted in unacceptability did not characterise the chip samples.

External preference mapping techniques (McEwan, Earthy & Ducher 1998; Elmore, Heymann, Johnson, & Hewett, 1999) were used to observe if consumer preferences were influenced by the differences in the sensory attributes of the potato chips. In this technique, the descriptive analysis data is used for correlation with consumer responses for purposes of building predictive or explanatory models of factors driving preference (Lawless, 2001). An interpretation of this technique is that the external sensory space represents the perceptual summary of stimuli that consumers form during synthesis (Jaeger, Wakeling & MacFie, 2000). It was expected that insight into the sensory attributes that were important to individual consumers would be explained by the vector, circular, elliptical, or quadratic models. However, only a few consumers were significantly fitted into any of the four models. According to McEwan & Ducher (1998) a correlation of 1 indicates a perfect model, while 0 indicates total incompatibility of the model and the data. The poor consumer fit in these models suggested that factors driving consumer preference were not clearly linked to the differences in sensory attributes. Jaeger *et al*. (2000) observed that it was not always the case that differences in consumer preferences corresponded to differences identified through descriptive sensory analysis. Jaeger *et al*. (2000) further stated that for external preference mapping technique to be successful, the external stimulus space had to provide a meaningful view of stimuli differences i.e. the sample set assessed had to represent clear dislike and like assessments by the consumers and preferably represent clear differences in consumer sub-groups based on sample preferences. This technique did not contribute more insight on sensory attributes driving preference possibly due to very slight differences among samples as judged by the consumers. Therefore, although differences were perceived by the trained panel these differences did not necessarily clearly influence consumer preference of one chip sample over the others.

3.1.5 CONCLUSIONS

The magnitude of differences in the physico-chemical characteristics of the potatoes were relatively small and did not clearly influence consumer liking of one potato chip sample over the others. It was possible to manufacture chips from potatoes of a specific gravity ranging from 1.073 to 1.098 g/cm^3 with acceptable quality as judged by consumers. Crispness, an important sensory attribute of potato chip, did not differ among all chip samples. Differences in colour of chips were observed although the reducing sugars content of all potato samples were below 0.05 %. Other constituents such as amino nitrogen or ascorbic acid could have played a role in these differences. Although slight variations in the physico-chemical characteristics of potatoes were experienced their impact on the sensory quality of the chips were minimal and thus did not affect consumer acceptability of the chips.

CHAPTER 4: GENERAL DISCUSSION

This chapter is divided into two sections. The first section will discuss challenges with procurement of samples and some of the methodologies used in this study, including principles, strengths and weaknesses. The second section will discuss the results obtained to determine the effect of the physico-chemical characteristics of potatoes on the sensory quality of potato chips.

In the initial experimental planning, samples were to be sourced from three potato varieties grown in three different regions and during two different seasons. It was projected that these samples would reflect the practical differences in physico-chemical characteristics that are experienced as a result of different growing seasons and locations. However, due to the unusual heavy rains experienced in the first quarter of 2006 sourcing of potatoes was seriously affected as planned harvesting of potatoes could not take place as a result of rains. Therefore, a forced change in the experimental design had to be made in consultation with the manufacturer. It was agreed to sample eight times as long as the premium product i.e. flat cut chips, with sour cream and onion flavouring was manufactured. It was felt that this would still reflect the practical variations although the probable effect of growth location and harvesting season could not be addressed by the new experimental design.

The sourcing of samples at the manufacturer posed some problems. The manufacture of flat cut chips flavoured with sour cream and onion was dependent on the market requirements. Therefore, no regular or definite long term scheduling of sampling could be made. The delay due to rains and sampling for the selected chip prolonged the sampling period (March to August 2006). The unspecified sampling schedules and short notices from the processor of the manufacture of the specified chip (flat cut chips flavoured with sour cream and onion) meant immediate arrangements had to be made to be at the factory (50 km from the university campus) which was not always possible. Sampling was at times done late at night (e.g. midnight) leading to logistical problems. For instance on two sampling occasions there were no gate passes organised and the samples had to be left at the manufacturer's premises to be collected later. It was also frustrating to sample at times (especially at night) with production personnel who were not aware of the ongoing project and who were unwilling to assist with the procurement of samples.

The access to the processing line, sampling of the unflavoured product during production and immediate packaging required support from the production team. It was noted specifically that some packaging lines had to be stopped for the unflavoured chips to be packaged. Therefore, it would not have been possible to sample successfully for 8 times without the support of production staff. These are some of the practical challenges faced in conducting a scientific research project in a commercial environment.

4.1 METHODOLOGIES

Total starch content of raw potato was determined on the freeze dried potato tissue. AOAC (2002) method 996.11 using the Megazyme Total Starch Assay Kit (Megazyme Ltd, Bray, Ireland) was used for this determination. In this method the starch is hydrolysed into glucose which is then quantitatively determined colorimetrically (Rasmussen & Henry, 1990). This hydrolysis is achieved enzymatically. The procedure involves gelatinization of starch, liquefaction and dextrinisation, hydrolysis of dextrins to glucose and glucose measurement. Potato starch is stored in small granules which are quite resistant to water and hydrolytic enzyme penetration due to inter and intra hydrogen bonding. Therefore by heating in an aqueous medium the bonds are weakened and water is absorbed. The swelling of the starch granule and the subsequent loss of the ordered crystalline granule structure i.e. gelatinisation, increases the accessibility of enzymes to starch molecules (Hoseney, 1994). A pre-treatment step of the samples with warm aqueous ethanol was done to remove free glucose and dextrins which could be present (Rasmussen & Henry, 1990).

Starch is made of two types of polysaccharides: amylose (linear) and amylopectin (branched). These consist of glucose units with α (1, 4) (linear) and α (1, 6) (branched) linkages respectively (Rasmussen & Henry, 1990). A thermostable α amylase enzyme allows hydrolysis at high (>100 ^{o}C) gelatinization temperatures. This step yields the initial breakdown products; dextrins and oligosaccharides. These are then quantitatively converted into glucose during incubation with amyloglucosidase. Glucose concentration was then determined colorimetrically at 510 nm after reaction with glucose oxidase/peroxidase. The advantage of this method is its simplicity and the use of a heat stable α-amylase enables gelatinization and starch hydrolysis steps to be combined at high temperatures.

Potato chip oil content was determined by Soxhlet extraction method 920.39 (AOAC, 2002). The method involves extraction of oil from the sample by use of extraction solvents such as petroleum ether. The extraction is based on the solubility of the lipids in an organic solvent (Hoseney, 1994). Extraction is achieved by recirculation of the solvent through a reflux system ensuring repeated contact of the solvent with the ground sample (Luque de Castro & García-Ayuso, 1998). This is done at the boiling point of the solvent for a relatively long period of time. After cooling and evaporation of the solvent, the oil content is measured gravimetrically. The method is relatively simple although time consuming. Particle sizes are reported to influence the amount of extracted oil due to the available surface area (Moreira *et al*., 1999). To achieve maximum oil extraction the sample was finely ground. This increased the surface area, allowing for exposure of occluded oil in the potato chip matrix (Aguilera & Gloria-Hernández, 2000).

Potato chip moisture was determined by the oven air drying method 934.06 (AOAC, 2002). This is the standard method in moisture determination in food. It is based on drying the food sample above the boiling point of water until equilibrium moisture content is reached. The time and temperature used should ensure that all but chemically bound moisture is lost. According to Gamble & Rice (1988a) and Baumann & Escher (1995) the oven temperature and heating time for moisture content determination in chips should be 103-105 ^{o}C and 12 hr respectively.

Colour is an important factor determining consumer acceptability of potato chips and influences subjective sensory impressions (Frydecka-Mazurczyk & Zgórska, 2003). For instance the golden yellow colour of a potato chip would indicate a high quality product (Miranda & Aguilera, 2006). Instrumental colour measurement should offer quantitative measures of colour quality which is more reliable to the subjective measurements done sensorially (Frydecka-Mazurczyk & Zgórska, 2003). Colour is a three-dimensional (3-D) characteristic of appearance and thus objective colour measurement systems describe colour in 3-D (Moreira *et al*., 1999).

Objective colour measurements are used to relate colour measurements to the tristimulus sensory perception of colour by the human eye (Moreira *et al*., 1999). Therefore, the International Committee on Illumination (CIE) has adopted colour measurement instrumentally by the use of X, Y, Z or L* a* b*(CIELAB) standard values as numerical representative of the three sensory colour responses by the human eye (McGuire, 1992; Moreira *et al*., 1999; Segnini *et al*., 1999). In general, instrumental colour measurement provides relatively precise colour evaluation as it avoids the effect of differences in colour perception by humans (Voss, 1992). Conventional colour meters such as the CR210 Minolta chromameter are used to objectively determine colour differences among samples by using the L* a* b* colour scale (Voss, 1992; Segnini *et al*., 1999). The L* a* b* colour scale is considered more uniform than X, Y, Z therefore suitable for comparison with sensory data (Segnini *et al*., 1999). Although many researchers publish their data in the CIELAB (L*, a*, b*) scale, McGuire (1992) observed that only the measure of lightness, L*, is correctly reported while a* and b* are simply coordinates that indirectly refer to hue and chroma. Statistical analysis on these coordinates, although yielding significant differences, would not be of significance in colour interpretation (McGuire, 1992). Chroma and hue are thus, a more appropriate measure of colour. Hue angle represents pure colour with angles of 0, 90, 180 and 270 representing red-purple, yellow, bluish-green, and blue hues, respectively (McGuire, 1992). Chroma relates to the saturation or intensity of a colour. Published research evaluating potato chip colour measure differences in terms of L*, a*, b*(Pedreschi *et al*., 2006; Frydecka-Mazurczyk & Zgórska, 2003; Garayo & Moreira, 2002 Krokida *et al*., 2001). In order to address the highlighted differences L*, a* and b* values, chroma and hue angle were all analysed in this study.

Colour measurement could have been affected by light reflection on the potato chips as a result of a curled surface of the chips (Segnini *et al*., 1999). Better colour measurement by a colorimeter could be achieved by crushing the chips to reduce the effect of the reflected light (Segnini *et al*., 1999). However this would not represent the chip colour as perceived by the consumer. It was observed that potato chip colour varied among fried chip slices and even within the surface of a single chip. Some of the chips were characterized with more brown spots than others within a sample. Potato chip surface colour is highly non-homogenous as a result of differences in composition of constituents affecting colour development such as reducing sugars (Pedreschi *et al*., 2006; Segnini *et al*., 1999). In order to report colour that was representative, five random readings on each side of five randomly selected chips were done. The tristimulus colorimetric methods are also highly correlated with sensory perception of colour by the human eye and are non destructive (Ward, Resurreccion & McWatters, 1995).

Instrumental texture analysis of potato chips using a punch test was considered in an attempt to correlate instrumental and sensory measures of texture. However, the potato chip samples had irregular shapes, sizes and curvatures which would lead to irreproducible results (Segnini, Pedreschi, & Dejmek, 2004). Flavour profiling by the use of gas chromatography was one technique that could elucidate chemical volatile compounds that contributed to overall flavour of the potato chips.

"Sensory evaluation has been defined as a scientific discipline used to evoke, measure, analyse, and interpret reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch and hearing"(IFT according Lawless, 1993). Selection of a sensory test method is dependent on the objective of the research question. In this study, sensory tests were employed to:

- establish if there were differences in the sensory characteristics of the potato chip samples and to quantify these differences.
- establish how much the potato chip samples were liked by consumers and determine individual preferences.

Therefore both descriptive and consumer sensory evaluation were used. Descriptive sensory evaluation involves the discrimination and description of qualitative and quantitative sensory characteristics of consumer products by using human subjects trained for this purpose (panel of judges) (Meilgaard *et al*., 1991). The panel identifies the product attributes (qualitative) and measures the intensity of these attributes (quantitative) (Murray, Delahunty & Baxter, 2001). Quantitative measure of these attributes is achieved by using a set of scales which provides a numerical response to their perceived intensities (Lawless, 2001). A generic descriptive sensory evaluation procedure as described by Einstein according to Lawless & Heymann

(1998) was used. Descriptive sensory evaluation involved panel selection and training, development of descriptive terms and anchors, creation of score sheet structures, and evaluation of products. Panelists are regarded as an analytical instrument for measuring sensory attributes (Hunter, 1996). Therefore, effective training is critical for objective and reliable sensory measurement (Munõz & Civille, 1998). Panellists should ideally evaluate products from an agreed frame of references (Piggot, 1995). Selection of descriptive terms poses a major challenge especially with olfactory characteristics and texture terms which are less uniformly agreed upon (Lawless, 2001). Terms in literature or physical references (Piggot, 1995) are used to aid the panel to agree on descriptive terms. In this study, descriptive terms reported in literature (Campbell, 1997) and where possible, physical references were used. The performance of the trained sensory panel could have been optimised by constantly monitoring individual panellist consistency. One problem encountered was in the final selection of descriptive terms which should be achieved through consensus (Murray *et al*., 2001). Some panellists perceived differences where others did not. These were regarding defects such as greening on chip surface, presence of peel, darkened regions as a result of bruised potato tuber. It was decided not to include these defect terms as they were incidental and not representative of the chip samples.

One of the main purposes of conducting consumer sensory evaluation is usually to establish a relationship between the consumer's response and food composition or between intensity of perceptible attributes and degree of acceptance (Barrios & Costell, 2004). In consumer sensory evaluation, the overall liking and/or liking of particular sensory attributes in a product are determined by the users of the product. A quantitative test using a 9- point hedonic scale (Peryam & Pilgrim, 1957) was used. Although used as an acceptability measurement the ratings can provide information on preference (Lawless, 2001). Standardised situation tests or home tests are methodologies used in consumer sensory evaluation (Boutrolle, Arranz, Rogeaux & Delarue, 2005). In this study a standardised situation test procedure was employed (i.e. a sensory laboratory). Conditions of evaluation were controlled and standardised. Home use test (HUT), although less controlled, is considered to yield more realistic data that takes into account normal home environment (Boutrolle *et al*., 2005). Snack foods such as chips require no preparation and can be consumed anywhere thus the test could be carried out in the sensory laboratory. In retrospect a home end testing should have been included to reflect the normal consumption environment.

4.2 EFFECTS OF PHYSICO-CHEMICAL CHARACTERISTICS OF POTATO SAMPLES ON PHYSICO-CHEMICAL CHARACTERISTICS OF POTATO CHIPS

It was expected that by sampling potatoes of different varieties from different regions over a period of six months would represent typical variations in physico-chemical characteristics experienced by a chip processor. This is because potato variety, growth location and season are known to influence the physico-chemical characteristics of potatoes (Sengul *et al*., 2004; Kumar *et al*., 2004). As hypothesised there were significant differences in the specific gravity/solids content and starch content of the potato samples. However, the reducing sugars content of all potato samples were not detected at 0.05% minimum level. Potato samples of relatively high specific gravity were expected to have higher starch content. However, this was not the case for all the potato samples. Although it was generally observed that a high specific gravity/solids content would mean a high starch content (Miranda & Aguilera, 2006) exceptions for this observation have been reported (Hassanpanah *et al*., 2006). This would imply that other dry matter constituents such as non-starch polysaccharides, lignin, nitrogen compounds and mineral substances contributed to the observed differences in specific gravity. However, taking into account the precision of the total starch assay method employed (± 2%); the differences in starch content among the samples were relatively small.

In subsequent chip processing under the manufacturer's conditions, chips yielded significant differences in the oil content, moisture content and colour (a* , b*, hue angle and chroma). These potato chip characteristics are influenced by physico-chemical characteristics of potatoes and processing conditions (Kita, 2002). Studies have reported the influence of specific gravity /solids content on the final oil content and moisture of chips (Baumann & Escher, 1995). At the same frying temperature and duration higher specific gravity/solids content potatoes are observed to yield chips of a lower oil content in comparison to low specific gravity potatoes (Baumann & Escher, 1995). Mechanisms explaining fat uptake in fried potato products state that the frying oil replaces the space occupied by moisture during frying (Mellema, 2003). Higher specific gravity /solids content potatoes are of a higher dry matter and lower in moisture content and thus would leave a relatively smaller space to be occupied by oil when the moisture is lost (Mellema, 2003). The hypothesis that potato samples of a high specific gravity would yield potatoes of a lower oil content and moisture content were not established. Frying temperature and duration were made constant in studies citing this observation (Ufheil & Escher, 1996, Baumann & Escher, 1995). The limiting factor in this study was the control of conditions during chip processing especially the frying temperature and duration. For instance, in industrial chip processing, the inlet oil temperature in a continuous fryer is adjusted to produce an exit oil temperature of approximately 157 ^{o}C and not exceeding 163 ^{o}C (Bennet, 2001). At standard production rates the inlet oil temperature is in the range of 180 to 185 ºC (Bennet, 2001). The residence time in the fryer is adjusted depending on the set specification of the final moisture content (Bennet, 2001). The moisture content of all chip samples were within the critical range of 1 to 2 % moisture content (Mottur, 1989). The researcher was not able to control the adjustments made by the processor to ensure that the chips met the set specification and this information was proprietary.

The reducing sugar concentration in the potato samples were either absent or below 0.05%. There is agreement in literature that reducing sugars content of potatoes are the major constituent influencing the final colour of potato chips (Brierley *et al*., 1996; Marquez & Anõn, 1986). The effect of high levels of reducing sugars is that of dark coloured chips. Therefore reducing sugars content are used as a criterion for assessing suitability of potatoes for processing. However literature differs on the minimum acceptable level of reducing sugars in potatoes destined for chip manufacture (Stark *et al*., 2005; Kita, 2002; Dahlenburg *et al*., 1990). At very low reducing sugars levels it appears that other constituents (such as ascorbic acid and amino acid content) could have influenced the colour differences in the potato chip samples.

Although there were significant differences in colour as measured instrumentally, no chip sample was particularly dark as there were no significant differences in L^*value. Moreover the chip samples that appeared dark (*BW2* and *CX*) were characterized by patches that were brown rather than an overall appearance of the chips suggesting that the overall sugar content in tubers were very minimal, if present. The same observations have been reported as causing problems in the interpretation of fried potato colour. A non-uniform browning in potato chip (Pedreschi *et al*., 2006) and French fries (Jankowski, Parkin & Von Elbe, 1996) as a result of localised differences in reducing sugars concentrations within different sections of a tuber have been reported. Dahlenburg *et al*. (1990) suggested that correlations between chip colour and the reducing sugar content could be improved by determining the reducing sugar content in the specific region of a tuber assessed for colour. The excessive overall brownness reported as a result of high reducing sugars did not characterize any of the chip samples.

4.3 EFFECTS OF PHYSICO-CHEMICAL CHARACTERISTICS ON THE SENSORY QUALITY OF POTATO CHIPS

Differences in physico-chemical characteristics of potatoes are known to yield chips of different sensory quality on frying (Miranda & Aguilera, 2006; Kita, 2002) as the sensory characteristics are developed by the chemical and physical changes on the raw potato constituents particularly during frying. Did the observed differences in the physico-chemical characteristics of the potatoes and potato chips influence these sensory quality attributes as hypothesised? Descriptive sensory analysis showed significant differences in colour of the unflavoured chips. In particular two chip samples (*BW2* and *CX*) were characterized as darker than the other chip samples. These observations were in agreement with higher a* value and low hue angle, as measured instrumentally.

Although there were significant differences in the specific gravity and solids content and starch of the potatoes their effect on texture of the potato chips was not clearly established. High specific gravity potatoes yield chips of higher hardness (Segnini *et al*., 1999) and crispness (Miranda & Aguilera, 2006; Kita, 2002) compared to those of low specific gravity. This is because texture of fried potato products is dependent on the structural and chemical changes that the dry matter constituents undergo during frying (Bouchon *et al*.,2001; Kita 2002). For instance, (*BW*) had a higher specific gravity but lower intensity of hardness in comparison with (*AV*) which had a lower specific gravity. This was further evidenced by a weak correlation. These observations would suggest that the differences in the specific gravity and starch content although statistically significant, were small and thus, did not necessarily impact on the sensory texture attributes of the potato chips. However, crispness which is considered an important sensory attribute of potato chips did not differ significantly among the potato chip samples.

The darker chips (*BW2* and *CX*) had a slightly higher intensity of burnt aroma and burnt flavour. Burnt flavour and bitter taste in potato chips are associated with products of Maillard reactions. Bitter tasting compounds (melanoidins) in potato chips would result from potatoes of high reducing sugar content (Pedreschi, Kaack, Granby & Troncoso, 2007). The low bitter taste intensity among the chips showed that the excessive browning leading to chips of bitter taste (Lærke & Christiansen, 2005) did not characterize any of the chip samples. This could be due to very low reducing sugar contents (<0.05%) observed in all potato samples.

Oily appearance and oily flavour intensities did not differ significantly as expected despite of significant differences in the oil content of chips. The oil content in all chip samples were within the 30 to 40 % range reported in literature (Mellema, 2003). Although the range appears large and could be expected to be perceived orally, the perception of oil related sensory attributes such as oiliness, in low moisture foods are poorly correlated (Mela & Christensen, 1987). In corn-meal based snacks, Mela & Christensen (1987) observed that about 15% differences in oil content were required before consistent differences in perceived oiliness could be perceived. This suggested that differences would have been perceived if the oil content differences were large (i.e. probably above 10 %). Even though chip flavour differences were small, assessment of the frying oil quality (e.g. peroxide value, *p*- aniside value) as sampled during the different production runs of the chips could have explained possible differences in flavour as contributed by the oil degradation products such as oxidised fatty acids.

Differences in consumer acceptability of both categories (flavoured and unflavoured) with respect to overall liking and liking of appearance, colour, texture and taste were significant ($p<0.01$). Practically, the differences were very slight as indicated by the small ranges in all attributes. Flavoured chips received higher ratings in comparison to unflavoured chips due to the fact that potato chips are consumed flavoured. Generally, all the potato chip samples were fairly well-liked as indicated by high mean overall liking ratings.

Consumers respond differently regarding preference of sensory attributes of a product (Guinard *et al*., 2001; Moskowitz, 1997). Therefore expressing preference (overall liking) in terms of a mean value would fail to account for inter-individual differences (Guinard *et al*., 2001). Thus, it was important to investigate the direction of preference for each consumer (internal preference mapping) and sensory attributes influencing their preferences (external preference mapping). Internal preference mapping supported the observation that potato chip samples in both categories had similar overall preference as the samples were plotted on one plane (McEwan & Ducher, 1998). In external preference mapping, the poor consumer fit in the regression models suggested that factors driving consumer preference were not clearly linked to the differences in sensory attributes. Studies done to evaluate the effect of physico-chemical characteristics of potatoes included potatoes that could be considered not of chipping quality. In such studies the impact of including chipping grade potatoes and those that are not would result in large variations in chip characteristics affecting consumer preference. Thus, the difference would be clearly perceived by the consumers. It is suggested that although differences in some sensory attributes were significant, these differences did not necessarily mean a difference that could impact on consumer acceptance. For instance some consumers preferred *BW2* and *CX* chip samples which were characterised as darker in colour and having a slight burnt flavour. Excessive browning reported to result in unacceptable dark colour and bitter tasting chips (Roe & Faulks, 1991) did not characterise any of the chip samples.

CHAPTER 5: CONCLUSIONS AND RECOMMEDATIONS

The study was developed to address a particular concern of variability in the physico-chemical variations of potato tubers identified by a potato chip manufacturer. What was the impact of the physico-chemical variations of raw potato tubers (a common feature in the chipping industry) on chip quality as processed under practical processing conditions? In the experimental planning it was expected that significant variations in potato samples would be present. To the manufacturer this research could be regarded as of a quality control nature as all the potato samples used in this study were sourced from chipping varieties.

Contrary to the hypotheses formulated, it was not found that a higher reducing sugar content led to darker coloured chips since the reducing sugars were not detected at a minimum level of 0.05%. Colour differences in the chip samples could have resulted from differences in other constituents such as amino acids content, ascorbic acid content or differences in frying temperature.

The bitterness associated with intense browning did not characterise any of the chip samples due to the low content or absence of reducing sugars.

Low specific gravity/solids content did not lead to chips of a higher oil content. Differences in chip oil content as influenced by the specific gravity/solids content were not observed. This could have resulted from differences in frying temperatures and durations during processing of different chip samples. The differences in specific gravity/solids content were not of practical significance and therefore did not influence differences in the perception of crispness, all chip samples were perceived to be of a crispy texture. No differences in flavouring (sour cream & onion) perception of chips of varying oil content were found. The differences in oil content were not large enough to cause differences in the rate of flavour release that could be perceived by the human subjects.

However although differences were found in sensory characteristics of the potato chips, they did not result in practical differences that influenced consumer acceptance in a predictable manner.

From this research, it is concluded that as long as the manufacturer accepts potato tubers within the generally acceptable specifications of physico-chemical characteristics reported in literature, the chips produced should not result in consumer rejection or dislike. However, the question still remains as to where the limits are for physico-chemical characteristics of raw potatoes leading to rejection or dislike of sensory attributes of potato chips (e.g. colour, oiliness, crispness) by the consumer. Unfortunately, this study did not identify these limits as the potato samples were within specifications and the chips yielded did not challenge consumers' level of dislike. In an attempt to understand these limits, a further investigation including potatoes of wider variations in physico-chemical characteristics yielding potato chips of practical significant sensory differences as judged by consumers would be recommended.

CHAPTER 6: REFERENCES

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Appendix A

Consent form for descriptive sensory panelists.

SENSORY PANELLIST CONSENT FORM

Sensory evaluation of Potato Chips

Thank you for willingness to potentially participate in a sensory evaluation project at the Department of Food Science, University of Pretoria.

Date of Participation: 22 August to 21 September 2006.

Voluntary nature of Participation: I understand that participation in this project is completely voluntary. I do not have to participate in this sensory project. If I do agree to participate I can withdraw my participation any time.

Risks to the Individual: I understand that I will evaluate potato chips using descriptive sensory evaluation. The risk involved in eating the potato chip samples is no greater than eating chips purchased in the retail consumer market. I understand that the product samples may contain permitted additives such as flavour enhancers, antioxidant(TBHQ), sodium diacetate, acidifying agent, maltodextrin, free flow agent and corn starch.

Medical Liability: I understand that no financial compensation will be paid to me in connection with any physical injury or illness in the unlikely event of physical injury or illness as a direct or indirect result of my participation in this sensory project.

Confidentiality: Participants are not required to reveal any confidential information. All responses to questions will be treated in confidential manner. Responses to sensory questions via the evaluation form are tracked using numbers only. These numbers are not in any way related to the participant's name.

If you have any questions about this sensory project, please contact Dr H.L. de Kock, Department of Food Science, University of Pretoria at (012) 420 3238.

I HAD THE OPPORTUNITY TO READ THIS FORM, ASK QUESTIONS ABOUT THE SENSORY PROJECT AND AM PREPARED TO PARTICIPATE IN THIS PROJECT.

Participant's Signature Date

Participant's Name *please print clearly*

Sensory Panel Leader Signature Date

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Appendix B

Advertisement poster for consumer panellists.

Appendix C

Consent form for consumer sensory panellists

SENSORY PANELLIST CONSENT FORM

Sensory evaluation of Potato Chips

Thank you for willingness to potentially participate in a sensory evaluation project at the Department of Food Science, University of Pretoria.

Date of Participation: 24 October to 25 October 2006.

Voluntary nature of Participation: I understand that participation in this project is completely voluntary. I do not have to participate in this sensory project. If I do agree to participate I can withdraw my participation any time.

Risks to the Individual: I understand that I will evaluate potato chips. The risk involved in eating the potato chip samples is no greater than eating chips purchased in the retail consumer market. I understand that the product samples may contain permitted additives such as flavour enhancers, MSG, HVP(soy),wheat starch(gluten),yeast extract product, herbs antioxidant(TBHQ), sodium diacetate, acidifying agent, maltodextrin, free flow agent and corn starch.

Medical Liability: I understand that no financial compensation will be paid to me in connection with any physical injury or illness in the unlikely event of physical injury or illness as a direct or indirect result of my participation in this sensory project.

Confidentiality: Participants are not required to reveal any confidential information. All responses to questions will be treated in confidential manner. Responses to sensory questions via the evaluation form are tracked using numbers only. These numbers are not in any way related to the participant's name.

If you have any questions about this sensory project, please contact Dr H.L. de Kock, Department of Food Science, University of Pretoria at (012) 420 3238.

I HAD THE OPPORTUNITY TO READ THIS FORM, ASK QUESTIONS ABOUT THE SENSORY PROJECT AND AM PREPARED TO PARTICIPATE IN THIS PROJECT.

Participant's Signature Date

Participant's Name *please print clearly*

Sensory Panel Leader Signature Date