

Biodiversity of potatoes as related to nutrient content and quality

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Thesis

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Study leader: Prof Dr Hettie Schönfeldt

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Biodiversity of potatoes as related to nutrient content and quality

by

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Dedicated to:

my brother, Pieter van Niekerk.

Thank you for teaching me to always want the best.

Declaration

I, Carmen van Niekerk, hereby declare that the thesis for the MSc Nutrition degree at the University of Pretoria, hereby submitted by me, has not previously been submitted for a degree at this or any other university and that it is my own work in design and execution and that all reference material contained herein has been duly acknowledged.

Carmen van Niekerk

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Abstract

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Degree: MSc Human Nutrition

Biodiversity is essential to human nutrition and food security as it can ensure stable and sustainable food production and contribute to a diverse diet. Biodiversity is classified as the degree of variation within a species. The higher the degree of variation within a species the stronger the species and the greater the chance of species survival. More than 4 000 different potato cultivars are cultivated worldwide making potatoes a highly biodiverse crop that can be easily grown under a variety of agronomical conditions particularly in many developing countries to contribute towards human nutrition, agriculture and economics. More than 80 different cultivars are produced in South Africa and it is possible that there may be a significant difference in the nutritional value of these different cultivars.

The purpose of this study was to investigate the effect of cultivar on macronutrient and mineral content (with and without the skin) and culinary applications of the 11 most commonly consumed potato cultivars in South Africa. Nutrient analysis was conducted on tubers with and without the skin.

The potatoes were boiled, baked, microwaved and deep fat fried prior to objective and sensory analysis. A market investigation was conducted to develop a repeatable cooking method for the traditional South African deep fat fried “slap chips” that mimics market conditions. Focus groups were used to develop new descriptive words for labelling purposes that describe the best preparation techniques for cultivars with different intrinsic qualities.

It was found that there is a significant difference in the macronutrient and mineral values of different potato cultivars irrespective if analysed with or without the skin. This confirms the variation of nutrient delivery within the species *Solanum tuberosum* as currently available on the South African market. It was found that when using less invasive cooking methods such as boiling, baking and microwaving cultivar characteristics remain the predominant determining factor influencing textural characteristics. Dry matter and starch proved to be the objective measures that best described the variance in data. By means of a descriptive sensory panel it was found that there is no clear pattern of differences amongst the types of cultivars (waxy, waxy/floury, floury) for any of the sensory attributes evaluated with a more invasive culinary application such as deep fat frying. It can therefore be assumed that all the cultivars will be suitable for preparation in this manner.

Potatoes are a highly biodiverse, nutrient dense crop that can be promoted for their contribution to a diverse diet. As potatoes can be cultivated in a wide variety of agronomical conditions they can form part of a nutrient sensitive agricultural approach to alleviate global malnutrition and contribute to dietary diversity. Further investigation into the contribution of particular cultivars in this regard is recommended.

List of acronyms and abbreviations

ARC	Agricultural Research Council
ASTM	American Society for Testing and Materials
Ava	Avalanche
BFAP	Bureau for Food and Agricultural Policy
BP13	Buffelspoort
Car	Caren
CIP	International Potato Centre
DAFF	Department of Agriculture, Forestry and Fishery
Dar	Darius
DoH	Department of Health
Fab	Fabula
FAO	Food and Agricultural Organisation
FBDG	Food-Based Dietary Guidelines
Fia	Fianna
LSM	Living Standard Measurement
MDG	Millennium Development Goal
Mon	Mondial
MRC	Medical Research Council
NAMC	National and Agricultural Marketing Council
NRV	Nutrient Reference Value
SANBI	South African National Biodiversity Institute
SANHANES	South African National Health and Nutrition Examination Survey
UK	United Kingdom
UN	United Nations
USDA	United States Department of Agriculture
UTD	Up-to-Date
Val	Valor
VDP	Van der Plank

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Chapter 1: The study in perspective

“Fairy tales are more than true: not because they tell us that potatoes exist, but because they tell us that potatoes can be eaten” - Neil Gaiman

1.1 Background to the study

Potatoes are a nutrient dense crop (Ezekiel, et al., 2013) that can assist in contributing to dietary diversity and food security of many countries. Potatoes are a highly biodiverse crop and yield more food product more quickly and on less land than any other major crop (Gibson & Kurilich, 2013), as well as producing more edible food than fish and meat combined (Klikocka & Glowacka, 2013).

Potatoes are grown in more than 80% of countries throughout the world (Pedreschi, et al., 2005) with the global consumption of potatoes steadily increasing. The main reasons for the increasing popularity of potatoes in developing countries are ascribed to the simplicity of their cultivation (Ferne & Willmitzer, 2001) as well as their affordability (King & Slavin, 2013). Potatoes are easy to plant (Bennett, et al., 2012), they are a high yielding crop (Vreugdenhil, et al., 2011) and a source of nutrient dense carbohydrates in the diet (International Potato Centre, 2014; FAO, 2008^a).

Potatoes, are consumed on all continents by more than a billion people with production exceeding 300 million metric tons (Juhasz, et al., 2014). This highly biodiverse crop from the *Solanum* family is made up of more than 4 000 edible species ranging from wild grown crops, to the more commonly known *Solanum tuberosum* (International Potato Center, 2014).

In South Africa potatoes are a widely consumed crop by all income groups, with between 7% - 8% of total household food expenditure from Living Standards Measurement (LSM) 1-10 groups being spent on potatoes (Stats SA, 2012; Stats SA, 2008). As these tubers are so widely consumed it is of interest to determine what contribution they make to the human diet. The South Africa Food-Based Dietary Guidelines (FBDG) state that tubers are part of the starch food group and that starchy food should form part of most meals (Vorster, et al., 2013).

Currently there is a global focus on biodiversity (Reed, 2012) and maintaining biodiversity is part of the seventh goal of the current Millennium Development Goals. As of 2015 the Sustainable Development Goals draw even more attention to biodiversity as part of the Post 2015 Development Agenda (United Nations, 2014). The more cultivars within a specific species the greater the biodiversity as well as the genetic diversity of the crop (Frison, et al., 2011). Biodiversity can be used

as a critically important indicator of sustainability in the agricultural sector making it a globally important factor that can be used to combat malnutrition, pests and diseases and contribute to a healthy agricultural environment (Bioversity International, 2014).

Potatoes are the fourth most common global crop, after rice, wheat and maize, and can make a noteworthy contribution to nutrition and food security of people living in developing communities. This crop contains minerals such as potassium, phosphorus, manganese and magnesium that are highly bio-available (Dilworth, et al., 2007). Significant amounts of promoter substances such as ascorbate, β -carotene and cysteine found in this crop (Subramanian, et al., 2011). These factors all contribute to the substantial nutritional impact that these tubers and biodiversity can have on the diet.

The above mentioned highly bio-available nutrients can make a substantial contribution to the diet of malnourished persons (Mouille, et al., 2010; Gilani & Nasim, 2007). In many countries and studies the nutritional value of potatoes is ignored due to their low protein content greater and focus is placed on orange flesh sweet potatoes as they contain significant amounts of vitamin A, which is a scarcely consumed vitamin in most developing countries (De Moura, et al., 2014). However, since 1998 researchers are focusing on the protein bio-fortification of potatoes. This method can increase the already highly bioavailable protein content of potatoes by 33%-40% making them contenders as whole foods and contributors in alleviating malnutrition (Haynes, et al., 2012). Baseline data on the current nutrient composition of different potato cultivars available on the market can inform future research.

As of 2013 there were 83 registered species of potato in South Africa but this is a constantly growing number (Potatoes South Africa, 2013). With the passage of time the consumption of different species changed as production patterns changed, for instance BP1 was the most commonly consumed potato in 1990, but it was replaced by Mondial in 2004 (Van der Waals, et al., 2004). As there is a significant difference in the nutritional value of different potato cultivars, biodiversity of a diet can be improved by consuming a variety of cultivars. This would contribute to the goal of achieving optimal nutrition worldwide (King & Slavin, 2013).

The United States Department of Agriculture (USDA) dietary guidelines state that potatoes can fit into more than one category when it comes to being classified as a starch or a vegetable. Depending on the manner in which a potato is prepared and consumed, it can either be classified as a starch and included in the grain family, or a vegetable but never as both (Dennison, et al., 1998). As already noted in the South African Food-Based Dietary Guidelines, potatoes are classified as vegetables (King

& Slavin, 2013). However, the fact that potatoes are increasingly consumed as a processed product with added oil, should in future be considered when formulating food-based dietary guidelines.

1.1.1 The need for research

In South Africa, as well as the rest of the world, a great deal of research is conducted on potato diseases and pests as these are some of the main problems seen in the potato industry (Fiers, et al., 2012).

However, limited research is focused and reported on the nutrition and consumer aspects of potatoes. Due to negative associations and limited consumer education in the past, potatoes have a relatively negative consumer image, because they are generally considered to be unhealthy and fattening (Ronaldo, 2012). Although this notion is changing (King & Slavin, 2013), sound scientific data on the nutritional content of the potatoes offered on the South African market, together with consumer education is needed to promote sustainable growth of the industry. To contribute to global biodiversity scores and become a role player in the benchmarking, monitoring and reporting of biodiversity aspects, more peer reviewed science based research is needed on the topic (FAO, 2014).

1.2 Classification of potatoes

Different potato cultivars have textural differences. These textural differences are mostly due to biodiversity of the crop, but can also be caused by agronomical conditions such as irrigation or dry land practices. Due to textural differences between cultivars certain potatoes are better suited to specific culinary applications (Thybo & Martens, 1998).

For this reason it was decided to implement a potato classification system in South Africa based on the eating quality of different cultivars. The classification system was implemented as a direct form of communication to the consumer, assisting consumers during their decision making and purchasing process (Potatoes South Africa, 2011). Consumers directly link the textural characteristics of a potato to the quality of the potato (Thybo, et al., 2004). This is an important aspect when considering the classification of food products as consumers expect consistent quality from the same product (Garcia-Segovia, et al., 2008).

Therefore, it is important to have an accurate descriptive system to ensure potatoes with similar properties are grouped together assuring consistent end results. The fact that potatoes are a highly biodiverse crop and can be cooked in so many ways, is a further challenge when implementing such a system, as these different culinary applications can alter textural properties (Feltran, et al., 2004).

The current South African potato classification system has three groupings namely; waxy, waxy/floury and floury. Furthermore, cultivars are grouped according to the cooking methods they are ideally suited for, namely; boil, roast, chipping (referring to oven bake), microwave, mash and retain shape when boiled. The most commonly consumed cultivars at the time of the development of the system, are depicted in the classification system. Provision has also been made for expansion.

This classification system can be used as a form of consumer education, assisting consumers when purchasing potatoes for a specific culinary application (Potatoes South Africa, 2013).

1.3 Justification for the study

South Africa produces more than 2 090 2010 metric tons of potatoes annually, making it a noteworthy crop in terms of agriculture as well as food and nutrition security (European Commission, 2014). The magnitude of production and consumption which has an effect on economics and nutrition makes it necessary to carry out research to ensure the sustainable production of potatoes in South Africa.

1.3.1 Nutrient content of different cultivars of potatoes

There is a significant difference in the nutrient content of different cultivars of potatoes (Burlingame, et al., 2009). Subsequently some cultivars can contribute more significantly to the diet than others (Mouille, et al., 2010). In South Africa the nutritional composition information on potatoes found in the Medical Research Council (MRC) food composition database is limited. Currently the database reports on the nutritional value of a single sub-species of potato, presumably BP1 as it was the cultivar of choice at the time when commonly consumed fruits and vegetables were analysed (Kruger, et al., 1998). It was proposed therefore, that nutritional analyses be conducted on different potato cultivars to evaluate the contribution they make to the diet.

Nutrient analysis is costly process that can only be performed at specific laboratories in South Africa. Due to the high cost and the lack of laboratories only minerals were analysed in this study.

1.3.2 Description of potato texture as influenced by cultivar and culinary application

The classification of potatoes is a complex process as there are textural differences between most cultivars. Textural differences are influenced by region (South Africa has 9 potato production regions), season (2 of the 9 regions in South Africa plant twice a year), agronomical practices (i.e. irrigation or dry land; optimal time in soil before harvesting) and the sugar to starch ratio. This is further complicated by the fact that the same cultivar performs differently if exposed to some of these differences. It is assumed that the variation in cultivars leads them to perform differently when culinary applications are applied and that certain cultivars are better suited to particular

culinary applications. Consequently the effect of different cooking methods on the internal textural properties of different cultivars was explored.

Subsequently, these differences in textural properties were further investigated to determine if the differences can be used to describe suitable culinary applications to consumers. Communicating to consumers in understandable language can be challenging, therefore standardised, tested terms are needed that are meaningful and descriptive to the consumer. Descriptive words will assist the consumer in the decision making process that is based on culinary application.

Words like waxy, mealy and floury are associated with potato classification all over the world. Although these words have very little meaning to the average consumer, they have been used for many years. In 2012 the United Kingdom was one of the first countries to implement descriptive terms for potato classification (United Kingdom Potato Council, 2014). Words used in Europe include fluffy, creamy, firm, smooth and salad (Park, 2014). More descriptive words could potentially make the current South African potato classification system more user friendly and better understood by the consumer.

1.3.3 “Slap chips” in the South African classification system

“Slap chips” are the bendable, thicker and softer equivalent of the French fry and are a uniquely South African product (Posthumus, 2010). In South Africa slap chips, are made from a variety of different potato cultivars and are consumed throughout the country, supplied most commonly by street vendors and cafes (Marraccini, 2011). Currently the South African potato classification system has categories for boil, bake, roast, chipping (oven bake), microwave, mash and retain shape when boiled (Potatoes South Africa, 2014), but not for the widely consumed slap chip. Therefore, Potatoes South Africa deemed it necessary to investigate if slap chips can be included in the current South African potato classification system.

1.4 Objectives of the study

The purpose of this study was to investigate the effect of cultivar on macronutrient and mineral content (with and without the skin) and culinary applications of the most commonly consumed cultivars in South Africa. Nutrient analysis was conducted on tubers with and without the skin.

The objectives of the study are as follows:

Objective 1: Determining the nutrient (macronutrient and mineral) content of different cultivars of commonly consumed potato cultivars (with and without skin) in South Africa.

Objective 2: Determining the effect of culinary applications (boil, bake and microwave) on the textural properties of potatoes and to develop descriptive terms to describe these intrinsic qualities.

Objective 3: To develop a repeatable method to prepare deep fat fried slap chips to determine its effect on the textural properties of potatoes.

1.5 Presentation and structure of the thesis

The structure and outline of the thesis is as follows:

Chapter 1: The study in perspective

This chapter provides a brief background and describes the objectives of the study.

Chapter 2: Literature review

A literature review is presented on potatoes in general, how they are grown, and biodiversity considerations seen against the perspective of the South African market as opposed to international markets. This chapter also highlights the importance of continued research on potatoes.

Chapter 3: The role of biodiversity in food security and nutrition: A potato cultivar case study

Chapter 3 addresses the first objective of the study to determine the nutritional value of different potato cultivars. Cultivar specific nutritional analysis has been taking place in other countries since the 1970s, but no such data is available in South Africa. Currently available nutritional information is based on the three different classes of potatoes and not the individual cultivars. Significant differences can occur in the nutritional value of root vegetables, which indicates that certain varieties can contribute more substantially to nutritional requirements. By knowing the sub-species specific nutritional information, cultivars can be used to combat specific nutritional deficiencies.

This chapter describes how the nutrient content of eleven different South African cultivars was determined (objective 1). Tubers were planted in one of the most productive production areas in the Eastern Free State of South Africa under dry land conditions and normal agronomical practices were applied. Subsequently macronutrient and mineral analysis was performed on the fresh raw tubers with and without the skin.

Chapter 4: Description of potato texture as influenced by cultivar and culinary application

This chapter presents the sensory and objective data obtained from analysing the effect of culinary applications on the textural properties of potatoes, as well as the descriptive terms developed for potato classification so that objective 2 could be addressed.

Different culinary applications can have an effect on the textural properties of potato cultivars. Sensory and objective tests were used to determine the changes in textural properties of cultivars when applying different culinary applications.

Potatoes are a diverse crop that do not deliver a uniform product, therefore a classification system is needed to describe the characteristics of these different cultivars. South African potatoes are currently classified in three main categories namely: floury, waxy and waxy/floury. Although these are fairly descriptive terms, the possibility does however exist that in keeping with the international and industrial perspective they have little meaning to the majority of South African consumers. Focus groups were used to evaluate descriptive terms collected by means of consumer research in an attempt to find better descriptive terms. These descriptive terms can be used in the market and thereby provide consumers with a better understanding of the performance of the potato they are purchasing.

Chapter 5: Mapping of deep fat fried slap chips made from 11 potato cultivars

Chapter 5 presents the results obtained from sensory and objective evaluations of slap chips in line with objective 3. Slap chips is a “proudly South African product”. They are thicker than French fries and have textural differences due to the different frying times and temperatures of the different methods. To describe potato cultivars that are most suitable for slap chips, the 11 most commonly consumed potato cultivars in the South African market were evaluated by a sensory panel for their slap chips eating quality. A Lexicon with descriptive words was developed, standardised and used by the sensory panel. This was done to categorise slap chips in terms of the current South African potato classification system.

Chapter 6: Conclusion and recommendation

The final chapter summarises the main findings of the research that was carried out. The implications of these findings and recommendations which should in future be considered are presented and discussed.

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Chapter 2: Literature review

“It is easy to halve the potato where there is love” – Irish proverb

2.1 Introduction

Potatoes are a popular crop all over the world with deep cultural and historical roots in many countries. They are consumed in a wide variety of ways with each country having their own unique method of preparation. Potatoes are a favourable source of carbohydrates (White, 2011) and in their fresh form, potatoes can form part of a balanced diet (Aziz, et al., 2013; Bethke & Jansky, 2008). According to the International Potato Centre potatoes are the world’s first modern day convenience food as they are nutritious, energy rich and can be easily planted and harvested on a small scale (International Potato Center, 2014).

World potato production is a multibillion dollar industry providing a livelihood to countless families (Haase, et al., 2007). From its origin in Peru hundreds of years ago up until today, the potato has provided countless meals to families, making it one of the oldest cultivated crops known to mankind (International Potato Center, 2014).

2.2 General overview on potatoes

2.2.1 A brief history

A variety of studies indicate that potatoes originated in the Andes Mountains in Peru. The origin of the plant dates back to 4th century A.D. It is believed that most of the tubers being planted today had their origin in these wild potatoes in Peru (Hawkes, 1978).

During the time of the Spanish Inquisition, Spanish pilgrims came across potatoes on their journeys around and through Peru (Horton, 1987). The potato was seen as a remarkable crop as it was grown at the coast as well as the highlands, where temperatures were significantly lower (Luis, et al., 2011). The potato could be dried and ground into a type of flour, called chuño that could be taken on long voyages across the ocean making it an ideal food that did not spoil (Salaman, 1985). During the 16th century the Spanish explorers brought potatoes to Europe from where they spread all over the globe (Gibson & Kurilich, 2013).

It is assumed that tubers came to Africa, more specifically sub-Saharan Africa, together with Bartholomeu Diaz in 1488 when he discovered the Cape of Good Hope (Howcroft, 2015). However,

the cultivation of potatoes as a crop was thought to have started during the colonial period in the 1880s. (Department of Agriculture, Forestry and Fishery, 2013)

2.2.2 The tuber

Potatoes (*Solanum tuberosum*) are underground carbohydrate storage organs from the *Solanum* family which is a genus of flowering plants (Dilworth, et al., 2007) that also includes tomatoes and egg plants (Mohamed, et al., 2012). Roots and tubers are the third most commonly consumed carbohydrate crop globally. Potatoes comprise nearly half of this mentioned figure (International Potato Center, 2014; Ek, et al., 2012; FAO, 2008^b). These tubers absorb all their nutrients from the soil they are grown in (Doring, et al., 2005). The nutrients are then spread unevenly throughout the skin and flesh of the tuber depending on the mobility of the specific nutrient (Subramanian, et al., 2011).

Potatoes are inexpensive and contain a wide variety of minerals (calcium, manganese, magnesium, potassium, iron, zinc) and even a highly bioavailable form of protein (Camire, et al., 2009). In addition, to the wide variety of nutrients found in potatoes, they also contain flavonoids, carotenoids, phenol compounds, antioxidant phytochemicals (Andre, et al., 2007) and vitamins all of which have a beneficial effect on human health (Rodriguez, et al., 2012). In most countries potatoes are classified as a vegetable because they are of plant origin and contain a wide variety of nutrients, minerals and antioxidants (Decker & Ferruzzi, 2013). In other cases they are categorised with starches, such as pasta and rice due to their high starch content and techniques of preparation (Robert, et al., 2006). The Food and Agricultural Organisation (FAO) classifies potatoes as “A seasonal crop grown in temperate zones all over the world, but primarily in the northern hemisphere” (FAO, 1994).

As potatoes are one of the most genetically diverse crops known to man, they are able to grow in a wide variety of agronomical conditions (Burlingame, et al., 2009), which makes them a favoured food crop all over the world (Abbas, et al., 2011; Luis, et al., 2011). More than a million people around the world consume potatoes on a daily basis necessitating an annual global crop production of more than 300 million metric tons (International Potato Center, 2014). The total African production of potatoes is currently quantified at 10.3 million metric tons annually (European Commission, 2014). In South Africa, more than 2 million tons of potatoes are produced annually, on just under 55 000 hectares, by more than 640 formal producers, and a total value of R6 billion per annum, with a current average price of R24.21/10kg bag (Potatoes South Africa, 2015).

Production of potatoes around the world is a multimillion dollar industry and provides an income from a variety of sources to many families contributing positively to global economics (Wambugu, 2014; Lutaladio, N., & Castaldi, L, 2009; Haase, et al., 2007).

Potatoes are not only diverse at a genetic level, but also in regard to their textural properties. Different cultivars, with varying textural properties can meet the demands of a variety of consumer preferences (van Dijk, et al., 2002). In most countries fresh potatoes are available all year round either due to yearly growing cycles or their extensive storage time, making constant global consumption possible (Oruna-Concha, et al., 2001).

In South Africa, as well as many other countries around the world, nutrition, food safety, and security are key challenges that constantly need attention (Vorster & Hautvast, 2002). Thus a nutrient dense, easy growing crop is ideal and can provide part of the solution. Potatoes are a resourceful food crop as production delivers more dry matter, nutrients per gram and protein per hectare than any other cereal crops (Ezekiel, et al., 2013).

2.2.3 Biodiversity

For many years it was believed that a diverse crop is merely a way of improving the production of food as certain sub-species deliver better crop yields. The importance of biodiversity from a food security point of view only became an important factor in the last couple of years (Frison, et al., 2011). In many countries it is believed that there is a trade-off to be made between biodiversity and food crop yield, especially in poor countries that do not have the ability to produce a diverse food crop because of land and economic restraints. There is a belief that if a country wants to produce high volumes of food economically and be agriculturally productive they will have to sacrifice biodiversity. This statement has been proven incorrect repeatedly. When agriculture and government work together a win-win situation can be created (Tscharntke, 2013; Brussaard, 2010). Although there are costs involved with the conservation of biodiversity, these costs will ensure a food future for all (FAO, 2014; Pimentel, 1997).

The significance of biodiversity is important both on the genetic and the species level. Genetic diversity of food products lies at the heart of biodiversity (Reed, 2012). Biodiversity of food has three levels. When all of these levels are in place they can contribute to food security and improved nutrition. These three levels are: the ecosystem, the specific species within that system and the genetic diversity of the species (Toledo & Burlingame, 2006).

Biodiversity can be a critical measure of the world's health because biodiversity not only contributes to the food security and nutritional needs of a country, but also provides a platform for economic

growth. Biodiversity in a country has to be treasured, as once a species has become extinct, it is practically impossible to get it back (Reed, 2012). It is an essential part of human existence, as biodiversity not only provides us with food to keep us alive, but also supplies medicine, income, employment and tourism to name but a few other advantages (Pimentel, 1997).

The history of the potato should give us a clear indication that a diverse food crop is essential for survival (International Year of the Potato, 2008). One of the major causes of the Great Potato Famine in Ireland, which led to hundreds of thousands of deaths, was the lack of potato biodiversity (Relman, 2011). At the time of the famine two main cultivars were planted, the Lumper and the Cup. These two cultivars were high yielding and easy to plant and harvest and thus favoured among farmers. When the potato virus was introduced from the Irish coast both these species were susceptible to the virus and died out (Japikse, 1994). Another such tragedy occurred in 2010 in Peru, when late blight spread across the country and destroyed all the potato crops of that year. The devastation was of such a magnitude that the government declared a national state of emergency. One of the only reasons Peru could continue with potato production the following year was due to new cultivars that were introduced to the country which were resistant to the specific type of blight (CGIAR, 2012). Papua New Guinea and the Democratic Peoples Republic of Korea are two more examples of countries which were affected by late blight and were able to recover by having a diverse potato crop (International Potato Center, 2012).

Because potatoes are vulnerable to a variety of pests and diseases, a diverse crop is essential for the continued production of the crop. It is estimated that about a quarter (25%) of potatoes produced each year are lost due to pests or disease (Nowicki, et al., 2012; Gebhardt & Valkonen, 2001). Amongst others potatoes are susceptible to the following diseases; wet and dry rot, blight, rust, wilting, scab, a variety of potato viruses, and leaf viruses. These diseases affect the leaves, roots, stems and tubers. Most diseases and pests leave the potatoes inedible (Van Der Waals, et al., 2013). By having a biodiverse crop the impact of disease losses can be controlled by means of area specific cultivation practices (Denner, et al., 2012).

Local food biodiversity is an important contributor to the nutritional status of countries. The locally available foods in a country are the main sources of energy, micronutrients and dietary diversity. The higher the biodiversity of an area, the more likely people are to consume biodiverse diets with a variety of nutrients. In third world countries there is a desperate need for own food production as this is the main source of energy and nutrients. It is believed that by increasing the biodiversity of crops that are planted and consumed, the nutritional status of a country can be improved (Frison, et

al., 2011). The biodiversity of the food profile of a country will not only improve the present nutritional status but also the future status.

In developing countries focus is placed on specific nutritional plans. This will ensure that the crops available in a country are used to combat the nutritional problem of that specific country (FAO, 2014; Vorster, et al., 2013). Biodiversity should be treasured and guarded to ensure stable crop production for years to come. With certain food crops, such as potatoes, the nutritional content differs so vastly between sub-species that by consuming a certain variety over another can be the difference between nutrient deficiency and adequacy (Bioversity International, 2014; Mouille, et al., 2010).

The ever expanding global population poses a problem in terms of food security. The greater number of people requires increased amounts of nutritious food to avoid even more malnutrition and hunger (Kahane, et al., 2013). This is where biodiversity can play a role as a critical indicator of the agricultural and nutritional health of a country (FAO, 2014). Nutrition, health, sustainability and agriculture go hand in hand and protecting all these elements will ensure a food future for all (Bioversity International, 2014; Schönfeldt, et al., 2012).

Although enough food is being produced globally to feed the world population this food is not necessarily available where it is needed leading to food insecurity in many parts of the world. Many of these reasons for food insecurity are related to monetary restraints and access to food (Pretty, et al., 2003).

South Africa is regarded as a self-sufficient food nation at a national level and it has enough food to export, but there are numerous individuals in this country who are malnourished at a household level (Lewu, et al., 2010). This goes against the mandate that was implemented in 1994 that every South African has the right to sufficient food (Du Toit, 2011).

Malnutrition, food insecurity and hidden hunger are serious issues faced by third world countries, which are further intensified by poverty and unemployment. The main reason for food insecurity on a household level is poverty, where individuals simply cannot afford to buy food (Labadarios, et al., 2011). Lack of dietary diversity is also an indicator of food insecurity. In South Africa this is the most commonly seen food insecurity, with most individuals in this situation following a monotonous diet of fortified maize porridge and bread (Labadarios, et al., 2011). Adding diversity to these diets in the form of an easy growing, low cost biodiverse staple that is already cultivated in the country, such as potatoes, can have a significant impact on the nutritional status of these individuals.

Food security cannot be discussed without considering sustainability of production practises. Due to the growing global population the world is drawing closer to the universal threshold for agricultural production (Bioversity International, 2014). For this reason sustainable and precision farming is needed which can lead to higher yielding crops that can produce more food on less land in a more environmentally acceptable manner (Kutter, et al., 2011).

2.3 Potatoes in the South African market

In South Africa, potatoes are produced all year round. This is made possible due to bio-diversity of the crop and the different climatic conditions of different regions. The tubers are most commonly planted in rotation with maize and wheat (Department of Agriculture, Forestry and Fishery, 2013). The 12 main production regions, as seen in Figure 2-1, are the Eastern Free State, Limpopo, the Sandveld, the Western Free State, Mpumalanga, the North West and Northern Cape. Potatoes are also produced in the South Western Free State, North Eastern Cape, Eastern Cape, Loskop Valley, Gauteng, Ceres, Southern Cape and South Western Cape (Potatoes South Africa, 2015). Potato farming accounts for approximately 45% of the total amount of vegetables produced in South Africa and 14% of total plant production. Potatoes also account for 4% of total agricultural production in the country (Syngenta South Africa, 2013). This quantity is lower than the 15% seen in America (USDA, 2012).

Potato production in South Africa has been increasing steadily over the last couple of years. There has been a concurrent increase in the per capita consumption of potatoes, as shown in Figure 2-2 (Bureau for Food and Agricultural Policy, 2014).

Due to the increase in meat prices, the production of vegetables is predicted to increase which in turn may ensure stable vegetable costs and production (NAMC, 2013). According to the Bureau for Food and Agricultural Policy (BFAP) an increased consumption of potatoes is expected over the next 10 years. Currently the South Africa per capita consumption of potatoes is 36kg/capita/annum which is estimated to increase to 42kg/capita/annum in 2023 (Bureau for Food and Agricultural Policy, 2014). This is still significantly less than the 90kg/capita/annum of Europe (Year of the Potato, 2008), but higher than the mean global per capita consumption of 33kg (King & Slavin, 2013).

It is evident that potatoes are starting to find their place as a staple food in the South African market and are also one of the most important crops currently being produced worldwide. After rice, maize and wheat, potatoes and other tubers are the 4th most consumed staple food in the world (FAO, 2011; Andre, et al., 2007; FAO, 1998).

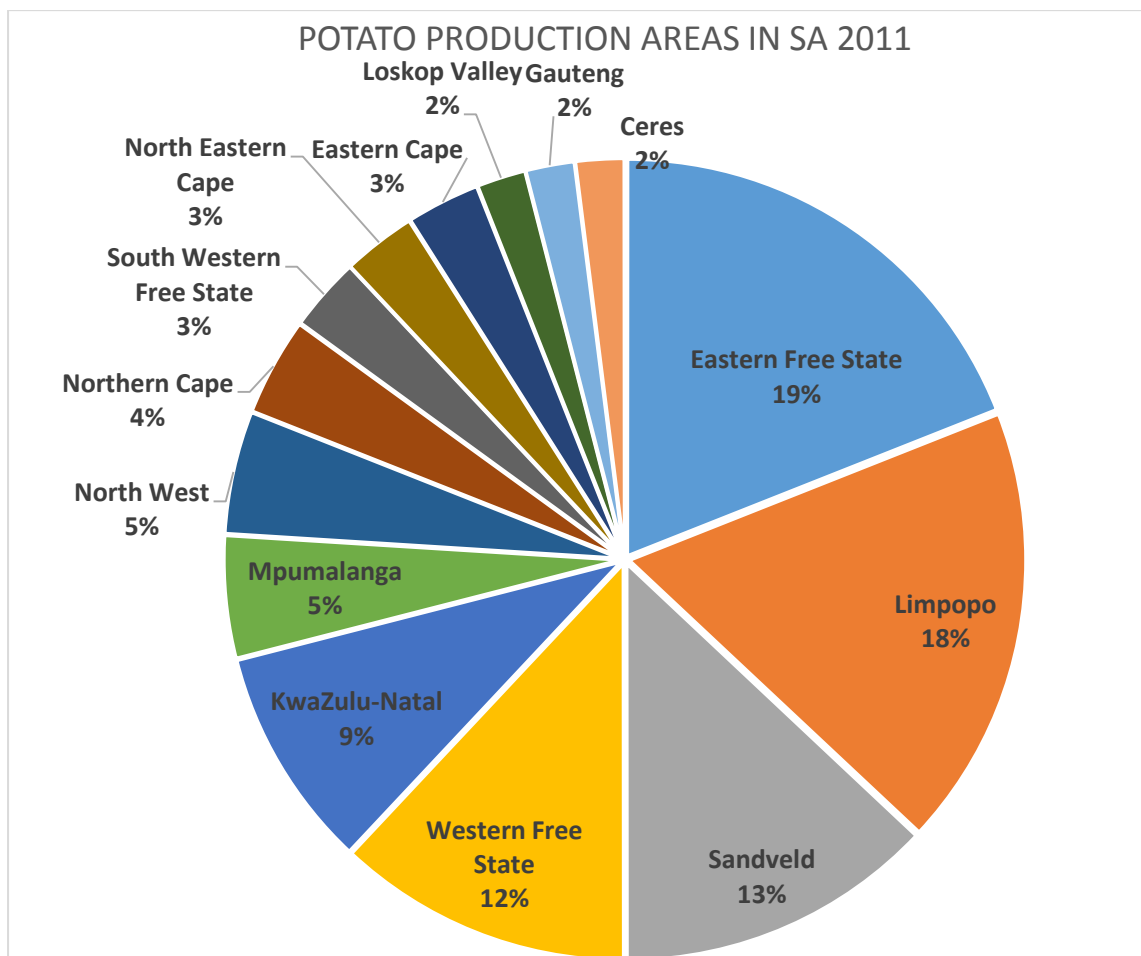


Figure 2-1: Percentage production of potatoes in different regions of South Africa in 2011 (Potatoes South Africa, 2015)

In addition to being a staple food, potatoes are also becoming a food security crop (South African Department of Agriculture, 2011). In 2012, 65 000 hectares of potatoes were planted in South Africa which produced just over 220 million 10kg bags (Potatoes South Africa, 2015). The total potato production value for 2012 was estimated at R2.8 billion distributed between different industries as follows: 7% exports, 9% processors, 31% formal trade and 53% informal trade (Potatoes South Africa, 2012). Potatoes provide livelihoods for producers and labourers and has notable multiplier effects up and downstream in the supply chain in the input, transport, processing, retail, packaging and formal and informal trade sectors (South African Department of Agriculture, 2006).

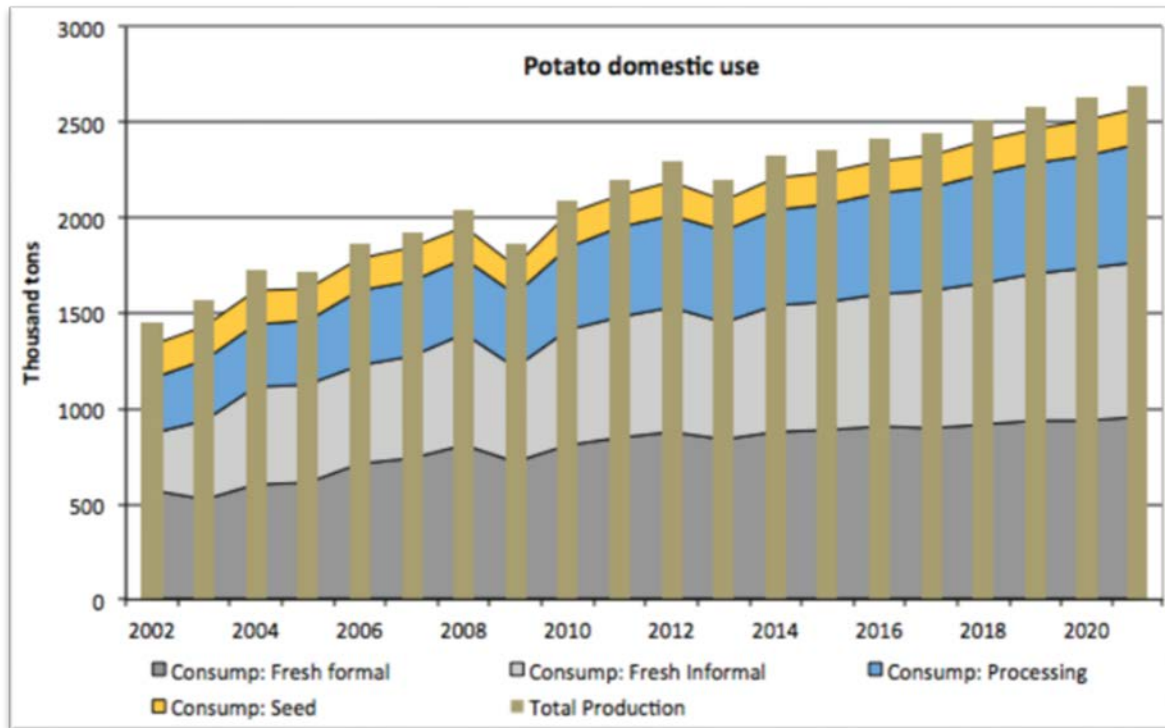


Figure 2-2: Projected growth rate of potato production (Bureau for Food and Agricultural Policy, 2014)

The price of a bag of potatoes has steadily been increasing over the last decade, with a price increase of 7.37% in the 2012/2013 budget year. This increase was significant because it was 1.4% above that year’s inflation rate. In that same year the price of sweet potatoes increased by 11.14% per bag. Meat prices are increasing at a more rapid pace than vegetable prices, making fresh produce markets hopeful that this could indicate increased consumption of vegetables (NAMC, 2013). Current projections predict that the nominal price of potatoes will increase from the current price of R36 per 10kg bag to R61 per 10kg bag in 2023 but with little real market growth taking place (BFAP, 2014). This small to no real market growth will probably be due to the high agronomical costs of potato production (Department of Agriculture, Forestry and Fishery, 2013). As with most products the price of potatoes is influenced by supply and demand (McGregor, 2011). Because potato consumption is increasing a need has arisen to determine the effect they have as a staple in the South African diet.

In South Africa maize meal is the dominant staple food commodity for low- and middle income consumers, accounting for up to 31% of total staple food expenditure of households in 2010. For high income consumers staple food choices are dominated by white bread and brown bread, accounting for 17% and 16% respectively of total staple food expenditure of households in 2010. Across socio-economic sub-groups 7% to 8% of total staple food expenditure is allocated to

potatoes. It should be noted that the total value of household monthly staple food expenditure in 2010 varied so that the 7 – 8% only amounted to about R140 to R300 across the socio-economic spectrum (Stats SA, 2012; Stats SA, 2008).

2.3.1 Cultivars

For many years the BP1 cultivar was the market leader in South Africa. In 2000 BP1 comprised the largest share of the market at 43% (van der Waals, et al., 2004; Food Composition Database, 1999). This cultivar, which was cultivated in South African, has white skin and flesh, is high yielding and is seen as a good all round potato with waxy and floury characteristics.

Since 1995 there has been a decline in the production of traditional cultivars. In 1995 potatoes which had originated in South African BP1, Van der Plank, Buffelspoort (BP13), together with Up-to-Date from the United Kingdom, comprised 91.4% of the market. Currently these four cultivars comprise less than 20% of the market. The shift in production and consumption of different cultivars is mainly due to the introduction of international cultivars to the South African market. In 1949 the Agricultural Research Council (ARC) Roodeplaat Vegetable and Ornamental Plant Institute (Agricultural Research Council, 2014), started with breeding programmes to develop and test seed potatoes that are disease resistant, higher yielding, adaptable to varying planting conditions and suited for niche markets. From these breeding programmes the newly introduced cultivar Mondial, from the Netherlands, proved to be a reputable potato meeting all the requirements for farmers and consumers. This cultivar has many of the characteristics that BP1 has and it is an exceptionally high yielding plant with large to medium sized tubers which is favoured among farmers. Shifts in production and consumption patterns of different cultivars will continue to occur in the future as new and improve cultivars are developed in this ever changing industry (Denner, et al., 2012). Figure 2-3 indicates the market share of the different cultivars in 2012.

2.3.2 Seed potatoes

South Africa is regarded as a country with a biodiverse potato crop. Currently there are 83 registered cultivars that are all unique and are adapted to the different potato production areas in South Africa. To ensure that continued potato development and seed production occurs, 10 000 ha is annually registered for seed potato production (Potatoes South Africa, 2015). Continuous production of new seed potatoes ensures that new disease resistant cultivars are constantly introduced into the market. Because potatoes are such a disease prone crop, it is essential to establish new tuber generations which are immune to rapidly spreading diseases. Potato crops can be used for seed potatoes for a maximum of 10 generations after which a new generation has to be planted to ensure a strong disease resistant crop (South African Potato Certification Service, 2014). Another reason for

continuous research and development of new potato tubers is that increased consumption leads to increased demand. As the area on which potatoes are grown cannot necessarily increase, yield per plant needs to be increased (Lokendrajit, et al., 2013).

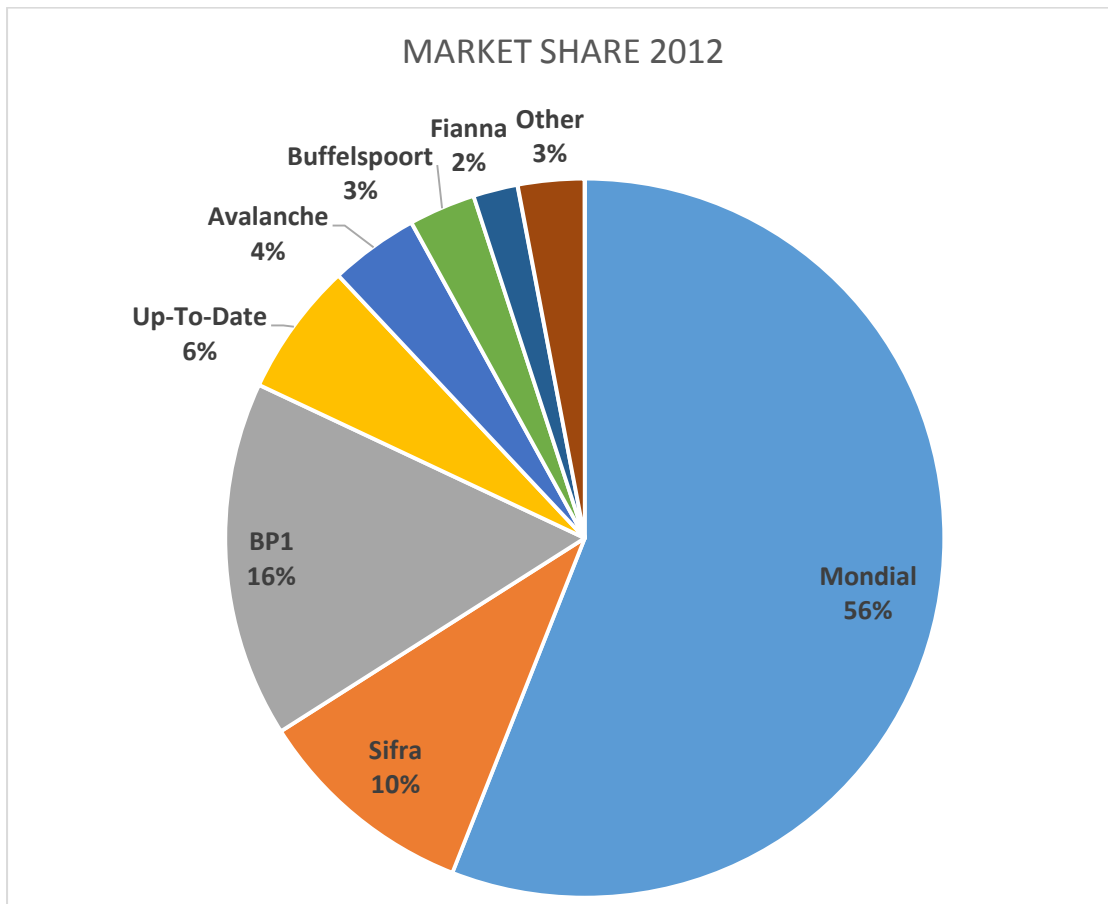


Figure 2-3: Percentage of cultivars traded on the South African fresh produce market during 2012 (Potatoes South Africa, 2015)

2.4 Potato world

Potatoes are grown all over the world, with a global production of 324 420 782 metric tons annually (European Commission, 2014).

2.4.1 Europe

Potatoes have been cultivated in Europe since the late 15th century making it the oldest commercial potato producing continent on earth (Rios, et al., 2007). Today the European Union is the second largest producer of potatoes in the world with an annual production of 82 946 426 metric tons on 3 648 116ha. First place is held by Asia with an annual production of 94 314 323 metric tons on 6 349 790ha (European Commission, 2014) (Figure 2-4).

Due to the increased consumption of processed potatoes a great deal of effort has been put into rebranding the tuber in the United Kingdom (UK) over the last three years. The first step was to revise the (UK) potato classification system in 2011 (Agricultural and Horticultural Development Board, 2012). The rebranding campaign was backed by a further overall education campaign named “Love Potatoes”. The main focus of this campaign was to educate consumers on how to make potatoes part of a healthy meal and to educate them about the nutritional benefits of potatoes (United Kingdom Potato Council, 2014).

2.4.2 Australia and New Zealand

In comparison to European countries, Australia and New Zealand are fairly new potato producing countries. Production is respectively 1.2 million metric tons and 430 thousand metric tons (European Commission, 2014). In both these countries extensive consumer research is taking place in an attempt to better understand the role of potatoes in the consumer’s home and diet. Emphasis is placed on the packaging size and price which researchers found had a significant impact on the quantity purchased. Marketing, as well as education programmes are being implemented in both these countries to promote increased consumption of potatoes (Australia Bureau of Statistics, 2010).

A potato classification system was launched in New Zealand in an attempt to increase the consumption of potatoes by consumers. Consumers were educated on the best ways to prepare different cultivars. Similar to the South African classification system New Zealand has three classes namely smooth, smooth/fluffy and fluffy. Whether this programme is successful is yet to be determined (Potatoes New Zealand, 2014).

2.4.3 America

According to the US Department of Agriculture and the My Plate guide, potatoes are classified together with vegetables (United States Department of Agriculture, 2012). More than 38 million metric tons of potatoes are cultivated in America each year (European Commission, 2014) with more than 60% of these potatoes being used by the processing industry (National Potato Council, 2014). These potatoes are planted on 1 579 644 hectares of land (National Potato Council, 2014) which is ten times as large as the area used in South Africa. Currently the per capita consumption of potatoes in America is 53kg per annum, with 37kg being consumed in a processed form (Guenther, 2001). The increased consumption of processed and fried potatoes is seen as one of the main causes of obesity and its related diseases in America (Cahill, et al., 2014).

2.4.4 South America

Currently potato production in South America is growing by 1.3% annually with current annual production figures of 15 682 943 metric tons (FAO, 2015; European Commission, 2014). Peru is believed to be the country of origin of potatoes, and the country that till today still has the richest genetic diversity of potatoes and is rated as the 17th largest producer of potatoes in the world (FAO, 2015; FAO, 2008).

2.4.5 Asia

Asia is the world’s largest producer of potatoes with annual production figures of 137 343 664 metric tons, exporting 1 008 134 metric tons of the crop as processed and frozen potatoes (European Commission, 2014). China is the biggest potato producing country in Asia with an annual crop of 85 920 000 metric tons (Figure 2-4), which contributes 20% of the annual global potato crop (FAO, 2015; Potato Pro, 2014). Potato production contributes significantly to the Chinese economy as up to half of rural household income is from potatoes (Koning, et al., 2014).

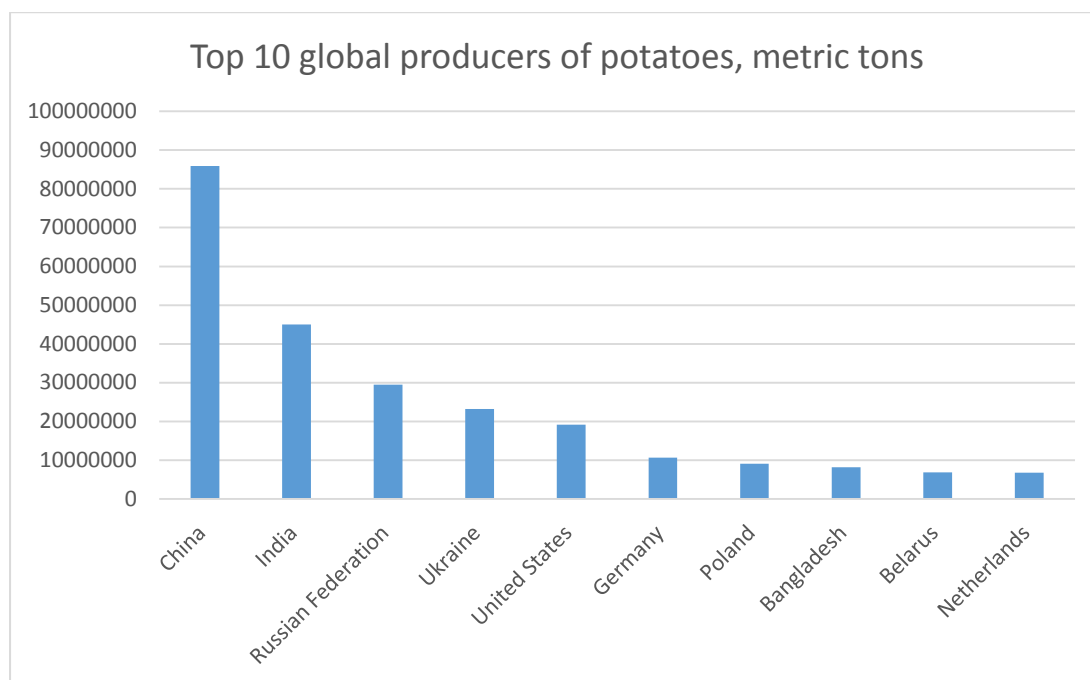


Figure 2-4: Top 10 global producers of potatoes

2.5 Nutritional value of potatoes

Potatoes are a nutritious source of carbohydrates consisting of 80% water and 20% dry matter as well as a wide variety of vitamins and minerals (Murniece, et al., 2011). Starch, which forms the main plant carbohydrate (Lee & Moon, 2015), is the major storage compound found in potatoes (Chen, et

al., 2001). As potatoes are a nutritious form of carbohydrates they can form part of a balanced diet. Tubers are more nutrient dense than their carbohydrate counterparts, rice and maize and provide nutrients necessary to the human diet (International Potato Center, 2015; King & Slavin, 2013). Potatoes also contain antioxidants (e.g. carotenoids, lutein, zexanthin (Brown, 2005)) which can contribute meaningfully to the human diet (Lachman, et al., 2000).

Potatoes have a role to play as a staple food in countries all over the world and are contributing substantially to healthy diets as they are a staple food containing a variety of nutrients (Camire, et al., 2009; Andre, et al., 2007). Tubers are a high yielding, low cost crop that produces more nutrients per monetary input value than any other vegetable crop (Drewnowski & Rehm, 2013). Table 2-1 indicates how potatoes contribute to the diet and daily nutrient reference values (NRV).

Table 2-1: Nutritional contribution of potato flesh and skin (100g) to Nutrient Reference Values (NRV)

Nutrient	Unit	Average per 100g raw potato, flesh and skin[#]	NRV*	% of NRV
Protein	g	1.5	56	2.68
Fat	g	0.01	20	0.05
Calcium	mg	6	1300	0.46
Phosphorus	mg	45	1250	3.6
Magnesium	mg	15	365	4.11
Copper	mg	0.09	0.9	10
Iron	mg	1.2	13	9.23
Manganese	mg	1.4	2.3	60.8
Zinc	mg	0.29	10	2.9
Potassium	mg	398	>4700	6.34
Sodium	mg	2	<2000	0.1

* (Department of Health, 2014) NRV for individuals 4 years and older

[#] (Wolmarans, et al., 2010)

[§] According to R146 nutrient values may only be listed if a portion provides more than 5% of the NRV (Department of Health, 2014)

Tubers contain a variety of nutrients, however not all of these nutrients contribute meaningfully to human nutrition. A 100g serving of potatoes do not contain significant amounts of protein, fat, calcium phosphorus, magnesium, zinc and potassium. A 100g serving contains moderate amounts of copper and iron and is high in potassium.

2.6 How the market views potatoes

Many people have the impression that potatoes are unhealthy and fattening which is a notion that has been formed over many years. In an attempt to overturn this notion a lot of time, effort and money has been invested by the potato industry of various countries to change the consumer perception of potatoes, as mentioned above (United States Potato Board, 2014).

Although a boiled potato is nutritious, the way it is commonly consumed often is not (Kolasa , 1993; True, et al., 1978). By adding fats such as frying oil, butter and cream to potatoes, either during preparation or at the table, the kilojoule value of potatoes changes drastically. These high fat additions and preparation methods have led consumers to describe potato chips as being one of the unhealthiest snacks available on the market. Unfortunately, this perception about processed potatoes has been carried over to fresh potatoes which are naturally healthy products (Hrncirik & Zeelenberg, 2014; Carles, et al., 2006).

The shift in consumption patterns of food products, such as potatoes, is a reason for concern (Monteiro, et al., 2011). Monteiro states; “The issue is not foods, nor nutrients, so much as processing”. The nutritional value of potatoes is being changed so drastically through processing and unhealthy cooking techniques that the effect on diet and health is reason for concern (Monteiro, 2009). As shown in Figure 2-5, 20% of potatoes cultivated in South Africa are used by the processing industry were most of the tubers are processed into frozen chips.

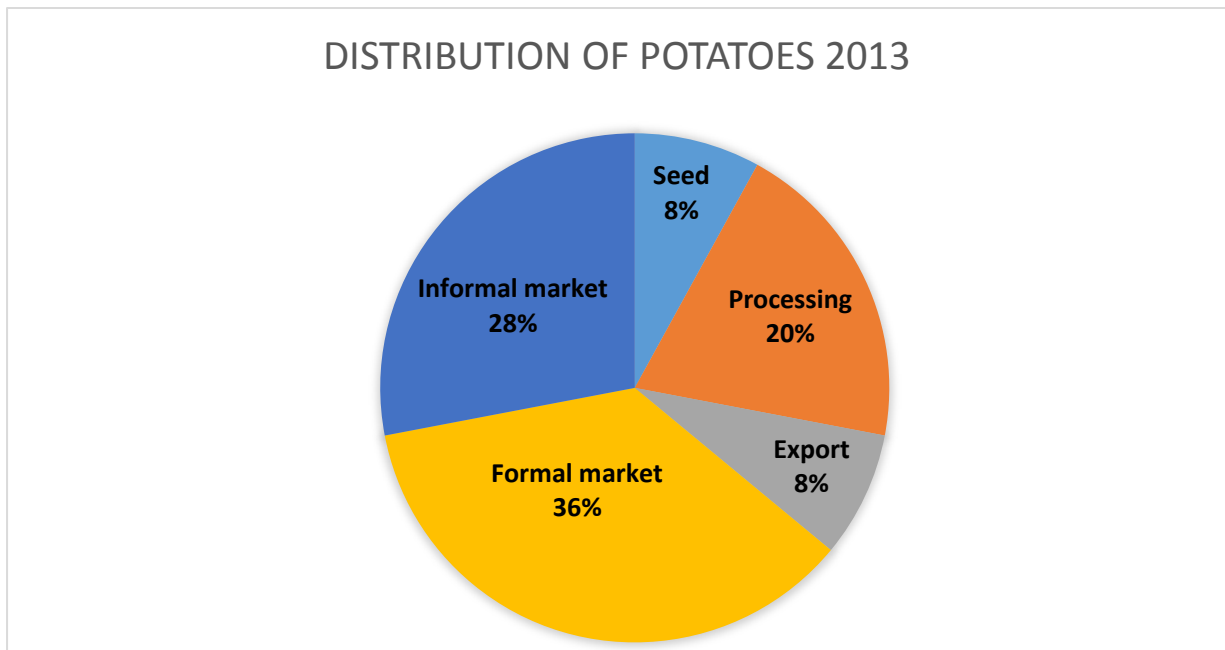


Figure 2-5: Distribution of total South African potato crop to different sectors (Potatoes South Africa, 2015)

For this reason scientific research is essential so that the potato market can base its consumer education programmes on valid results. Marketing campaigns that mislead the consumer into purchasing these high fat processed foods can be regarded as a problematic adversary for health professionals as they struggle to fight against the multi-billion dollar snack food industry (Harris, et al., 2009). In the South African context cultivar specific nutritional data can form part of the Medical Research Councils Food Composition Database. It can also be used in the biodiversity score sheet of the International Potato Centre (International Potato Center, 2014; FAO, 2014).

2.7 Concluding remarks

Potatoes are a nutritious form of starch that is grown successfully all over the world making them an important and bio-diverse food crop. This bio-diverse crop can contribute to food and nutrition security in many third world countries. They are a fairly easy growing crop that can be cultivated with minimal input costs in a variety of agronomical conditions by subsistence farmers. Due to their easy cultivation, tubers can contribute to economic growth in many third world countries. Subsistence farmers can grow tubers on a small plot of land and sell the tubers for an income or as use them as a food source for their own family.

As the tubers are more nutritious than other staple foods, such as rice and maize meal, they can contribute to diets by adding diversity to otherwise monotonous diets.

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Chapter 3: The role of biodiversity in food security and nutrition: A potato cultivar case study

“It is easy to think of potatoes, and fortunately for men who have not much money it is easy to think of them with a certain safety. Potatoes are one of the last things to disappear, in times of war, which is probably why they should not be forgotten in times of peace.”

— M.F.K. Fisher, *How to Cook a Wolf*

Abstract

Biodiversity is considered a critical measure of the agricultural health of the world. Not only does increased biodiversity contribute to nutrient production and consumption, but it acts as a safeguard against food shortages due to pests and diseases by spreading the risk. Biodiversity can improve dietary diversity in such a way to ultimately contribute to improved food and nutrition security. As a result biodiversity is often highlighted in global discussions related to food and nutrition security.

Potatoes (*Solanum Tuberosum L.*) are highly biodiverse food crops, with more than 4000 different cultivars grown globally. The crop is sometimes considered as part of the vegetable component of food baskets, but it is mainly added to meals as a starch because potatoes have a high starch content and are thus high in energy. However, significant differences in the nutritional content (including micronutrient composition) of different potato cultivars have been reported in many countries. It is therefore proposed that specific cultivars could potentially contribute more to critical nutrients required in the diet of countries at risk of malnutrition. The nutritional profile (macronutrients and minerals) of 11 potato cultivars cultivated in sub-Saharan Africa was determined and the contribution which these different potatoes could make to the diet, and consequently to food and nutrition security, is discussed.

The results showed that significant differences are found in the nutritional content between the different cultivars. Significant differences ($p < 0.001$) were found in macronutrients such as protein and fat as well as micronutrients such as copper, phosphorus and potassium. These results indicate the potentially beneficial role which a biodiverse range of crops such as potatoes, could play in the food and nutrition security of developing countries.

Keywords: Potatoes, *Solanum tuberosum*, nutrient content, biodiversity, Sub-Saharan, food and nutrition security

3.1 Introduction

Food, as well as the lack thereof, has a significant impact on human health, therefore food and nutrition security, dietary adequacy and biodiversity are currently amongst the most vigorously discussed global topics in the field of nutrition (FAO, 2015; Jones, et al., 2013). Even though these topics have been main focus areas in the field of nutrition for many years, resulting in slow to moderate changes in the nutrition status of populations (FAO, 2015), little progress is observed in sub-Saharan countries (Schönfeldt, et al., 2014). The Millennium Development Goal, 1C related to halving under nutrition in developing countries was not reached in 2015, particularly not so in sub-Saharan Africa (FAO, IFAD and WFP, 2014; United Nations, 2014). This slow progress is often blamed on population growth, poor agricultural conditions and environmental changes, etc., which place strain on food production and food security (FAO, IFAD and WFP, 2014).

Individuals who are food secure and have the ability to acquire adequate food for a healthy and active life (Meade & Rosen, 2013), are more likely to be able to contribute significantly to the economy than their undernourished counterparts (Bommarco, et al., 2013). Globally food programmes are being implemented to fight food and nutrition insecurity (Tanuminhardjo, et al., 2007). Even though these programmes lead to a decrease in food insecurity, very little change is observed in nutrition security, while a drastic increase in obesity rates tends to occur (Lear, et al., 2014; Shisana, et al., 2014). These programmes are mainly focused on supplying food insecure individuals with energy dense food to combat food insecurity rather than nutrient dense foods to achieve both food and nutrition security (Khoury, et al., 2014). Staple foods in Third World Countries include fortified bread and maize products that do not supply individuals with all the nutrients necessary for good health. Furthermore these diets are supplemented by increased consumption of high fat foods (Popkin, et al., 2012). This monotonous consumption of staple foods and fat is leading to stunting in young children and under nutrition (lack of certain essential nutrients) in adults (Smith & Haddad, 2015; Papathakis & Pearson, 2012).

The main cause of stunting is under nutrition, which (despite various interventions) is increasing in sub-Saharan Africa. In the age group 0-3 years 26.9% of boys and 25.9% of girls were stunted in 2012 as opposed to 19% of boys and 16% of girls in 2008 (Shisana, et al., 2014). Sub-Saharan countries are faced with hidden hunger (micronutrient deficiency), which is seen in children and adults. These individuals suffer from micronutrient deficiencies most commonly due to a lack of fruit and vegetables in their diets (Grubben, et al., 2014). Eighteen out of 20 top countries that suffer from hidden hunger, are in sub-Saharan Africa (Muthayya, et al., 2013).

These countries are also faced with the growing occurrence of overweight and obesity. According to the South African National Health and Nutrition Examination Survey (SANHANES) 24.8% of females are overweight and 39.2% are obese. It was reported that 20.2% of males and 68.2% of females were at risk of metabolic complications due to their weight (Shisana, et al., 2014; McCormick, et al., 2014). These figures are high when compared to other developing countries. Brazil has lower obesity rates, only 12.5% of males and 16.9% of females are obese. (Jaime, et al., 2013).

Promoting agricultural diversity can lead to dietary diversity through increased consumption of different cultivars of fruits and vegetables (Toledo & Burlingame, 2006). The United Nations (UN) together with the International Institute for Sustainable Development listed biodiversity as one of the most important aspects of food and nutrition security because it has the potential to decrease the occurrence of micronutrient deficiency (IISD, FAO, 2015; Bioversity International, 2014).

3.1.1 Potatoes in South Africa

South Africa is classified as a country with high biodiversity levels (SANBI, 2015). Potatoes are one of the crops that contribute to this high biodiversity score with more than 80 registered cultivars. These tubers are grown in 16 production regions in the country (Potatoes South Africa, 2014). Due to the biodiversity of these tubers, they can be grown in a variety of agronomical conditions by commercial and subsistence farmers (International Potato Center, 2014). Because these tubers are nutrient dense carbohydrate, they can form part of an affordable balanced diet along with other starches such as bread and maize meal (Drewnowski & Specter, 2004). The tubers are cheaper than cereals and provide more nutrients per monetary unit than any other carbohydrate crop, thus making them a noteworthy contributor to food and nutrition security (Drewnowski & Rehm, 2013; Bethke & Jansky, 2008). Furthermore they fit into the Food and Agricultural Organisation (FAO) goals of promoting crops that are locally available and that are adapted to cultivation practices of the countries in question (IISD, FAO, 2015^a).

Even though there are so many cultivars available, the nutritional value of only one cultivar is recorded in the South African Food Composition Tables (Wolmarans, et al., 2010). In 2000, a South African cultivated cultivar, known as BP1, was the market leader with a 43% market share. Although not recorded, it is generally accepted that it was this cultivar that was analysed for nutrient content in 1999 and included in the national food composition database. At that time the Department of Health commissioned analyses of fruit and vegetables and all samples were purchased from the fresh fruit and vegetable market in Johannesburg (Food Composition Database, 1999). It is therefore probable that BP1 values were used in the South Africa Food Composition Tables.

Over the last decade the market share held by different cultivars has changed drastically as shown in Table 3-1. New cultivars that are higher yielding, disease resistant and suited for specific agronomical conditions are constantly being developed. When farmers start using these new cultivars, changes in production patterns occur (Denner & Venter, 2011) which lead to changes in consumption. By 2012, BP1 only comprised 1% of the market, while Mondial was the market leader with a market share of 63% compared to 2000 when it only had an 8% market share (Potatoes South Africa, 2014; Nortje, et al., 2000). These changes seen in consumption of different cultivars motivate the need for the nutritional analysis of different cultivars.

Table 3-1: Change in market share of potato cultivars from 2000 to 2013 (Potatoes South Africa, 2014; Nortje, et al., 2000)

Cultivar	2000	2009	2012
	%	%	%
BP1	43	14	1
Up-to-date	22	5	5
Buffelspoort	10	4	0
Mondial	8	65	63
Van der Plank	5	2	2
Sifra	0	0	16
Other	12	10	13

*Other includes all other cultivars cultivated in South Africa

3.1.2 Objective

The objective of this case study was to explore the reported differences between the nutrient values of different potato cultivars to determine the contribution which these different cultivars could make to food and nutrition security.

3.2 Materials and methods

3.2.1 Sampling and sample preparation

The cultivars with the largest market share, as well as those with the greatest potential for growth, as identified by Potatoes South Africa, were chosen for the study. The cultivars included Mondial, Fabula, Buffelspoort (BP13), BP1, Van der Plank, Fianna, Valor, Sifra, Up-To-Date, Darius, Avalanche. See Table 3-2 for a description of the eleven cultivars included in the study.

Table 3-2: Description of the eleven potato cultivars identified for sampling (Potatoes South Africa, 2013; Denner & Venter, 2011)

Cultivar	Shape	Colour of the skin and flesh	Classification system	Cooking characteristics
Mondial	Oval	White	Waxy	An ideal boiling potato as it does not slough.
Fabula	Oval	Light yellow	Waxy	Suited for boiling and baking.
Buffelspoort	Round -Oval	White	Waxy	Ideal for boiling as it retains its shape.
BP1	Flat Oval	White	Waxy/Floury	Combination potatoes lend themselves to a variety of cooking techniques, especially boiling and roasting.
Van der Plank	Oval – Pear	White	Waxy/Floury	Can be prepared using a variety of cooking techniques. Best suited for boiling and frying.
Fianna	Oval	Light yellow	Waxy/Floury	Can be used in the processing industry as it is firm with a fluffy mouthfeel.
Valor	Oval	Cream white	Waxy/Floury	Ideal roasting potatoes as they keep their form and have a fluffy mouthfeel.
Sifra	Round	White	Waxy/Floury	An all-round potato that is ideally suited for most cooking techniques.
Up-To-Date (UTD)	Flat Oval	Cream white	Floury	Floury texture, makes this potato ideal for mash.
Darius	Oval	White	Floury	Floury texture but keeps its shape when cooked.
Avalanche	Oval	White	Floury	Good for roasting, frying and mash with a fluffy texture.

Seed potatoes of each cultivar included in the study were provided by Potatoes South Africa. The potatoes were planted on a commercial potato farm in Reitz situated in the Eastern Free State Province, the largest potato production area in South Africa (Potatoes South Africa, 2014). These tubers were grown under controlled dry land conditions during the summer of 2012/2013 according to normal commercial potato agronomy practices. All the tubers were planted on the same plot of

land with the same watering, sunshine, fertilizer and treatment applications. The potatoes were harvested on the 11th of April 2013. After the harvest, the tubers of each cultivar were randomly selected and packed into two brown 10kg bags and transported on the following day to the Agricultural Research Council (ARC) at Irene, Pretoria. The potatoes were kept in a cool dark room at 20°C for 7 days to mimic market conditions. After storage, five average sized tubers from each cultivar were randomly selected. These tubers were thoroughly washed with distilled water to remove excess dirt and dried on absorbent paper at room temperature. The tubers were sliced in half perpendicular to the core as shown in Figure 3-1. One half was peeled and the skin on the other half was not removed, this was done separately. Samples were individually grated, sealed in ziplock plastic-bags and sent to the laboratory for freeze-drying. Freeze-dried samples were stored at 20°C. Freeze-drying the grated tubers ensured that the dried product retained its nutritional value (Lin, et al., 1998).

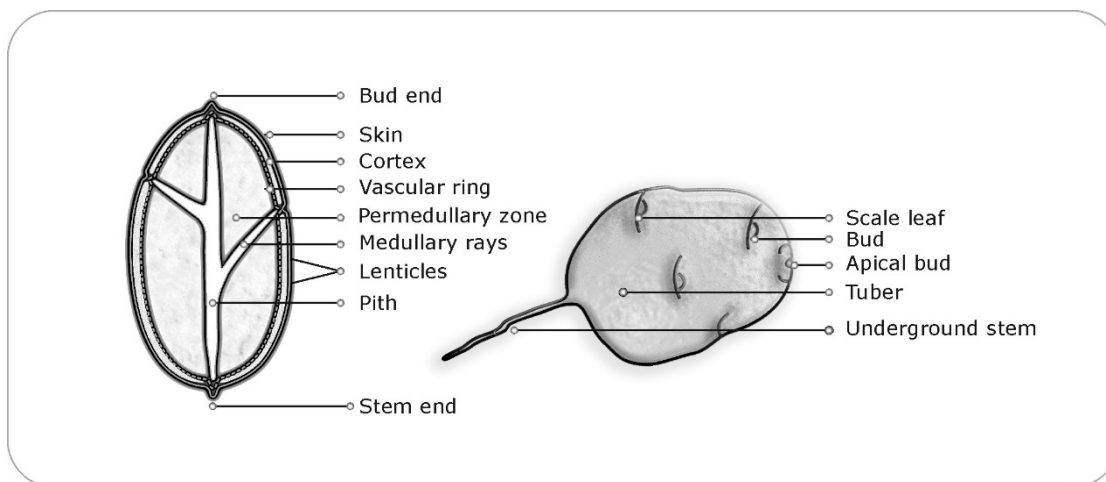


Figure 3-1: Potato tuber sliced perpendicular to the core (FAO, 1998^b)

3.2.2 Analysis

The nutritional analyses were performed on a double-blind basis at NutriLab, University of Pretoria, South Africa. A composite sample consisting of 5 randomly selected raw tubers was used for evaluation with and without skin. Samples were analysed according to the methods summarized in Table 3-3. To ensure accuracy of the assays, standard reference samples were included in all batches of samples analysed. The laboratory is certified by the Agri-Laboratory Association of Southern Africa (AgriLASA) as a laboratory participating in their quality control programmes.

Table 3-3: Analytical methods used for nutrient analysis.

Analysis	Method
Moisture (water)	AOAC, 2000. Official method of analysis 934.01 *
Ash	AOAC, 2000. Official method of analysis 942.05 *
Protein (N)	AOAC, 2000. Official method of analysis 968.06 *
Fat	AOAC, 2000. Official method of analysis 920.39 *
Energy (calculated)	Greenfield, H. and Southgate, D.A.T., 2003 #
Carbohydrates (calculated)	Greenfield, H. and Southgate, D.A.T., 2003 #
Available carbohydrates	Available carbohydrates= Dry Matter – Protein – Fat – Ash – NDF (neutral detergent fibre) (Ferreira, 2014)
Starch	Enzymatic spectrophotometer (In-house method)
Minerals	AOAC, 2000. Official method of analysis 935.13 * (Giron, 1973)

*(AOAC, 2000)

(Greenfield, H & Southgate, 2003)

3.2.3 Statistical analyses

Data received from the laboratory was arranged in tabular format and statistically analysed using the GenStat for Windows (2008) statistical computer programme (Payne, et al., 2012). A one-way analysis of variance (ANOVA) test was applied with Fisher's protected t-test least significant difference at the 5% level of significance among cultivar means. The mean nutritional values of the “flesh only potatoes” was statistically compared to the nutritional value of the “flesh and skin potatoes” at a 1% level of significance.

3.3 Results and discussion

3.3.1 Contribution to Nutrient Reference Values made by potatoes

In sub-Saharan countries maize and wheat are common staple crops, but they need further processing to produce staple foods (maize meal porridge and brown bread) (Steyn, et al., 2009). Both of these products are fortified. Contrary to this, potatoes are a crop that grow easily. It can be grown by subsistence farmers and requires very little to no further processing (Parsa, et al., 2011). Potatoes can be classified as a nutrient dense carbohydrate (Slavin, 2013), which together with other staples can improve dietary diversity (King & Slavin, 2013).

It has been proposed that potatoes are most commonly consumed without the skin. Therefore it was necessary to identify whether there is a significant difference in the nutritional values of tubers with or without skin.

Potatoes contain a variety of minerals that are required in the human diet. Tubers contain large amounts of carbohydrate, they do not contribute significantly to protein intake and are naturally low in fat. Very few significant differences in the nutritional value of the tubers with and without the skin were observed. Significant differences were observed in the minerals; calcium ($p=0.009$), iron ($p<0.001$) and manganese ($p<0.001$). Higher levels of calcium and iron were found in potato samples consisting of flesh and skin, while manganese values were higher in tubers without the skin, indicating that manganese storage occurs in the flesh (Table 3-4). Values for phosphorus, magnesium, copper, zinc, potassium and sodium did not differ significantly between tubers with and without the skin. Even though there are only a few minerals that differ significantly in mineral concentration of tubers with and without the skin, the skin plays a cardinal role in preventing nutrients from being leached out during the cooking process (Phillippy, et al., 2004).

In the rest of this paper only the nutritional values of tubers without the skin (Table 3-5), will be presented. Table 3-6 is also included to illustrate the nutritional values of tubers with the skin however only calcium, iron and manganese differed significantly from the nutritional value of tubers without the skin.

Table 3-4: The average nutrient content of eleven different potato cultivars, per 100g raw potato (flesh and skin) and skin only.

Nutrient	Unit	p – value	Flesh only	% of NRV*	Flesh and skin	% of NRV*
Energy (calculated)	g	0.513	282	-	290	-
Protein	g	0.673	1.37	2.68	1.33	2.38
Fat	g	0.425	0.0177	0.09	0.0239	0.145
Available carbohydrates	g	0.472	15.2	-	15.7	-
Calcium	mg	0.009	4.03 ^a	0.31	4.82 ^b	0.371
Phosphorus	mg	0.857	50.3	4.02	49.8	3.98
Magnesium	mg	0.968	25	6.83	24.9	6.82
Copper	mg	0.089	0.107	11.9	0.0945	10.5
Iron	mg	<0.001	0.742 ^a	5.71	1.17 ^b	9
Manganese	mg	<0.001	1.41 ^b	61.3	1.09 ^a	47.4
Zinc	mg	0.653	0.371	3.71	0.362	3.62
Potassium	mg	0.515	439	9.34	453	9.64
Sodium	mg	0.693	8.01	0.4	8.16	0.408

* NRV for individuals 4 years and older (Department of Health, 2014)

3.3.2 Nutritional analysis of potato tubers (flesh only) from eleven cultivars

The energy content of potatoes is almost entirely derived from the carbohydrate content as 95% of total energy typically comes from the carbohydrates present within the tuber. This makes potatoes a nutrient dense source of energy that contains easily digestible carbohydrates which is essential for human existence (Peksa, et al., 2013). As expected these carbohydrates are almost entirely made up of starch (Alvani, et al., 2011). The average carbohydrate content of the cultivars included in the study was 16.8g/100g with an average starch content of 15.2g/100g (Table 3-5). A similar study conducted in Latvia found the average starch content of local Latvian potatoes to be 18.72g/100g (Murniece, et al., 2011). Energy and carbohydrate values had a high correlation ($r=0.9938$). In the current study, the Darius cultivar had the highest energy (380kJ/100g) and the highest carbohydrate contents (18.6g/100g) and Van der Plank the lowest energy (240kJ/100g) and second lowest carbohydrate content (13.7g/100g) after Fianna (21.8g/100g).

Starch content did not differ significantly between Van der Plank, UTD, Sifra, Valor and BP1. Darius had the highest starch content of 21.1g/100g. Starch is linked to cooking and processing qualities in the chipping industry (Jansky & Fajardo, 2014).

Although the protein content is low in potatoes it occurs in a highly bioavailable form (Lokendrajit, et al., 2013). A study conducted in Germany in 1997 and Pakistan in 2011 found a significant difference in the protein content of different cultivars (Abbas, et al., 2011; Jansen, et al., 2001). In a study conducted in Jordan, in which the Mondial cultivar was also included, it was observed to have the lowest protein content of all the cultivars in that trial (Ereifej, et al., 1997). In the current study (Table 3-5), Mondial had an average protein content of 1.49g/100g when compared to the other cultivars included in the study. The United States Department of Agriculture (USDA) food database reports protein values of white potato tubers to be between 1.00-1.97g/100g (USDA, 2013). The New Zealand and Australian food database reports protein levels of 2.3g/100g (NUTTAB, 2010). These levels are slightly higher than the levels found in the current study. Protein content differs significantly between cultivars (0.883-1.75g/100g) with Buffelspoort and Fianna containing almost double the protein found in UTD. Potatoes are one of the best plant sources of the amino acid lysine (although not determined in this study) (Peksa, et al., 2013). Lysine is one of the amino acids that is a necessary component of complete proteins. Protein-energy malnutrition is a regular occurrence in sub-Saharan Africa. The consumption of animal and plant based foods can increase the consumption of complete proteins (Schönfeldt & Gibson Hall, 2012)

Potatoes are naturally very low in fat (Luis, et al., 2011) with an average fat content of 0.0176mg/100g as seen in Table 3-5. Three of the cultivars contained no detectable fat. The United

States Potato Board states that potatoes are naturally fat free, contain no saturated fat and no cholesterol (United States Potato Board, 2013; McGregor, 2011). Potatoes can therefore be promoted as a fat free food in a country with high rates of obesity such as South Africa where 39.2% of women and 20.2% of men are classified as being either overweight or obese (Steyn, et al., 2011). Although fat content in all cultivars was very low, statistically significant differences were observed between most cultivars ($p < 0.001$). At such a low level these differences make little difference to the human diet.

A review of American grown potatoes showed an average zinc content of 0.35mg/100g which decreased to 0.30mg/100g when the potatoes were boiled with its skin. The zinc content can decrease by up to 50% when boiled without the skin (McGill, et al., 2013). The value for zinc is similar to the values found in the current study. Avalanche had the highest zinc content, 0.473mg/100g and Sifra the lowest, 0.254mg/100g. Zinc and iron deficiencies are among the main causes of child morbidity in African countries as a deficiency of these minerals can lead to increase infections (Sazawal, et al., 2014). Potatoes generally have a low phytate content which results in a lower inhibitory effect on minerals such as iron and zinc and lead to better absorption of these minerals (Phillippy, et al., 2004).

Compared to other vegetables, the potato is one of the best sources of dietary potassium (Weichselbaum, 2010). Apart from nitrogen, potassium is the most essential mineral for plant formation and growth. Correct potassium levels improve crop yield, tuber quality, decrease bruising and decrease sugar levels which in turn increase storability. This ensures that tubers can be stored for a longer period of time after harvesting (Brown, et al., 2013). Potatoes can be a notable sources of potassium in the human diet (Storey & Anderson, 2013) with a 100g tuber contributing up to 15% of daily nutrient reference values for potassium (Department of Health, 2014). Boiling a potato without the skin can reduce its potassium content by up to 50% (Bethke & Jansky, 2008). The tubers in this study had an average potassium content of 439mg/100g. Darius (537mg/100g) and Fianna (527mg/100g) contained the highest amounts potassium and Fabula (370mg/100g), UTD (401mg/100g) and Buffelspoort (383mg/100g) the lowest. These levels are consistent with those reported in New Zealand and Australia (NUTTAB, 2010).

Together with high levels of potassium, potatoes are naturally low in sodium (McGill, et al., 2013). High sodium consumption is seen all over the world as the ingestion of processed foods increases (Garcia-Garcia & Totosaus, 2008). Fruit and vegetables in their natural form are low in sodium and a heart healthy option that can decrease the likelihood of hypertension and heart disease (Flock & Kris-Etherton, 2011). The sodium content of the potatoes in this study varied between 7.38mg/100g

and 9.69mg/100g with BP1 having the lowest, and Avalanche and Fianna the highest values. In many countries potassium consumption is decreasing due to a decreased consumption of fruits and vegetables and sodium intake is increasing due to over-consumption of processed food (Steffen, 2014). Potatoes consumed in their fresh form can be part of the solution to overturn this trend (Weaver, 2013).

3.3.3 Nutrient contribution to culinary application

The phosphorus content of potatoes has been shown to be directly influenced by the phosphorus concentration in the fertilizer used during production (Hammond, 2009). Correct phosphorus fertilisation of plants increases the yield, but can have a negative effect on the availability of other micronutrients in the soil (Monteiro, et al., 2011). Phosphorus levels differed significantly between cultivars with a wide range and an average of 50.3mg/100g, a lowest value of 35.6mg/100g found in Mondial and a highest value of 70.3mg/100g in Darius (Table 3-5).

According to the literature, dry matter values of potatoes most commonly range between 16.5%-24% (Fernando & Slater, 2010). There is a significant difference in the distribution of dry matter throughout the flesh and skin of the tuber. Peeling, slicing and handling can have an effect on the dry matter content of a tuber. With this all taken into account, dry matter is still the best way to evaluate the total quantity of solids in a tuber (Thybo, et al., 2002; Ereifej, et al., 1997). In Table 3-5 dry matter values range between 19.3mg/100g for Van der Plank and 27.3mg/100g for Fianna. The higher the dry matter content, the lower the water content, which will mean that such a potato has a higher specific gravity. Potatoes with a higher dry matter and low moisture content are mealy, ideal for baking, and potatoes with low dry matter and high moisture content are waxy and ideal for boiling (South African Department of Environment and Primary Industries, 2000).

3.3.4 Nutrient contribution to plant growth

Certain mineral found in in tubers, be it in trace or significant amounts,

Calcium differed significantly between the cultivars, $p < 0.001$. Calcium levels were found between 3.09mg/100g in Van der Plank and 5.56mg/100g in Fabula. The calcium content of potatoes is low and does not contribute meaningfully to the human diet (Camire, et al., 2009). The calcium content of tubers does however, play an important role in cell wall structure, which in turn play an important role in texture and eating quality. It increases cell wall stability because it strengthens the links between cells (Palta, 2010). Fruit and vegetable firmness is essentially determined by the strength of

the cell walls (Glenn & Poovaiah, 1990). Stronger cell structures also decrease the chance that a potato will form brown or bruised spots (Brown, et al., 2012). This is of significance in relation to machine harvested tubers that are exposed to rough handling. Higher cell wall stability can also increase the storage life of the product (Karlsson, et al., 2006; van der Waals, et al., 2004).

Like phosphorus, manganese contributes to the total yield of the potato crop resulting in a larger overall crop yield which can contribute to food security (Scott, 2010). Manganese values ranged between 1.19mg/100g for Fabula and 1.68mg/100g for Darius and 1.70mg/100g for Fianna. Manganese is one of the minerals that decreases significantly when a potato is boiled without the peel (Dugo, et al., 2005). In this study a strong correlation was seen between manganese and protein values ($r=0.7209$).

The main uptake of magnesium by tubers occurs during the tuber initiation phase which is at 31-40 days (Zhao, et al., 2010). A 290g serving of cooked potato can provide up to 24% of the required daily allowance of magnesium (Volpe, 2013). The South African values for magnesium in potatoes are higher than those seen in New Zealand and Australia where potatoes have an average of 20mg/100g (NUTTAB, 2010). Fianna had the highest magnesium content of 32.8mg/100g and Sifra the lowest, at 20.3mg/100g. In this study iron values were at a low of 0.618mg/100g in Van der Plank and a high of 0.942mg/100g in Darius, which according to the USDA is correlated with colour differences between cultivars (USDA, 2013).

Zinc together with copper is essential during the plant formation stage (Dugo, et al., 2004). Copper levels were found to be between 0.0751mg/100g of Sifra and 0.144mg/100g of BP1. These are higher concentrations than those found in potatoes from Australia and New Zealand. In their combined food database they reported that potatoes contain 0.038mg/100g copper (NUTTAB, 2010). The results of the present study is also higher than levels reported in Korean potatoes which had an average copper content of 0.067mg/100g (Choi, et al., 2009). These variations could be due to the effect of irrigation water, as well as postharvest activities (Din, 2013).

Table 3-5: Nutrient content per 100g of raw potato, flesh only

Nutrient (flesh only)	Units	p-value	VDP	UTD	Sifra	Valor	BP1	Mondial	Avalanche	Buffelspoort (BP13)	Darius	Fabula	Fianna
Energy (calculated)	kJ	<0.001	240 ^a	253 ^{ab}	256 ^{abc}	251 ^{ab}	251 ^{ab}	276 ^{cd}	269 ^{bcd}	287 ^d	380 ^f	283 ^d	349 ^e
Starch	g	<0.001	12.9 ^a	13.9 ^{abc}	14.0 ^{abcd}	13.2 ^{ab}	13.2 ^a	14.7 ^{cde}	14.4 ^{bcde}	15.2 ^{de}	21.1 ^g	15.3 ^e	18.8 ^f
Carbohydrates (calculated)	g	<0.001	13.7 ^a	16.6 ^e	15.6 ^d	14.7 ^c	14.2 ^b	17.0 ^f	14.5 ^{bc}	17.3 ^g	21.3 ⁱ	17.9 ^h	21.8 ^j
Available carbohydrates	%	<0.001	13.4 ^a	16.2 ^e	15.2 ^d	14.3 ^c	13.7 ^{ab}	16.6 ^e	14.0 ^{bc}	17.1 ^f	20.8 ^h	19.6 ^g	21.3 ⁱ
Moisture	g	-	80.7	79.1	79.6	79.6	79.9	77.8	80.2	77.6	73.5	77.4	72.7
Protein	g	<0.001	1.12 ^c	0.883 ^a	1.00 ^b	1.51 ^f	1.56 ^g	1.49 ^f	1.39 ^e	1.69 ^h	1.31 ^d	1.32 ^d	1.75 ⁱ
Fat	g	<0.001	0.00929 ^b	0.0322 ^h	0.0211 ^e	0.0313 ^g	0.0209 ^d	0.0228 ^f	0.0205 ^c	<0.0001 ^a	<0.0001 ^a	0.0353 ⁱ	<0.0001 ^a
Calcium	mg	<0.001	3.09 ^a	3.76 ^{cd}	3.88 ^d	3.32 ^b	3.69 ^c	5.43 ^g	4.25 ^e	3.28 ^b	4.77 ^f	5.57 ^g	3.28 ^b
Phosphorus	mg	<0.001	52.5 ^{fg}	44.1 ^d	50.2 ^e	53.7 ^g	51.9 ^{efg}	35.6 ^a	41.5 ^c	50.7 ^{ef}	70.3 ⁱ	37.6 ^b	65.6 ^h
Manganese	mg	<0.001	1.22 ^{ab}	1.20 ^{ab}	1.27 ^b	1.47 ^c	1.26 ^{ab}	1.44 ^c	1.57 ^d	1.51 ^{cd}	1.68 ^e	1.19 ^a	1.70 ^e
Magnesium	mg	<0.001	22.0 ^b	20.5 ^{ab}	20.3 ^a	21.8 ^{ab}	24.2 ^c	23.2 ^d	28.9 ^e	21.1 ^{ab}	28.7 ^e	27.8 ^{de}	32.8 ^f
Iron	mg	<0.001	0.618 ^a	0.624 ^a	0.736 ^{bc}	0.685 ^{ab}	0.787 ^c	0.728 ^{bc}	0.619 ^a	0.797 ^{cd}	0.942 ^e	0.756 ^{bc}	0.869 ^{de}
Zinc	mg	<0.001	0.317 ^b	0.322 ^{bc}	0.254 ^a	0.376 ^d	0.377 ^d	0.343 ^{bc}	0.473 ^f	0.437 ^e	0.344 ^c	0.377 ^d	0.465 ^f
Copper	mg	<0.001	0.0882 ^b	0.0879 ^b	0.075 ^a	0.094 ^c	0.144 ^h	0.119 ^e	0.102 ^d	0.139 ^g	0.0894 ^b	0.105 ^d	0.128 ^f
Potassium	mg	<0.001	420 ^{cd}	401 ^{abc}	416 ^{bcd}	440 ^d	475 ^e	427 ^{cd}	434 ^{cd}	383 ^{ab}	537 ^f	370 ^a	527 ^f
Sodium	mg	<0.001	7.39 ^a	7.59 ^a	7.45 ^a	7.73 ^a	7.38 ^a	7.77 ^a	7.65 ^a	7.45 ^a	9.69 ^c	8.35 ^b	9.69 ^c
DM	g	-	19.3	20.9	20.4	20.4	20.1	22.2	19.8	22.4	26.5	22.6	27.3

(Note: Means with different superscripts in a row differ significantly)

Nutrient flesh and skin	Units	p-value	VDP	UTD	Sifra	Valor	BP1	Mondial	Avalanche	Buffelspoort (BP13)	Darius	Fabula	Fianna
Energy (calculated)	KJ	<0.001	277 ^c	309 ^{de}	271 ^{bc}	257 ^b	349 ^f	274 ^c	214 ^a	306 ^{de}	319 ^e	298 ^d	305 ^{de}
Starch	g	<0.001	13.8 ^c	16.0 ^f	14.3 ^d	12.6 ^b	18.1 ^g	14.1 ^{cd}	10.8 ^a	15.2 ^e	17.9 ^g	14.9 ^e	15.7 ^f
Carbohydrates (calculated)	g	<0.001	17.5 ^c	20.1 ^h	17.5 ^c	16.3 ^b	21.6 ⁱ	17.6 ^d	14.4 ^a	18.7 ^f	22.0 ^j	18.5 ^e	19.4 ^g

Table 3-6: Nutrient content per 100g of raw potato, flesh and skin

Available carbohydrates	%	<0.001	15.1 ^c	16.8 ^{de}	14.8 ^c	13.8 ^b	18.5 ^f	14.6 ^{bc}	11.6 ^a	16.4 ^d	17.4 ^e	16.1 ^d	16.9 ^{de}
Moisture	g	-	80.6	77.6	80.7	81.6	75.5	80.1	83.8	78.8	75.5	79.1	78.8
Protein	g	<0.001	1.15 ^c	1.16 ^c	1.00 ^a	1.35 ^e	1.96 ^h	1.45 ^f	1.03 ^b	1.65 ^g	1.32 ^d	1.47 ^f	1.05 ^b
Fat	g	<0.001	<0.0001 ^a	0.10 ^f	0.059 ^e	<0.0001 ^a	<0.0001 ^a	0.030 ^a	0.01 ^b	<0.0001 ^a	0.050 ^d	<0.0001 ^a	<0.0001 ^a
Calcium	mg	<0.001	3.48 ^a	5.49 ^f	4.35 ^c	4.77 ^e	4.51 ^d	6.86 ⁱ	3.57 ^a	3.91 ^b	5.84 ^g	6.01 ^h	4.23 ^c
Phosphorus	mg	<0.001	50.2 ^{ef}	57.3 ^g	42.7 ^c	45.4 ^d	58.9 ^h	30.8 ^a	38.9 ^b	50.3 ^{ef}	72.9 ⁱ	49.3 ^e	50.7 ^f
Manganese	mg	<0.001	0.976 ^{cd}	1.29 ^f	0.756 ^a	0.976 ^{cd}	1.48 ^g	1.31 ^f	0.866 ^b	1.25 ^f	1.03 ^{de}	1.08 ^e	0.917 ^{bc}
Magnesium	mg	<0.001	23.7 ^c	23.4 ^{bc}	20.1 ^a	21.8 ^{ab}	28.5 ^d	27.5 ^d	21.7 ^{ab}	24.2 ^c	31.5 ^e	28.2 ^d	23.4 ^{bc}
Iron	mg	<0.001	0.865 ^b	1.35 ^e	1.25 ^d	1.12 ^c	1.44 ^f	0.788 ^a	0.885 ^b	1.24 ^d	1.38 ^{ef}	1.41 ^{ef}	1.10 ^c
Zinc	mg	<0.001	0.282 ^b	0.419 ^g	0.249 ^a	0.344 ^{cd}	0.491 ^h	0.327 ^c	0.370 ^{de}	0.415 ^{fg}	0.367 ^{de}	0.389 ^{ef}	0.331 ^c
Copper	mg	<0.001	0.0795 ^b	0.0999 ^d	0.0697 ^a	0.0765 ^b	0.147 ^f	0.102 ^d	0.0689 ^a	0.127 ^e	0.0899 ^c	0.0986 ^d	0.0796 ^b
Potassium	mg	<0.001	406 ^b	545 ^f	349 ^a	366 ^a	497 ^e	410 ^b	412 ^b	433 ^c	618 ^g	462 ^d	477 ^d
Sodium	mg	<0.001	6.77 ^a	9.79 ^c	7.04 ^a	6.77 ^a	9.85 ^c	8.11 ^b	6.81 ^a	8.22 ^b	10.9 ^d	8.30 ^b	7.08 ^a
DM	g	-	19.4	22.4	19.3	18.4	24.5	19.9	16.2	21.2	24.5	20.9	21.3

(Note: Means with different superscripts in a row differ significantly)

3.4 Conclusion and recommendations

Potatoes contain significant amounts of potassium and are naturally low in sodium. A medium size potato (100g) contributes up to 60% of the daily nutrient reference value for manganese. On average tubers contain 0.0177g/100g making them a naturally low fat product.

Sub-Saharan Africa is struggling to overcome food insecurity and the micronutrient deficiency epidemic. This can be blamed on the lack of dietary diversity and the consumption of energy dense and nutrient poor foods. Therefore an easy-to-grow nutrient dense carbohydrate crop can be promoted to overcome the problem of a monotonous nutrient poor diet. Potatoes can be promoted as a nutrient dense crop for subsistence farmers to increase dietary diversity for rural households.

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Chapter 4: Mapping of traditional potato fries (slap chips) from eleven potato cultivars

“Potatoes are the quietest and most constant of friends; they are the most accessible and wisest of counsellors, and the most patient of teachers” - Charles William Eliot

Abstract

“Slap chips” are a traditionally South Africa product that is widely consumed throughout the country. These chips are similar to French fries but are thicker and fried for a longer time at a lower temperature using a double fry method. It is assumed that different textural properties of potatoes will lead to certain cultivars being better suited for deep fat frying than others.

As part of this study, a market investigation was conducted to better understand slap chip preparation methods so as to develop a repeatable slap chip preparation method that simulates market conditions. Chips prepared using this method were evaluated by a trained sensory panel to determine sensory attributes of aroma, appearance, flavour, texture and aftertaste.

Statistical analyses showed that waxy and oily attributes grouped cultivars together, while dry matter, fried chip and earthy flavours differentiated between chips from different cultivars. No obvious grouping for cultivars within the same class according to the current South African potato classification system was found.

4.1 Introduction

In South Africa, 17% of potatoes produced by farmers are used by the formal processing industry. This number excludes the fresh potatoes that are purchased and subsequently processed by street vendors, corner cafés and take-away outlets. It is estimated that more than 50% of potatoes produced in South Africa are consumed by the informal market, a large consumer market which comprises 46% of the South African population (Potatoes South Africa, 2014; Stats SA, 2013).

Potatoes are regarded as a biodiverse crop because various cultivars are grown and are readily available on the market. All potatoes do not deliver a uniform end (cooked/prepared) product due to species differences (dry matter), agronomical conditions (irrigation or dry land), storage and season planted and inherent textural differences due to variations between cultivars (van Marle, et al., 1997). This necessitates a classification system to categorise potato cultivars according to their eating quality and thus enable communication and enhance satisfaction from farm to fork.

The current South African potato classification system was implemented in 2008. The system classifies different potato cultivars according to their ideal cooking categories, i.e. boil, roast, chipping (oven bake), microwave, mash and shape retention when boiled. No category for slap chips has been included in the current classification system (Schönfeldt, 2011). A need was therefore identified to include slap chips, as a culturally popular cooking method for potatoes, in this classification system (Potatoes South Africa, 2014).

4.1.1 South African slap chips

Slap chips are widely consumed in South Africa and are most commonly sold by street vendors and at corner cafés and take-away outlets, which is generally considered as the informal market (Steyn, et al., 2011). Slap chips are different to French fries as they are thicker, have a softer exterior, creamy interior and are “slap” or bendable once cooked. They are fried at a lower temperature for a longer time, which can lead to an oilier end product with an oily mouthfeel (O'Connor, et al., 2001). Slap chips measurements range from a thickness of 1cm x 1cm or slightly thicker and have an average length of 7cm (Masekwameng, 2014; Donnelly, 2013). French fries are thinner with an average thickness of 0.6 × 0.6 cm and an average length of 4–5 cm . French fried are fried at a temperature of 180 ± 5 °C for 4.0 ± 0.3 min (Murniece, et al., 2011).

The global consumption of fried food is rapidly increasing, with fried potatoes being one of the most frequently consumed products (Rimac-Brcic, et al., 2004). According to the European Union’s report on potato production “the significant increase in the consumption of processed potato products has grown mainly because of the corresponding increase in fries' demand” (Fernqvist, et al., 2015; European Commission Working Group, 2007). Different generations have different food preferences which lead to such increased consumption figures. Individuals currently entering the consumer market have a higher preference for fried and processed foods (Wansink, et al., 2003). Consumers also have an increased preference for certain types of potato cultivars. As indicated in Table 4-1 different potato cultivars have different sensory and cooking characteristics, which have an effect on the cooked product (Thybo, et al., 2004).

Table 4-1: Description of the 11 potato cultivars identified for sampling (Potatoes South Africa, 2013)

Cultivar	Shape	Colour of the skin and flesh	Classification system	Cooking characteristics
Mondial	Oval	White	Waxy	An ideal boiling potato as it does not slough.
Fabula	Oval	Light yellow	Waxy	Suited for boiling and baking.
Buffelspoort	Round -Oval	White	Waxy	Ideal for boiling as it retains its shape.
BP1	Flat Oval	White	Waxy/Floury	Combination potatoes lend themselves to a variety of cooking techniques, especially boiling and roasting.
Van der Plank	Oval – Pear	White	Waxy/Floury	Can be prepared using a variety of cooking techniques. Best suited for boiling and frying.
Fianna	Oval	Light yellow	Waxy/Floury	Can be used in the processing industry as it is firm with a fluffy mouthfeel.
Valor	Oval	Cream white	Waxy/Floury	Ideal roasting potatoes as they keep their form and have a fluffy mouthfeel.
Sifra	Round	White	Waxy/Floury	An all-round potato that is ideally suited for most cooking techniques.
Up-To-Date (UTD)	Flat Oval	Cream white	Floury	Floury texture, makes this potato ideal for mash.
Darius	Oval	White	Floury	Floury texture but keeps its shape when cooked.
Avalanche	Oval	White	Floury	Good for roasting, frying and mash with a fluffy texture.

(Denner & Venter, 2011)

4.1.2 Objectives of the study

This study was conducted in an attempt to classify slap chips made from the 11 different types of cultivars most commonly consumed in South Africa. The purpose of the study was to determine whether certain sub-species of potatoes are better suited for making slap chips than others, considering their unique textural properties. As there is very little to no data available on slap chip preparation, there is no scientifically confirmed guideline available on the preparation methodology for the cooking of slap chips.

Therefore, the first objective of the study, namely to identify a standardised methodology to prepare slap chips was researched, a pilot study was carried out and standardised. Once the methodology had been developed and standardised, a trained descriptive sensory panel was used to extrapolate the second objective of the study, namely to describe the slap chip qualities of eleven South African potato cultivars.

4.2 Developing a standardized cooking method for slap chips

4.2.1 Methodology

When preparing slap chips, similar to most other foods, there are a wide variety of factors that have an influence on the final consumed product (i.e. species, cultivation, etc.). The most commonly consumed cultivars in the South African market were identified for this study to obtain a representative sample of all the different textural classes found in potatoes as shown in Table 4-1. Different preparation practises are also used all over the world to prepare chips, thus deeming it necessary to develop a standardised method to evaluate slap chips in the South African context.

4.2.2 Market investigation

To ensure that the study was true to market conditions a pilot study was conducted to understand the requirements of this market. A variety of vendors of slap chips were visited in three different areas across South Africa; rural (Limpopo), peri-urban (Vaal Triangle) and urban (Pretoria) and questioned on the methods they use to prepare slap chips, particularly in regard to cooking techniques used.

The pilot study found that vendors purchase 10kg bags of fresh potatoes, mostly those available at the lowest price (the most affordable cultivar at the time was Mondial). Potatoes were peeled with hand peelers and immersed in water until they were chipped, a mainly manual process. When all the potatoes required for that day had been chipped, they were removed from the water and placed on a towel to drain off excess water. The air dried chips were fried in either a pot or a metal drum at a low temperature, between 90°C - 140°C, for the first fry using sunflower oil. The cooking process lasted between 10-30 minutes. A temperature drop occurs when the raw chips are placed in the oil which leads to a longer cooking time because the oil has to be reheated. It was consequently difficult to estimate the exact temperature and time used by vendors, as they prepared different batch sizes and used different amounts of oil.

After the first frying the chips are removed from the oil and placed on a cloth or paper towel to drain off excess oil. These chips are then ready for the second fry. The second round of frying occurs when

the consumer purchases the chips. The chips are fried in smaller batches at temperatures between 100°C - 140°C and immediately served to the customer.

4.2.3 Final frying method

From the market investigation a standardised frying method was developed to ensure that the chips in the study were as similar as possible to the ones found in the informal market. A double fry method was used to prepare the slap chips. The potatoes were peeled and sliced into batons, with an average size of 1cm x 1cm and average length of 6cm, and dipped into a 2.5% (v/v) sulphur dioxide mixture to prevent browning. The raw chips were dried on a cloth and then placed in hot sunflower oil, heated to 120°C for 5 minutes, removed from the oil and allowed to cool on a cloth to room temperature. Once the chips reached room temperature they were fried for a second time at 120°C for 3 minutes and served immediately.

4.3 Mapping potato cultivars for slap chips

4.3.1 Methodology

4.3.1.1 Sampling

The potatoes used in this study were planted in the Reitz area in the Eastern Free State, South Africa, which is one of the most productive dry land potato production areas in the country. The potatoes from the different cultivars were supplied by Potatoes South Africa, planted on the same day under dry land conditions in the same field during the summer of 2012/2013. The tubers were harvested on the 11th of April 2013. The tubers were not washed, but packed straight out of the soil into cultivar specific bags and transported to the Agricultural Research Council (ARC) Irene, Pretoria within 24 hours of harvest. Tubers were placed into pre-marked boxes in a dark room at room temperature (20°C) until the slap chips were prepared. The textural properties of the chosen cultivars are shown in Table 4-1.

4.3.1.2 Sample preparation

The slap chip samples were prepared according to the standardised methodology that had been developed in 4.2.3. Each day 5-7 tubers of each cultivar were washed, dried and weighed. The tubers were peeled, chipped and placed in a bucket containing a 2.5% (v/v) sulphur dioxide and water mixture. Chips were cut into 1 cm x 1 cm batons lengthwise with an average length of 6 cm. The chips were allowed to stand in the sulphur dioxide mixture for 30 minutes, to reduce browning. After 30 minutes the chips were washed under running tap water for 10 seconds to remove excess sulphur dioxide and allowed to drip dry. The six centre chips were pre-fried in a DeLonghi Roto Fryer

in the preheated frying oil at 130°C to ensure that when the chips were lowered into the oil, the temperature dropped to the desired 120°C to be fried for 5 minutes. The DeLonghi Roto Fryer ensures that the basket containing the chips is submerged in oil and turned constantly to achieve even frying. The oil was kept at the same temperature throughout the fryer. Excella sunflower oil was used to fry the chips, as it is the oil that vendors in the pilot study had identified as the oil they most frequently use.

Oil temperature was constantly measured using a hand held digital stainless steel probe (Kane May C9003), equipped with a J-type thermocouple. The lid of the fryer was not used to imitate market conditions and to allow constant temperature measurement. After 5 minutes of frying the chips were removed from the oil and placed on paper towel to absorb excess oil. After cooking the chips had an internal temperature of 84°C.

The pre-fried chips were allowed to cool down to a room temperature of 23°C to mimic market conditions. For the second fry the same procedure was followed as for the pre-frying process but the chips were only fried for 3 minutes and as they were removed from the fryer, the excess oil was removed by shaking the basket. The chips were placed on paper towel to absorb excess oil. Subsequently the chips were wrapped in 10 cm x 15 cm aluminium foil envelopes to ensure that they retained their heat. This also allows them to steam to simulate market conditions. The aluminium foil envelopes were each pre-coded with a randomized three digit code. These envelopes of chips were placed in an 115°C pre-heated oven on a baking sheet. After 5 minutes the chips were removed from the oven and served to the panel on a pre-heated plate that had been warmed in a preheated oven at 60°C.

Samples were provided to the panellists through individual cubicle doors. In addition to the aluminium foil envelope of chips the panel received an evaluation form, a pencil, an eraser and a serviette. Water was also provided, carrot slices (used as palate cleansers) and a lexicon that was already in the tasting booth. Starting at 9 o'clock in the morning the panel tasted 11 samples during 4 sessions every day over 4 days. The first, second and third session each included three tasting samples and the final session of each day included two samples. The samples were served to the panel at 10 minute intervals with a 15 minute break between sessions.

4.3.2 Test facilities

All samples were evaluated according to the methods described in the Annual Book of ASTM Standards (ASTM, 1989). The sensory analysis facilities are equipped with all the elements necessary

for an efficient sensory programme and are constructed according to ASTM design guidelines for sensory facilities.

Panellists evaluated products one at a time (four sessions per day) in separate tasting booths to reduce distraction and panellist interaction, and to ensure uninterrupted, unbiased, individual responses. After completion each panellist's score sheet was collected individually and the data was captured directly from the score sheets onto an Excel Worksheet.

The full chip was evaluated under white light conditions. White light conditions are used to ensure that the product has a natural appearance.

4.3.3 Sensory evaluation

Twelve experienced panellists were selected to participate in this study. These panellists were all previously trained at the Sensory Unit of the Agricultural Research Council at Irene. Panellists were chosen based on their taste and smell acuity, interest, ability to discriminate between the five basic tastes (sweet, sour, salt, bitter and umami), and availability for the entire study. The panellists have been involved in numerous sensory evaluations on food products such as meat and meat products, fats and oils, dairy products, potatoes, beverages and many more.

Before the tasting the panellists for this study participated in a general training programme consisting of four sessions to:

- Develop appropriate descriptive terminology for the slap chips which could be used in the Lexicon
- Train, familiarize and test panellists for use of the evaluation scales that had been constructed and
- Develop and finalise the rating scales and terminology to be used.

During the training, the panellists were exposed to different potato cultivars and asked to analyse them and develop descriptive sensory terms which were used in the final evaluation Lexicon (Table 4-2). The lexicon of Thybo and Martens was used as a point of reference and adapted to include the attribute descriptors proposed by the panel members (Thybo & Martens, 1998). These descriptive words included aroma, non-oral texture, oral texture, flavour and aftertaste characteristics of the slap chips samples. A category rating scale, with one (1) denoting the least favourable condition (none: e.g. no clean / fresh oil aroma) and eight (8) denoting the most favourable condition (e.g.

extremely intense clean / fresh oil aroma) was constructed (Annexure 4-1) and used to evaluate the different samples. To ensure that panellists were not influenced in any way, no detailed information with regard to the purpose of the project was provided.

Table 4-2: Lexicon developed by panel members for descriptive sensory analysis of slap chips made from eleven different potato cultivars

ATTRIBUTE	DESCRIPTION
AROMA	Evaluate under white light condition Whole chip to be evaluate
Typical fresh fried chip Potato / earthy	Aromatic notes associated with fresh fried chips Aromatic notes associated with damp soil, slightly undercooked potatoes
Oily	Aromatic notes associated with fresh oil
APPEARANCE	Initial impression of appearance: Only look at the surface and evaluate the oily appearance of the chip
Oiliness	Appearance of the outside surface of the chip. Is it oily or dry?
Ease of breaking– Bending the chip till two ends meet) (<i>softness – how easily the potato breaks</i>)	Force required to divide the potato into two parts by bending the two ends together. Degree of bending before the potato is separated into 2 parts. Breaks easily, high ease to break (5-8) Elastic, makes a loop before it breaks (if at all) = low ease to break (1-5)
TEXTURE	Only evaluate the inside of the chip for texture
Oiliness	Oiliness inside the chip. Is it oily or dry?
Mealiness / Floury	Expresses how floury/crumblly or dry the potato feels in the mouth after chewing. A floury potato has a coarse overall texture
Waxy	A waxy potato has been described as moist, mushy and smooth and sometimes has glassy lumps . Is associated to some degree with stickiness. It has a smooth, waxy feeling on the palate after pressing potato with tongue. A waxy potato has a smooth overall texture with some glassy lumps in between
Graininess (particles) Coarse texture	Expresses the content of grainy particles in the mouth after chewing . Press potato against palate with tongue, large grainy pieces / particles are felt. The texture is uneven. The smoothness or coarseness of the texture. A texture can be even, but coarse or grainy, or it is smooth and fine. Evaluate the degree of coarseness or smoothness of the potato.
FLAVOUR	Evaluate the whole chip
Typical fried chip	A taste associated with typical fried potato chips
Earthy / potato skin	Taste associated with earthy potato skin notes
Bitter (Green potato note)	Taste on tongue stimulated by substance such as flavours associated with green/unripe potato, astringent, burned
AFTER TASTE	Evaluate the whole chip
Typical fried chip	An aftertaste associated with typical fried potato chips
Earthy / potato skin	Aftertaste associated with earthy potato skin notes
Bitter (Green potato note)	Aftertaste on tongue stimulated by substance such as aftertaste associated with green/unripe potato, astringent, burned

4.3.4 Objective evaluation

Dry matter analysis on the tubers was performed gravimetrically according to the AOAC 934.01 method. Specific gravity was determined by weighing five tubers individually as is, followed by an underwater weighing where the tuber is placed in a net and submerged in water. Specific gravity is then calculated with the following equation: (South African Department of Environment and Primary Industries, 2000)

$$\text{Specific gravity} = \frac{\text{Weight in air}}{(\text{Weight in air} - \text{Weight under water})}$$

4.3.5 Statistical analyses

The data was captured using an Excel spreadsheet. Data was inspected for outliers using a residual test.

Quantitative descriptive data of all attribute scores were subjected to analysis of variance (ANOVA) using the GenStat statistical software (Payne, et al., 2012). Analysis of variance was performed to determine the differences among cultivar effects at the 5% level. The Partial Least Squares regression procedure (PLS) of GenStat was used to establish which of the set of correlated objective (X matrix) variables and 11 cultivars were applied to determine and explain variation in the sensory profile (Y matrix) of slap chip potatoes.

4.4 Results and discussion

4.4.1 Grouping of potato cultivars according to slap chip qualities

The ANOVA analysis (Table 4-4) detected significant differences ($p \leq 0.05$) for 14 of the 17 sensory attributes between the different cultivars. Significant differences were seen in scores for aroma, non-oral texture, oral texture, flavour and aftertaste attributes in chips from the eleven cultivars, except for earthy aroma, earthy flavour and earthy aftertaste. In future earthy/soil attributes can be removed from the taste panel form and need no longer be measured as an attribute. Deep fat frying of food can significantly alter the texture as well as flavour of a food. Certain textural and flavour aspects that already exist in the tubers can be enhanced and others decreased during the process of frying (Urbancic, et al., 2014). The textural appeal of a potato has a critical influence on the acceptability of the potato and is a dominant indicator of quality among consumers (Bourne, 2002).

As there is no significant difference in the texture of the different slap chips, it can be assumed that all the cultivars would be texturally acceptable to consumers. However, no clear pattern of

differences amongst the types of cultivars (waxy, waxy/floury, floury) emerged for any of the attributes, indicating that there are no significant differences in the textural properties between the different classes of tubers in the current classification system. Although there is no cultivar that performed significantly better than the rest, seven (Mondial, BP1, Bp13, Van Der Plank, Fabula, Valor, Avalanche) of the eleven cultivars had generally higher values for typical fried chip flavour and typical fried chip aroma. This may indicate that they may be better suited for slap chip preparation.

Aroma is an important aspect of fried food as the smell is associated with the textural and flavour appeal of food prepared in this manner (Ansarifar, et al., 2015). All the cultivars had a typical fried chip aroma ($p < 0.001$), except for Fianna and Sifra, which had a low typical fried chip aroma and aftertaste.

When evaluated on appearance, Mondial, Fabula, VDP, Sifra and Avalanche had an oily surface ($p < 0.001$), with BP1, Darius and UTD differing significantly with a low oily surface. BP13 and Darius had a high ease of breaking ($p < 0.001$) and Valor a low ease of breaking.

The texture of Mondial, Fabula, VDP, Sifra and Avalanche inside the chip was higher ($p < 0.001$) and BP1 lower. This corresponds to the results on oily surface appearance. BP13, BP1, Valor, UTD and Darius had a floury texture ($p < 0.001$) and Mondial, Fabula, VDP, Sifra and Avalanche had a waxy texture ($p < 0.001$). All the cultivars except for BP1 and Valor had a high grainy texture ($p = 0.031$).

Overall oiliness (aroma, texture, flavour and aftertaste) was lowest in Darius, with few statistical differences observed between Darius and BP1, BP13, UTD and Valor. Although, dry matter (Table 4-3) was high for both Fianna (27.3) and Darius (26.5), it seems to have influenced oil absorption to a greater extent in Darius. Mondial, Fabula, BP1, VDP, Valor and Avalanche had a high typical fried chip flavour ($p < 0.001$). Darius had a low typical fried chip flavour. Mondial, Fabula and Avalanche had a high oily ($p < 0.001$) and bitter ($p = 0.006$) flavour and BP1 and Darius a low oily flavour, while Valor had a low bitter flavour. Fabula, UTD, BP1, Fianna and Sifra also had a high bitter aftertaste ($p < 0.001$).

Mondial, BP1, Valor and Avalanche had a typical fried chip aftertaste ($p < 0.001$), and Fianna and Sifra a low typical fried chip aftertaste. Mondial, Fabula, Sifra, Avalanche and VDP had a high oily aftertaste ($p < 0.001$) and Darius a low oily aftertaste, Darius also had a low oily aroma ($p < 0.001$).

Mondial and Fabula had high values for most of the attributes. Avalanche had high values for aroma and flavour attributes. Darius had low values for flavour. There was no significant difference in the earthiness of aroma, flavour and aftertaste of the chips ($p > 0.05$).

Table 4-3: Least squares mean values (Standard Error of Means (SEM)) as well as the F probability (p-value)) for sensory analysis on 11 potato cultivars

ATTRIBUTE	p-value	SEM	Cultivars and classification										
			1	2	3	4	5	6	7	8	9	10	11
AROMA													
Typical fresh fried chip	p<0.001	0.112	5.20 ^a	5.25 ^a	5.09 ^a	4.97 ^{ab}	5.10 ^a	5.02 ^{ab}	4.63 ^c	5.07 ^a	5.12 ^a	5.24 ^a	4.71 ^{bc}
Earthy	0.969	0.073	2.02	1.96	1.9	1.9	1.93	1.96	1.94	1.9	1.89	1.99	1.9
Oily	p<0.001	0.093	3.47 ^{ab}	3.95 ^a	3.32 ^{abc}	2.93 ^c	3.31 ^{abc}	3.38 ^{ab}	3.27 ^{bc}	3.56 ^a	3.08 ^{bc}	3.41 ^{ab}	3.38 ^{ab}
TEXTURE : NON-ORAL													
Oiliness on the surface	p<0.001	0.101	4.29 ^a	3.28 ^d	3.76 ^c	3.38 ^d	4.27 ^a	3.42 ^d	3.85 ^{bc}	4.34 ^a	3.71 ^c	4.18 ^a	4.01 ^{ab}
Ease of breaking	p<0.001	0.175	4.15 ^{defg}	4.34 ^{cdef}	5.08 ^{ab}	5.47 ^a	4.44 ^{cde}	4.26 ^{cdefg}	4.58 ^{cd}	3.83 ^e	3.87 ^{fg}	4.04 ^{efg}	4.65 ^{bc}
TEXTURE: ORAL													
Oiliness inside the chip	p<0.001	0.118	3.50 ^{ab}	3.01 ^d	3.12 ^{cd}	3.10 ^{cd}	3.39 ^{abc}	3.22 ^{bcd}	3.18 ^{bcd}	3.59 ^a	3.24 ^{bcd}	3.63 ^a	3.47 ^{ab}
Mealiness/Floury	p<0.001	0.218	3.31 ^{cd}	4.43 ^{ab}	4.13 ^{ab}	4.28 ^{ab}	2.92 ^d	4.44 ^a	3.83 ^{bc}	3.01 ^d	4.49 ^a	3.35 ^{cd}	3.01 ^d
Waxy	p<0.001	0.225	4.56 ^{ab}	3.47 ^c	3.76 ^{dc}	3.87 ^{cde}	4.83 ^{ab}	3.58 ^{de}	4.20 ^{bcd}	4.98 ^a	3.38 ^e	4.40 ^{abc}	4.79 ^{ab}
Grainy	0.031	0.131	2.68 ^{abc}	2.49 ^{bc}	2.92 ^a	2.91 ^a	2.58 ^{abc}	2.57 ^{abc}	2.85 ^{ab}	2.64 ^{abc}	2.32 ^c	2.84 ^{ab}	2.76 ^{ab}
FLAVOUR Whole chip													
Typical fried chip	p<0.001	0.102	5.04 ^{ab}	5.21 ^a	4.85 ^{bcde}	4.61 ^e	4.92 ^{abcd}	4.87 ^{bcde}	4.65 ^{de}	4.93 ^{abcd}	5.08 ^{ab}	4.96 ^{abc}	4.70 ^{cde}
Oily	p<0.001	0.092	3.56 ^{abc}	3.17 ^{de}	3.43 ^{bcd}	3.08 ^d	3.51 ^{bc}	3.37 ^{cd}	3.45 ^{bc}	3.85 ^a	3.42 ^{cd}	3.69 ^{ab}	3.57 ^{bc}
Bitter	p<0.006	0.096	2.01 ^{abcd}	2.08 ^{abc}	1.86 ^{bcd}	1.88 ^{bcd}	1.84 ^{cd}	2.22 ^a	2.17 ^a	2.13 ^{ab}	1.74 ^d	1.96 ^{abcd}	2.10 ^{abc}
Earthy / Soil	0.101	0.074	2.06	2.09	2.01	1.86	2.03	1.97	1.81	1.85	1.85	1.97	1.95
AFTERTASTE Whole chip													
Typical fried chip	p<0.001	0.088	4.70 ^{abc}	4.90 ^a	4.58 ^{cd}	4.48 ^{cd}	4.64 ^{bcd}	4.58 ^{bcd}	4.42 ^d	4.62 ^{bcd}	4.83 ^{ab}	4.70 ^{abc}	4.42 ^d
Oily	p<0.001	0.099	3.42 ^{ab}	3.03 ^{ef}	3.24 ^{bcde}	2.89 ^f	3.36 ^{abcd}	3.09 ^{def}	3.21 ^{bcd}	3.58 ^a	3.10 ^{cdef}	3.35 ^{abcd}	3.37 ^{abc}
Bitter	p<0.001	0.094	1.91 ^{bcd}	2.04 ^{abc}	1.85 ^{cd}	1.83 ^{cd}	1.75 ^d	2.22 ^a	2.13 ^{ab}	2.15 ^{ab}	1.72 ^d	1.85 ^{cd}	2.15 ^{ab}
Earthy / Soil	0.599	0.069	1.81	1.98	1.82	1.81	1.86	1.83	1.84	1.71	1.83	1.81	1.85

*1= None, 8= Extreme

Cultivars: 1-Mondial, 2-BP1, 3-Bp13, 4-Darius, 5-Van Der Plank, 6-Up-to-date, 7-Fianna, 8-Fabula, 9-Valor, 10-Avalanche, 11- Sifra
 (Note: Means with different superscript in a row are significantly different) *1 indicating none and 8 indicating extreme

4.4.2 Correlations between qualities

A single correlation matrix was drawn up to identify correlations between attributes identified by the taste panel. A correlation of 0.8 and higher indicates a significant correlation and a correlation of 0.6 and higher indicates a fair correlation (Schippers, 1976).

Strong correlations were found between all aspects of oiliness. Oily texture correlated with oily aroma ($r=0.7820$) and highly correlated with oily appearance ($r=0.8760$), oily flavour ($r=0.8859$) and oily aftertaste ($r=0.8480$). Frying potatoes for a long time at a low temperature can have a significant impact on the amount of oil absorbed (Rimac-Brncic, et al., 2004). This preparation method causes an overall oilier end product.

Oily texture correlated positively with a waxy texture ($r=0.7882$), while it correlated negatively with a floury texture ($r=-0.8201$). This indicates that slap chips with a waxy texture appear oilier than slap chips made from potatoes with a floury texture. It has repeatedly been found that potatoes with a higher moisture and lower solids content (waxy), absorb more oil during frying because larger amounts of moisture are lost during cooking, which gives the chips an oilier appearance and taste. For this reason floury potatoes are generally preferred when preparing chips (O'Connor, et al., 2001; Gamble, et al., 1987).

It was found that if a potato appeared oily it had an oily flavour ($r=0.9049$) as well as an oily aftertaste ($r=0.9423$). A very strong negative correlation was seen between the texture of floury and waxy potatoes ($r=-0.9813$) indicating that there was a significant difference in the textural properties of the different cultivars. A study conducted on boiled potatoes indicated that floury characteristics are among the most easily evaluated sensory attributes that can be evaluated by a sensory panel potatoes (Thybo & Martens, 2000). In this study panellists could also identify the difference between waxy and floury slap chips.

Waxy potatoes had a strong correlation with oily aftertaste ($r=0.8241$), while floury potatoes had a negative correlation with oily aftertaste ($r=-0.8241$). A chip with an oily flavour is highly likely to have an oily aftertaste ($r=0.9619$). A consumer preference study showed that American consumers prefer chips that do not have an oily aftertaste and appearance (Lloyd, et al., 2004). Chips that had a typical fresh potato aroma also had a typical fried chip flavour ($r=0.8204$) and typical fried aftertaste ($r=0.8490$).

Dry matter and specific gravity correlated less with each other than expected at $r=0.6831$. A study conducted in 1975 in America indicated that there was a strong correlation ($r=0.912$) between the specific gravity and dry matter content of 1 269 tubers (Schippers, 1976). In a study conducted in Pakistan, a correlation of $r=0.5966$ was seen between dry matter and specific gravity (Abbas, et al., 2011). Significant differences are generally seen in the correlation of specific gravity and dry matter in potatoes from different countries. These differences may be due to different cultivars and agronomical methods that are used in different countries.

Specific gravity is one of the most common methods used in the potato industry to determine the cooking and chipping quality of tubers as specific gravity is a determining factor of textural properties and cooking quality (Potatoes South Africa, 2014). The specific gravity determines the total solids and dry matter of a potato tuber (South African Department of Environment and Primary Industries, 2000).

Dry matter is seen as a more reliable, as it is a scientifically repeatable method of evaluation. Dry matter is measured by drying a known wet weight of finely grated tuber, placing it in a drying oven to extract all the moisture from the flesh and then weighing it again to determine the total dry matter content (van Dijk, et al., 2002).

Because specific gravity measurements are simpler to obtain they are more often the chosen method of evaluation. Oregon State University developed a specific gravity and dry matter reference guide which indicates the relationship between specific gravity and dry matter. Specific gravity measures most commonly fall in ranges between 1.055-1.095 with correlating dry matter values of between 16.5%-24% (Fernando & Slater, 2010; Mosley & Chase, 1993). In a study conducted in Pakistan the specific gravity of 32 different cultivars of potatoes was found to vary between 1.0343-1.1443 (Abbas, et al., 2011) which is a wider and higher range than the average values seen in European potatoes. Once again this can be due to different cultivars and agronomical methods that are used in different countries.

Dry matter correlated with typical fried chip flavour ($r=-0.6634$) and earthy flavour ($r=-0.6259$). Specific gravity correlated with typical fried chip flavour (-0.6634), earthy flavour (-0.6259), oily flavour (-0.6675) and oily texture ($r=0.8386$).

Typical fresh fried chip aroma correlated with typical fried chip flavour (0.8204) and typical fried chip aftertaste (0.8490). Typical fried chip aftertaste had a strong correlation with typical fried chip flavour (0.9665).

Both specific gravity and dry matter had a low correlation with floury ($r=0.5327$; $r=0.1836$) and waxy texture ($r=-0.4331$; $r=-0.0271$) indicating that, in the case of slap chips, neither of these criteria can be used as a determining factor for the floury or waxy texture observed through sensory testing. A consumer preference study found that fried potatoes with a low specific gravity content and thus a waxy texture were preferred over fried potatoes with a floury texture based on their textural appeal. However floury potatoes were preferred due to their flavour (Pardo, et al., 2000).

Attribute	p-value	Cultivars
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		1	2	3	4	5	6	7	8	9	10	11
Specific gravity	p<0.001	1.06 ^{ab}	1.07 ^{bc}	1.068 ^{bc}	1.073 ^{bc}	1.062 ^b	1.064 ^{bc}	1.077 ^c	1.061 ^{ab}	1.065 ^{bc}	1.047 ^a	1.059 ^{ab}
Dry matter	g	22.2	20.1	22.4	26.5	19.3	20.9	27.3	22.6	20.4	19.8	20.4

Table 4-4: Specific gravity and dry matter of analysis of eleven different potato cultivars

Cultivars: 1-Mondial, 2-BP1, 3-Bp13, 4-Darius, 5-Van Der Plank, 6-Up-to-date, 7-Fianna, 8-Fabula, 9-Valor, 10-Avalanche, 11- Sifra
(Note: Means with different superscripts in a row are significantly different) *1 indicating none and 8 indicating extreme

4.4.3 Partial Least Squares Analysis (PLS) of different cultivars

A PLS depicting the grouping of different cultivars on the basis of the sensory panel evaluation is depicted in Figure 4-1.

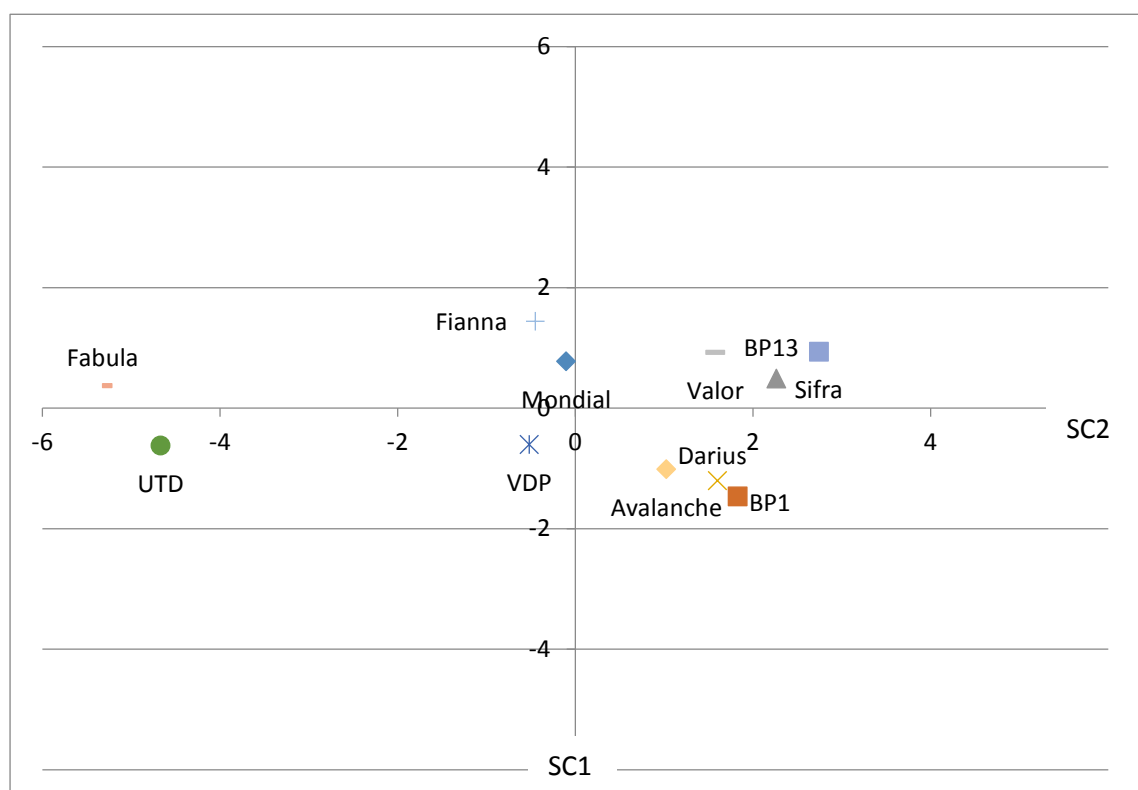


Figure 4-1: A Partial Least Squares (PLS) graph depicting the grouping of eleven different potato cultivars on the basis of a sensory panel and objective evaluation (SC1 = 83.71%; SC2 = 11.70%)

The first two dimensions of the PLS (SC1 and SC2) accounted for 95.41% of the data, 83.71% was declared in the first dimension and 11.70% was declared in the second dimension with latent roots of 72.66 and 10.16 (should be >1 to be significant).

In the first dimension (SC1) the positive loadings were typical fried chip flavour ($r=0.669$), earthy flavour ($r=0.620$); and dry matter ($r=-0.999$), depicted as a negative loading. These attributes of the first dimension explain the different grouping of Fabula and UTD versus Sifra, BP1, BP13 and Darius.

The second dimension (SC2) variance had negative loadings for floury texture ($r=-0.965$) and positive loading for waxy texture ($r=0.984$), oily appearance ($r=0.915$), oily aftertaste ($r=0.871$), oily flavour ($r=0.807$) and oily aroma ($r=0.743$).

Waxy texture and oily appearance, oily aftertaste and oily flavour contributed to the grouping of Fianna, Mondial, Valor, Sifra and Buffelspoort (BP13), in contrast to UTD, VDP, Avalanche, Darius and BP1.

Table 4-5: Percentage variance explained in the first and second dimension for sensory attributes and objective tests done on slap chips made from eleven different cultivars

Y Matrix	%Variance explained		X Matrix	%Variance explained	
	1 st Dimension	2 nd Dimension		Objective measures	1 st Dimension
Typical fresh fried chip aroma	4.17	5.48	NDF	0.81	2.32
Earthy aroma	0.28	0.34	DM	98.8	6.83
Oily Aroma	1.83	15.1	SG	0.16	0.01
Oiliness non-oral	3.38	35.2			
Ease of breaking	10.5	11.8			
Oiliness oral	2.88	17.5			
Mealiness oral	4.950	62.0			
Waxy oral	1.11	58.3			
Grainy oral	3.90	6.15			
Typical fried chip flavour	4.74	5.09			
Oily flavour	2.45	17.5			
Bitter flavour	0.86	3.30			
Earthy flavour	2.28	1.13			
Typical fried chip after taste	3.39	6.64			
Oily after taste	2.35	17.8			
Bitter after taste	0.97	2.96			
Earthy after taste	0.64	3.64			

Currently potato classification is mainly determined by measuring the specific gravity of a cultivar. Specific gravity is a relatively poor indicator ($r=-0.228$) of texture, but it appears that dry matter content can deliver more accurate results ($r=-0.999$) for chips.

The percentage variance (PLS) as explained in Table 4-5 shows that dependant variables (sensory attributes) are primarily explained by oral mealiness in the second dimension while no sensory attributes explained variance in the first dimension. Variance of the independent variables, i.e. chemical analysis, was explained by percentage dry matter.

4.5 Conclusions and recommendations

A standardised cooking method was developed to ensure that the slap chips tested in this study were true to market practices. The trained sensory panel that tested the slap chips found no obvious grouping for cultivars within the same class according to the South African potato classification system.

Oiliness was one of the biggest discriminating factors seen between cultivars. Chips that appeared oily had an oily flavour, aroma, feel and aftertaste. Darius was the cultivar that had the lowest scores for oily attributes. However, there was no clear difference amongst the types of cultivars (waxy, waxy/floury, floury) for sensory attributes, which indicates that there is no significant difference in the textural properties of the tubers when they are deep fat fried. However certain cultivars scored higher on typical slap chip attributes, these included Mondial, BP1, BP13, Van Der Plank, Fabula, Valor and Avalanche.

It can be concluded that deep fat frying has such a significant impact on the chip characteristics that cultivar specific attributes have a lesser impact on the final characteristics of the product.

It is recommended that preference for different cultivars be tested using typical consumers of slap chips.

4.6 Acknowledgement

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4.8 Annexure 4-1

Sensory evaluation of slap chips

April 2013

Name : _____

Day : 4 (19 April) Session : 3

ATTRIBUTE	Sample code 104							
AROMA Evaluate whole chip	None	Hint	Slight	Weak	Moderate	High	Very High	Extremely
Typical fresh fried chip	1	2	3	4	5	6	7	8
Earthy (with earthy potato skin notes)	1	2	3	4	5	6	7	8
Oily	1	2	3	4	5	6	7	8
TEXTURE : NON-ORAL	None	Hint	Slight	Weak	Moderate	High	Very High	Extremely
Oiliness on the surface	1	2	3	4	5	6	7	8
Ease of breaking (bend chip till two ends join)	1	2	3	4	5	6	7	8
TEXTURE: ORAL Evaluate the inside of the chip only	None	Hint	Slight	Weak	Moderate	High	Very High	Extremely
Oiliness inside the chip	1	2	3	4	5	6	7	8
Mealiness/Floury - how floury/crumbly or dry the potato is	1	2	3	4	5	6	7	8
Waxy: moist, mushy (smooth) with some lumps and stickiness	1	2	3	4	5	6	7	8
Grainy: content of grainy particles in the mouth after chewing	1	2	3	4	5	6	7	8
FLAVOUR Evaluate the whole chip	None	Hint	Slight	Weak	Moderate	High	Very High	Extremely
Typical fried chip	1	2	3	4	5	6	7	8
Oily	1	2	3	4	5	6	7	8
Bitter (caffeine) or (green/unripe potato, astringent, burned)	1	2	3	4	5	6	7	8
Earthy / Soil (with earthy potato skin notes)	1	2	3	4	5	6	7	8
AFTER TASTE Whole chip	None	Hint	Slight	Weak	Moderate	High	Very High	Extremely
Typical fried chip	1	2	3	4	5	6	7	8
Oily	1	2	3	4	5	6	7	8
Bitter (green/unripe potato, astringent, burned)	1	2	3	4	5	6	7	8
Earthy / Soil (with earthy potato skin notes)	1	2	3	4	5	6	7	8

Chapter 5: Description of potato texture as influenced by cultivar and culinary application

“I bought a big bag of potatoes and it's growing eyes like crazy. Other foods rot. Potatoes want to see.” — Bill Callahan, Letters to Emma Bowlcut

Abstract

Different potato cultivars have different textural properties that elicit different sensory qualities when prepared. These unique properties makes certain cultivars more suited for specific culinary applications. Research has shown that waxy potatoes are more suited for boiling and steaming, and potatoes with a more floury texture are generally more suitable for mash or roasting.

For this study a trained sensory panel was used to evaluate the intrinsic and extrinsic sensory properties of eleven potato cultivars when boiled, baked and microwaved. Partial Least Squares Analysis (PLS) was applied to determine which sensory or objective measures determined variance in the data the best, and to group cultivars together based on their properties

In addition, focus group discussions were conducted to investigate consumer perception of the different potato textures and associated culinary applications. The data facilitated the development of consumer friendly descriptive terms for different potato cultivars to best describe their most suited culinary applications.

Key words: potatoes, *Solanum tuberosum*, culinary application, cooking, descriptive terms

5.1 Introduction

The potato industry is a rapidly growing part of the agricultural sector (Vreugdenhil, et al., 2011) with more than 4 000 *Solanum tuberosum* species found globally (International Potato Center, 2014). Of the 324 420 782 tons produces globally, 22 333 333 tons are produced in Africa and 2 090 210 in South Africa making potatoes a notable crop in this country (European Commission, 2014). The South African potato crop is made up of a variety (more than 80) cultivars grown in over 16 different production regions (Potatoes South Africa, 2014).

Due to this diversity in the crop, differences in the eating quality of different cultivars are observed, with each cultivar's specific intrinsic characteristics being the main cause of textural differences between the potatoes (Ross, et al., 2011). The resulting variation in cooking or textural quality has led to confusion amongst consumers (Serban, et al., 2014; Thybo & Martens, 1998). Therefore a

classification system was required to classify potatoes according to their specific cooking characteristics, and to communicate these to the consumer so as to increase consumer satisfaction (Potatoes South Africa, 2014).

In 2008, Potatoes South Africa implemented a comprehensive potato classification system that grouped cultivars according to their textural and cooking properties. The current system has three classes; waxy, waxy/floury, and floury together with their associated culinary applications (Thybo, et al., 2004; van Dijk, et al., 2002). A marketing campaign was launched to coincide with the implementation of the new classification system. Waxy potatoes were marketed as ideal boiling and steaming potatoes, while floury potatoes were classified as mashing or baking potatoes. Waxy/floury potatoes are labelled as combination potatoes that can be used for most culinary applications (Potatoes South Africa, 2014; Martens & Thybo, 2000). The goal of the classification system is to enhance communication from the producer to the consumer, and enable consumers to choose specific cultivars, that are tailored to the purpose they must fulfil (Table 5-1) (Potatoes South Africa, 2014).

Table 5-1: Current South African potato classification system (Potatoes South Africa, 2014)

Grouping	Cultivar	Boil	Roast	Chipping/ Frying	Microwave	Mash	Retain shape when boiled
Waxy	Mondial	✓✓✓	✓✓	✓	✓	-	✓✓✓
	Fabula	✓✓✓	✓✓	✓	✓	-	✓✓✓
	BP13	✓✓✓	✓✓	✓	✓	-	✓✓✓
Waxy/Floury	BP1	✓✓✓	✓✓	✓✓	✓✓	✓	✓✓
	VDP	✓✓✓	✓✓	✓✓	✓✓	✓	✓✓
	Fianna	✓✓✓	✓✓	✓✓	✓✓	✓	✓✓
	Valor	✓✓✓	✓✓	✓✓	✓✓	✓	✓✓
Floury	UTD	-	✓✓✓	✓✓✓	✓✓	✓✓✓	✓
	Caren	-	✓✓✓	✓✓✓	✓✓	✓✓✓	✓
	Darius	-	✓✓✓	✓✓✓	✓✓	✓✓✓	✓
	Avalanche	-	✓✓✓	✓✓✓	✓✓	✓✓✓	✓

✓✓✓ - Most Suited ✓✓ - Suitable ✓ - Slightly Suited

The three categories used for classification: *floury*, *waxy* and *waxy/floury* are considered to be descriptive terms to describe usage from an industry perspective, but it is probable that they have limited meaning for the majority of South African consumers and could even elicit negative connotations (Jaeger, et al., 2014). Globally, easily understandable descriptive words pertaining to the culinary application used to prepare the tuber which are used by current educational and marketing campaigns, include words such as salad, firm, creamy (Potato Council UK, 2012), velvety, smooth (Park, 2014) and fluffy (Potatoes New Zealand, 2013). These common terms could provide the consumer with a better indication of the cooked characteristic that they can anticipate from the raw potato product. Enhanced understanding could positively contribute to product expectation,

utilisation and satisfaction, as well as promote biodiversity in potato consumption (Kempen, et al.,

Cultivar	Feb 2008	March 2008	Aug 2008	Feb/March 2010	Feb/March 2010
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2011; Wansink, et al., 2005). A general complaint was also received from the market agents that a forward slash in the classification system meant a negative connotation and therefore buyers did not want to purchase that cultivar. This inhibited the adoption of the cultivar classification system.

The aim of this study was to firstly determine the textural and sensory differences of eleven potato cultivars through sensory and objective evaluation. Secondly, the study aimed to identify and group culinary methods together based on common consumer associations and determine simple descriptive words (which consumers understand) to define and describe the desired outcomes associated with the culinary applications of potatoes.

5.2 Methodology

5.2.1 Study design

The research was conducted over a two year period and consisted of five projects. During this time the texture and flavour attributes of eleven different potato cultivars from three different potato production regions were evaluated by means of physical test and sensory evaluation. Mondial and BP1 were included in each region as control samples together with a combination of the following cultivars; Up-to-Date (UTD), Van der Plank (VDP), Caren, Fabula, Buffelspoort, Fianna, Darius, Valor and Avalanche. Table 5-2 indicates the different cultivars per region per project sampled. After these sensory evaluation sessions consumer focus group discussions were conducted in 2014.

5.2.2 Sampling and sample preparation

The selection of the cultivars included in this study was based on their market share at the time (Potatoes South Africa, 2014). All the tubers were planted on irrigated land. The cultivars included Mondial (Mon), BP1, Up-to-date (UTD), Van der Plank (VDP), Caren (Car), Fabula (Fab), Buffelspoort (BP13), Fianna (Fia), Avalanche (Ava), Valor (Val) and Darius (Dar). Potatoes for the study were cultivated throughout South Africa on irrigated land following standard potato cultivation practices. Samples for specific trials were harvested on the same day and delivered by Potatoes South Africa to the Sensory Analysis and Human Nutrition Unit, Meat Industry Centre, Agricultural Research Council (ARC), Irene. Three bags of 10kg each were used for the analysis. Samples were stored in an air conditioned room at a temperature of 18-24 °C, in cardboard boxes in a dark place.

Region	Mpumalanga	Northern Cape	Sandveld	Mpumalanga	Sandveld
Mondial	X	X	X	X	X
BP1	X	X	X	X	X
UTD	X				
VDP	X		X		
Caren	X	X			
Fabula	X				
Buffelspoort		X	X		
Fianna			X		
Darius			X		
Valor					X
Avalanche				X	
Cooking method	Boiled, baked, microwave	Boiled, baked, microwave	Boiled, baked, microwave	Boiled, baked, microwave	Boiled, baked, microwave

Table 5-2: Evaluation of potatoes according to regions, date and cultivars produced under irrigation

5.2.3 Physical analyses

Physical tests included the determination of dry matter content, specific gravity, starch, moisture content, percentage softening and shear force resistance.

- Dry matter (DM) refers to all substances that a potato contains excluding the moisture content. Potato dry matter was gravimetrically determined, AOAC934.01.
- Moisture was determined using the AOAC 934.01, official method of analysis.
- Starch was determined using an enzymatic spectrometer (in-house method based on AOAC 985.29).
- Shear force resistance is the amount of resistance that a potato exerts when it is being sliced. This study was done on both raw and cooked potatoes. The core of the potato was used for this test. One shear value for each raw and cooked core was obtained using an Instron Universal Testing Machine (Model 4301) (Instron Corporation, 1990), with a Warner Bratzler shear device mounted on a Universal Instron apparatus.
- Specific gravity (SG) was measured by weighing a sample of potatoes in air and then re-weighing the same sample in water. The specific gravity was determined using the following formula (Hegney, 2005):

$$\text{Specific gravity} = \frac{(\text{weight in air})}{(\text{weight in air}) - (\text{weight in water})}$$

5.2.4 Culinary applications

Three cooking methods were applied, namely baking (dry heat), boiling (moist heat) and microwave cooking. Mashed potatoes were also analysed, but the results are not reported as they were boiled prior to mashing.

- Baked (dry heat)

Five potatoes from each cultivar were washed to remove dirt and air dried at room temperature. Potatoes were weighed, and wrapped individually in foil with the shiny side on the inside. Five potatoes were placed in a roasting pan and placed in the oven (without a lid) at 220 °C, which was tested by inserting a hand-held digital stainless steel probe (Kane May C9003), equipped with a J-type thermocouple to record the internal temperature at the geometrical centre of the potato. Potatoes were baked until an internal temperature of 94-95 °C was reached. Potatoes were then removed from the oven. The foil was removed and the potatoes were cut in half, vertically from top to bottom.

- Boiling (moist heat)

Five potatoes from each cultivar were used in each batch / cultivar per day. The potatoes were washed to remove any soil or dirt that were present. Potatoes were placed into 2-litre stainless steel saucepans, covered with tap water at room temperature and boiled in their skins. The saucepan was covered with a lid, to prevent excessive moisture loss during the cooking process. The water was brought to boiling point and the heat was then reduced. The potatoes were allowed to simmer until cooked. Water was replenished with boiling water, when required. Just enough boiling water was added to ensure that the potatoes were covered with water.

The potatoes were boiled until soft and a core temperature of 94°C was reached. The approximate boiling time of the potatoes was 50 min to 1 hour, but varied slightly between the different cultivars and potato sizes.

The potatoes were removed from the heat and the water was drained off. The potatoes were transferred to a pre-heated glass bowl and kept warm at 75°C in calibrated Miele ovens for 10 minutes. After the resting period, the potatoes were cut into sample sizes (half of the potato) vertically from top to bottom.

- Microwave cooking

Five potatoes from each cultivar were washed to remove any dirt that was present. The potatoes were weighed and the cooking time was calculated according to size and weight. The cooking time of large potatoes was calculated as follows: 2 min/100 g and for medium sized potatoes: 1.4 min/100 g. Prior to cooking, the potatoes were pricked three times with a fork on each side, and placed in a 2 litre glass bowl. The larger side of the potato was positioned to the outside of the bowl. The bowl was covered with a lid, and heated on high (900W LG microwave ovens) for 50% of the calculated time. The potatoes were allowed to rest for 5 minutes with the lid in place. The lid was removed and the potatoes were turned. They were then returned to the microwave oven and, cooked for the remaining 50% of the cooking time with the lid in place. The potatoes were again allowed to rest for 5 minutes and were then tested by inserting a hand-held digital stainless steel probe (Kane May C9003), equipped with a J-type thermocouple to record the internal temperature at the geometrical centre of the potato. If the potatoes had reached an internal temperature of 94°C and felt uniformly soft, they were served to the panel immediately.

5.3 Taste panel analyses

5.3.1 Sample serving procedure

For boiled, baked and microwaved potatoes half of a potato wrapped in aluminium foil, with the shiny side on the inside, was served to each panellist. Samples were coded with a random three digit code. Samples were served to the panel at a temperature of 82-83°C. Each session included a different cultivar prepared according to the three cooking techniques.

The coded potato samples were served to the panel one at a time on a pre-heated porcelain side plate. Uniformity of each sample (volume served and serving temperature) of each replication of the different samples was ensured. Samples were randomized to exclude any bias due to the positioning effect. Panel members evaluated five potatoes per day, one at a time, over 2 hours. A score sheet for the evaluation accompanied each sample. Panel members were provided with water and carrots, as a palate cleanser, in between evaluation sessions (Johnson & Vickers, 2004).

5.3.2 Taste panel training

Ten experienced panellists were selected to participate in the profiling of the eleven different potato cultivars. The panellists were screened based on their participation in previous descriptive sensory panels, taste and smell acuity, interest, ability to discriminate between the five basic tastes and availability for the entire project.

During the first project (Feb 2008), four training sessions (2 hours per day) were conducted. During the following four projects (March 2008 – March 2010), two days were allocated for training prior to

evaluation. Panellists received representative samples of each of the different potato cultivars and were trained to increase their sensitivity and ability to discriminate between specific cultivars and the sensory attributes of each sample. A clear definition of each attribute was developed to describe the specific product attribute to be evaluated.

Training a panel is essential to ensure that all members are sensitised (Singh-Ackbarali & Maharaj, 2014). During the training sessions a Lexicon was developed (Table 5-3). This Lexicon consisted of words describing all the different attributes that potatoes cooked in different ways can have.

A category rating scale, with one (1) denoting the least intense condition (e.g. no earthy potato aroma) and eight (8) denoting the most intense condition (e.g. extremely intense earthy potato aroma) (Meilgaard, et al., 1999) was constructed and used to evaluate the different samples. The texture and flavour attributes of the boiled, baked and microwaved potatoes were evaluated under red light conditions.

To ensure that panellists were not influenced in any way, no information with regard to the nature of the samples was provided. Panellists were reminded not to use perfumed cosmetics and to avoid exposure to foods and / or fragrances at least 30 minutes before evaluation sessions.

5.3.3 Sensory evaluation

Each sample was evaluated for 15 sensory attributes. Cultivars were evaluated on aroma and flavour attributes (buttery, earthy and vegetable water), one texture attribute (hardness, the force required to slice through the potato with a knife), one oral first bite attribute (fracturability in mouth), and seven chewing attributes (mealiness in mouth after chewing, waxy, or sticky feeling on palate after pressing on tongue, moistness of potato in mouth, coarse texture, content of grainy particles in mouth after chewing, and compactness in mouth before swallowing) (Annexure 5-1).

Table 5-3: Lexicon for descriptive sensory analysis of 5 different potato cultivars

ATTRIBUTE	DESCRIPTION
-----------	-------------

AROMA and FLAVOUR (F)	Evaluate under red light condition
Potato / earthy	Aromatic notes associated with damp soil, slightly undercooked potatoes
Buttery	Aromatic notes associated with potato that has more flavour (almost as if a small amount of butter has been added)
Blanched water / earthy	An aroma of recycled water used to cooked potatoes, water is not fresh, slightly dirty, stale and earthy aroma and slightly metallic aroma
TEXTURE	Initial impression of appearance: Visual or break with fork and evaluate the appearance of the texture. (One evaluation)
Hardness-knife and fingers	Force required to shear / slice through potato with knife Force required to compress ¼ of the potato with one finger, when pressing longitudinally
(More difficult to cut – harder potato, higher value. BUT remember – potato is still soft)	Degree of compression between fingers before the potato fractures. If the potato fractures at a degree of low compression then the potato has high fracturability and vice versa.
First bite	
Mastication / chewing	
Fracturability – in mouth on first bite (softness – how easily the potato breaks)	Force required to divide the potato in to two parts with the front teeth on first bite. Degree of compression before the potato is separated into parts. Separates immediately, the potato has high fracturability. If the potato fractures at a low degree of compression the potato has high fracturability and vice versa (press potato lightly against palate with tongue). Breaks easily, soft and smooth = high fracturability Hard to break, breaks into pieces = low fracturability
Mealiness	Expresses how floury/crumblly or dry the potato feels in the mouth after chewing. A floury potato has a coarse overall texture
Waxy	A waxy potato has been described as moist, mushy and smooth. It is associated to some degree with stickiness. It has a smooth, waxy feeling on the palate after pressing potato with tongue. A waxy potato has a smooth overall texture

5.4 Developing descriptive terms

5.4.1 Questionnaires

In order to identify culinary applications and descriptive words commonly associated with preparing potatoes, a short questionnaire was developed. The questionnaire was distributed to South African consumers by means of the Survey Monkey online platform. Sixty (n=60) participants participated in this survey. These participants were asked to provide examples of the 5 best descriptive words for potatoes.

5.4.2 Focus groups

Focus group discussions were held with 25 respondents from the middle-income population group. The participants were presented with labels containing the culinary applications identified through the questionnaires and asked to sort them into groups, based on their own association, on a blank sheet (Figure 5-1). No limit was placed on the number of groups or the number of cooking techniques in a group. The participants were subsequently asked to write down next to each grouping the descriptive terms that best described that particular group.

To ensure independence, each respondent was seated at his/her own table and completed their own grouping sheet. Although the descriptive terms identified in the questionnaire were presented to the respondents as prompts they could also add any additional descriptive words which they associated with each culinary grouping.

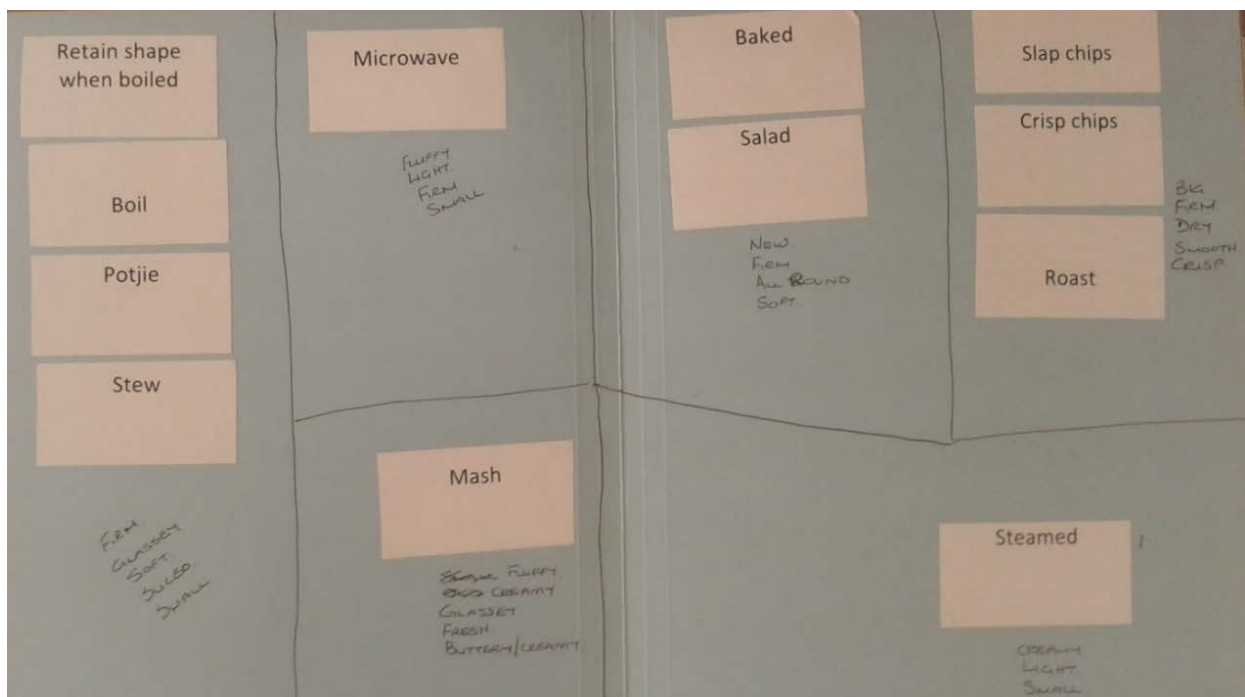


Figure 5-1: Example of a completed grouping sheet with associated culinary applications grouped together and descriptive words added to describe each grouping

5.5 Statistical analyses

The results for the sensory and objective evaluations were captured on an MS Excel spreadsheet. The Partial Least Squares regression procedure (PLS) of GenStat (Payne, et al., 2012) was used to analyse the relationship between the 15 sensory attributes, the Y matrix, of cooked (boiled), baked

and microwaved potatoes and six objective test measurements, the X matrix, with the objective of determining which attributes best describe variance in the data.

The data from the consumer groupings and associated descriptive terms were captured in an MS Excel spreadsheet. Statistical Correlation Analysis was applied to investigate the association with culinary applications. Furthermore, Frequency Analysis was applied to identify the dominant descriptive terminology association with each of the various culinary groupings.

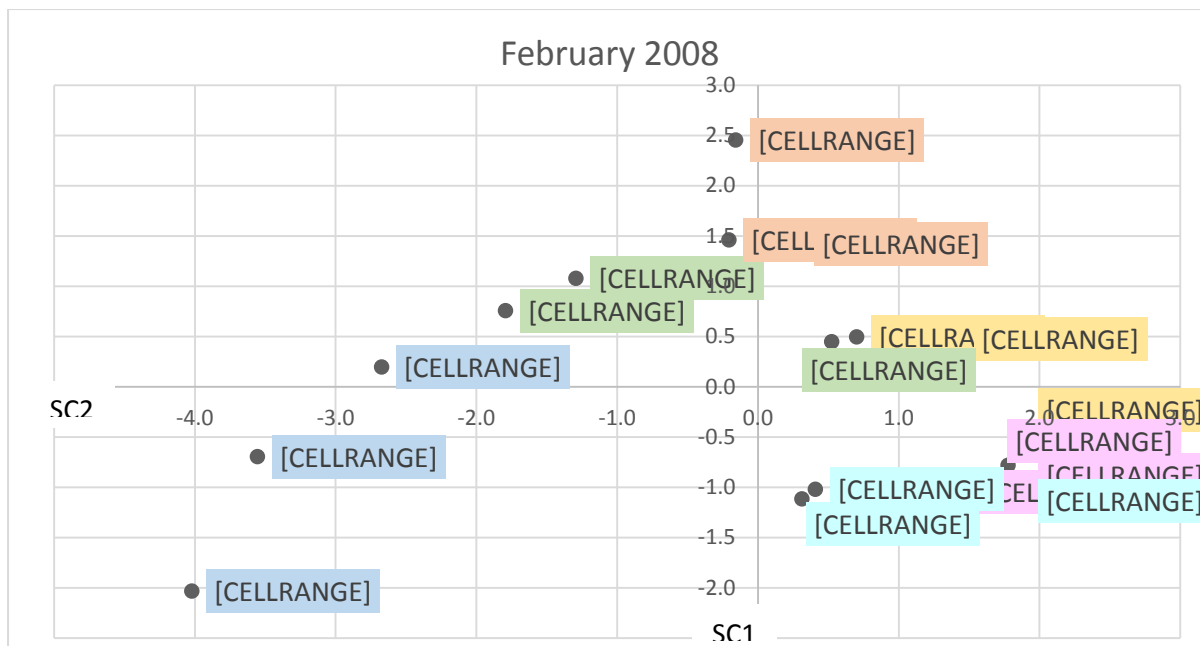
5.6 Results and discussions

The potatoes for the February 2008 study were planted in Mpumalanga Figure 5-2 and Table 5-4. Variance in the first dimension was declared by sensory attributes of mealiness ($r=89.4$) and waxy ($r=89.1$) and objective attributes of dry matter ($r=76.1$) and starch ($r=58.1$).

Variance in the second dimension was declared by a single sensory attribute; fracturability in the mouth ($r=60.4$).

Table 5-4: Ranked percentage variances expressed in the first and second dimensions for sensory attributes and objective tests carried out in February 2008

Y Matrix	% Variances explained		X Matrix	% Variances explained	
	1 st Dimension	2 nd Dimension		Objective measures	1 st Dimension
Hardness K	42.3	48.1	SG	52	4.1
Fracture M	26.3	60.4	DM	76.1	4.6
Mealiness	89.4	6.9	Starch	58.1	5.9
Waxy	89.1	7.8	Force Raw	35.4	15
Sticky	40.7	33	Force Cooked	40.3	1.7
Moist	25.5	1.1	%Softening	48.2	4.1
Coarse	59.7	18.3			
Grainy	27.9	8			
Compact	47.3	47.7			
Buttery F	0.2	19.5			



*C- boiled; B- baked; M-Microwaved

Figure 5-2: A Partial Least Square (PLS) Bi-plot depicting the grouping of six different potato cultivars on the basis of sensory and objective evaluation tested in February 2008

The second study (Figure 5-3, Table 5-5) was conducted in May 2008, with potatoes that were planted in the Northern Cape. Variance in sensory data in the first dimension (SC1) was declared by hardness when slicing the potato with a knife ($r=78.8$), fracturability with the mouth ($r=73$) and moistness ($r=60.6$), with dry matter ($r=78.3$) and starch ($r=67.8$) declaring the variance in the objective data.

Variance in the second dimension (SC2) was declared by a single sensory attribute; waxy ($r=68.5$).

Table 5-5: Ranked percentage variances expressed in the first and second dimensions for sensory attributes and objective tests carried out in May 2008

Y Matrix	% Variances explained		X Matrix	% Variances explained	
	1 st Dimension	2 nd Dimension		1 st Dimension	2 nd Dimension
Hardness K	78.8	2.2	SG	6.7	4.3
Fracture M	73	0.9	DM	78.3	7.9
Mealiness	30	48	Starch	67.8	8.6
Waxy	15.4	68.5	Force Raw	54.1	36.3
Sticky	32	52.5	Force Cook	24.6	14.8
Moist	60.6	0.1	%Softening	10.3	32.9
Grainy	49	41.8			
Compact	59.5	22.4			
Buttery F	0.8	15.2			

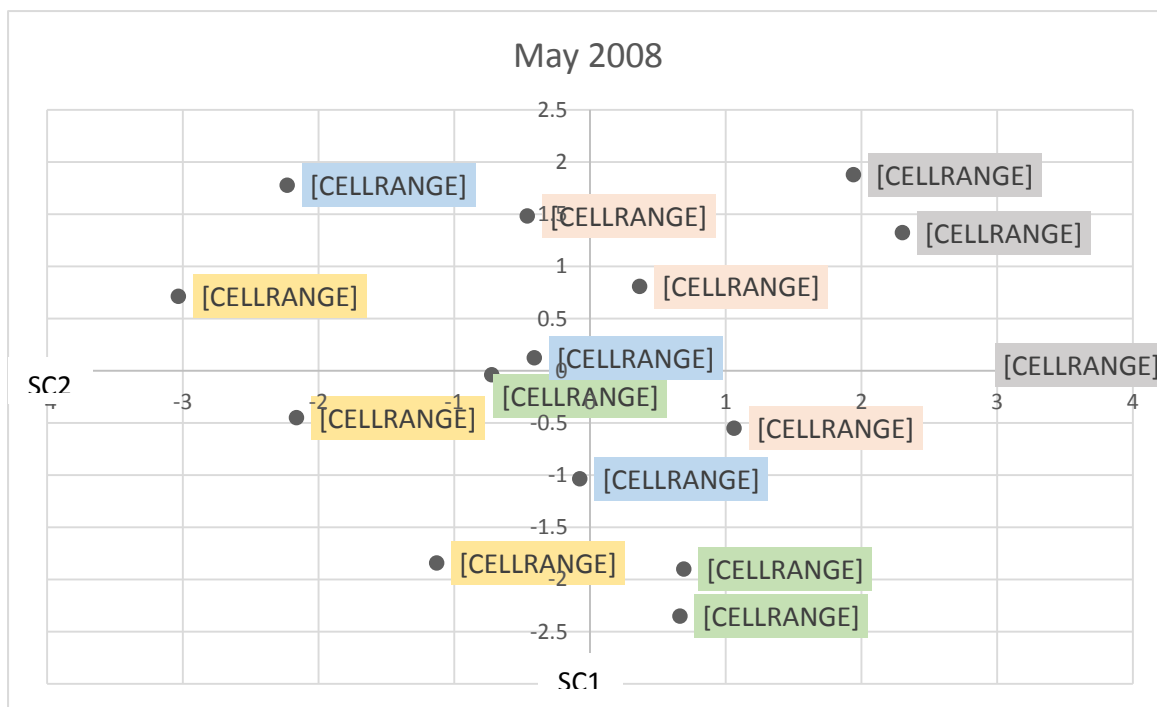


Figure 5-3: A Partial Least Square (PLS) Bi-plot depicting the grouping of five different potato cultivars on the basis of sensory and objective evaluation tested in May 2008

The third study (Figure 5-4, Table 5-6) was conducted in August 2008. Tubers were planted in the Sandveld (Western Cape). In the first dimension (SC1) variance was declared by sensory attribute moistness ($r=78.1$) and objective measures ($r=87.4$), dry matter ($r=86.0$) and specific gravity ($r=58.2$).

The second dimension (SC2) was declared by sensory attributes grainy texture ($r=71.4$) and fracturability in the mouth ($r=59.7$).

Table 5-6: Ranked percentage variances expressed in the first and second dimensions for sensory attributes and objective tests carried out in August 2008

Y Matrix	% Variances explained		X Matrix	% Variances explained	
	1 st Dimension	2 nd Dimension		1 st Dimension	2 nd Dimension
Hardness K	45.7	17.4	SG	58.2	2.7
Fracture M	17	59.7	DM	86	7.1
Mealiness	53.3	24	Starch	87.4	5.2
Waxy	30.8	4.2	Force Raw	0.7	56.3
Moist	78.1	0	Force Cooked	53.3	14.4
Grainy	1.8	71.4	%Softening	45.9	0.9
Compact	14.4	23			
Veg water F	24.5	1.3			

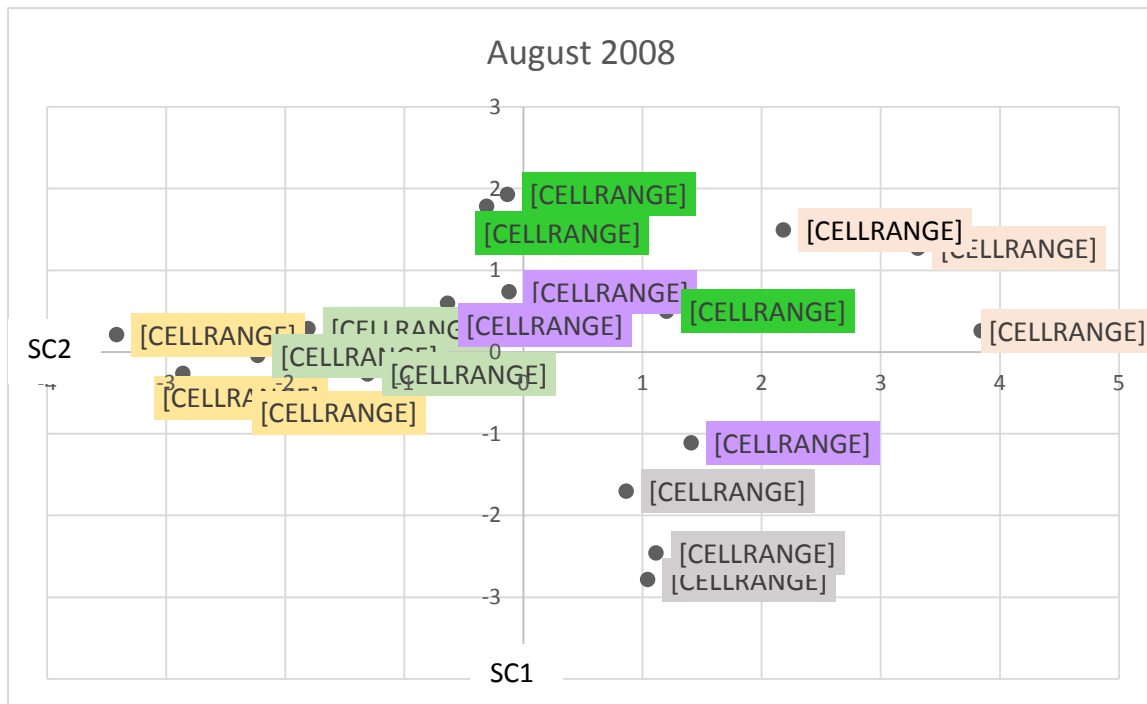


Figure 5-4: A Partial Least Square (PLS) Bi-plot depicting the grouping of six different potato cultivars on the basis of sensory and objective evaluation tested in August 2008

The fourth study was conducted in February 2010. For this study potatoes from the Sandveld (S) and Mpumalanga (M) were used (Figure 5-5, Table 5-7).

The first dimension (SC1) variance was declared by sensory attributes mealiness ($r=79.2$), fracturability in the mouth ($r=69.4$), graininess ($r=69.2$) and waxy ($r=62.7$) and objective measures specific gravity ($r=81$), dry matter ($r=72.3$) and starch ($r=66.5$). Variance in the second dimension (SC2) was declared by sensory attributes coarseness ($r=71.1$) and earthy flavour ($r=70.1$).

Table 5-7: Ranked percentage variances expressed in the first and second dimensions for sensory attributes and objective tests carried out in Feb 2010

Y Matrix	% Variances explained		X Matrix	% Variances explained	
	1 st Dimension	2 nd Dimension		1 st Dimension	2 nd Dimension
Fracture M	69.4	1.3	SG	81	14.2
Mealiness	79.2	11.4	DM	72.3	16
Waxy	62.7	31.2	Starch	66.5	10.8
Moist	42.2	0			
Sticky	34.5	25.5			
Grainy	69.2	22.9			
Compact	21.2	7.7			
Coarse	0.5	71.1			

Earthy F	13.8	70.1			
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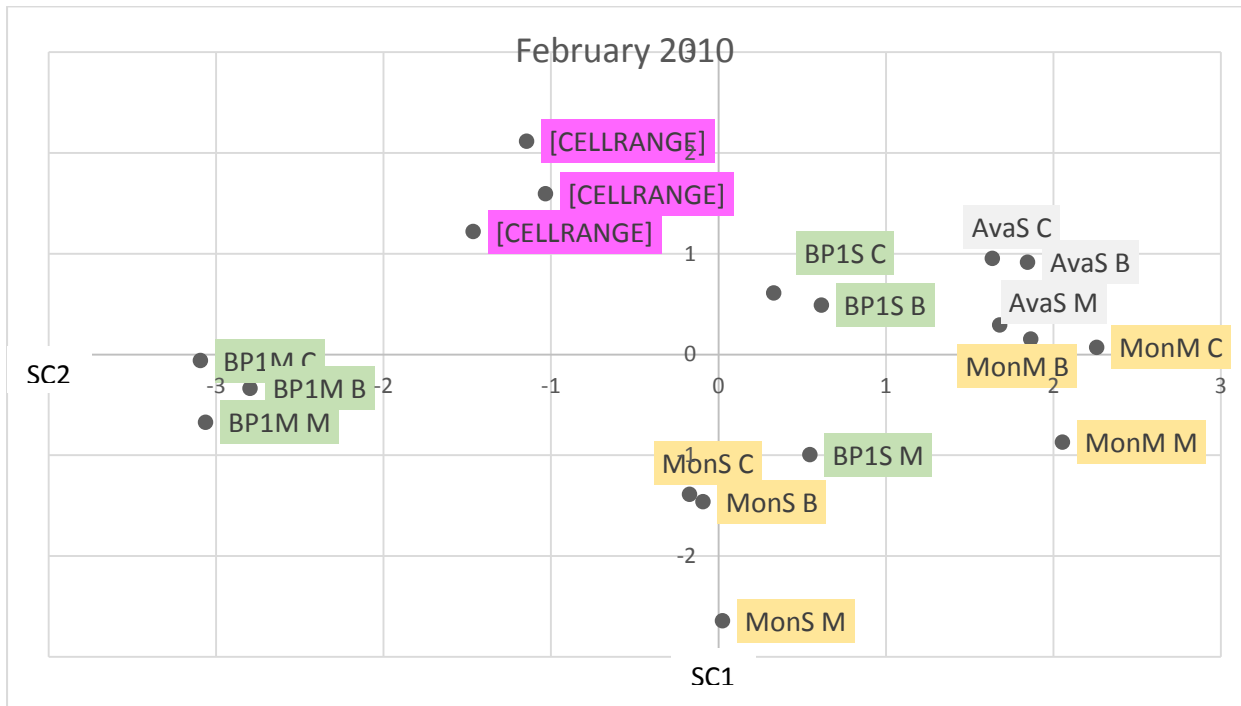


Figure 5-5: A Partial Least Square (PLS) Bi-plot depicting the grouping of six different potato cultivars on the basis of sensory and objective evaluation tested in February 2010

In all of the studies variance in the first dimension (SC1) for objective measures was declared by starch and dry matter, specific gravity declared variance in three of the studies. Fracturability in the mouth was an indicating factor of variance in the first and second dimensions (SC2) for sensory properties. Floury and waxy attributes declared variance in the first and second dimensions in three of the studies.

5.6.1 Descriptive terms used to describe cooked potatoes

5.6.1.1 Questionnaires

Twenty three descriptive terms were identified from the questionnaires (n=60), based on their popularity. These words are presented in Table 5-8 together with the 12 culinary applications the respondents most often referred to in their answers. Words such as soft, hard, smooth, buttery, crisp, big, floury, fluffy, creamy firm and waxy were frequently observed in the Survey Monkey results.

Fluffy and smooth are both terms used in the UK classification system (Potato Council, 2012) and fluffy is used in the New Zealand classification system, (Potatoes New Zealand, 2013). Both these terms were popular with the respondents of the questionnaire as seen in Table 5-8.

Table 5-8: The list of popular descriptive words and culinary applications used by consumers during the questionnaire

Culinary applications	Descriptive words	
Potjie*	Soft	Velvety
Boil	All round	Fluffy
Steam	Hard	Floury
Stew	Smooth	Versatile
Retain shape	Buttery	Hard
Microwave	Grainy	Creamy
Crisp chips (French fries)	Crisp	Sliced
Baked	Light	Crunchy
Roast	Whole	Waxy
Slap chips	Big	Firm
Mash	Dry	Small
Salad	Floury	

*Potjie is a traditional South African dish, similar to stew, where meat and vegetables are combined in a big black cast-iron pot and cooked over a low heat in a sauce.

5.6.1.2 Focus groups

The Correlation Matrix in Table 5-9 shows the associations between cooking methods made by the focus group respondents. A high number indicates that a large number of the focus group respondents considered these culinary applications as being similar / associated with each other.

The culinary application of baking (bake) had a meaningful association (correlation) with roast ($r=10$) and crisp chips ($r=9$), but a very low to no association (correlation) with mash ($r=2$), salad ($r=2$), boil ($r=1$), potjie ($r=0$) and stew ($r=0$). Potjie had an exceptionally high correlation with stew with 84% of participants grouping them together ($r=21$), as shown in Table 5-9.

As expected, boiling (boil) had a very high correlation with “shape retention when boiled” ($r=13$), as well as with salad ($r=10$), stew ($r=10$) and steamed ($r=9$). Boil correlated very little with slap chips ($r=1$), and no correlation was observed between boil and crisp chips ($r=0$) or roast ($r=0$). Crisp chips correlated best with slap chips ($r=16$), followed by roast ($r=9$) and bake ($r=9$).

Table 5-9 shows that mash did not have a strong correlation with any of the cooking methods. Microwave strongly correlated with steamed ($r=9$), but not with mash ($r=3$).

Table 5-9: Correlation Matrix indicating association between culinary applications of potatoes*
 (Number in cells indicates the number of focus group participants making the particular association)

	Bake	Boil	Crisp Chips	Mash	Microwave	Potjie	Retain Shape	Roast	Salad	Slap Chips	Steamed	Stew
Boil	1											
Crisp Chips	9	0										
Mash	2	7	0									
Microwave	4	7	0	3								
Potjie	0	6	0	5	0							
Retain Shape	2	13	0	6	3	8						
Roast	10	0	9	0	3	0	2					
Salad	2	10	0	6	1	3	10	0				
Slap Chips	4	1	16	3	1	1	2	5	3			
Steamed	3	9	0	7	9	2	9	0	6	1		
Stew	0	10	0	3	0	21	0	5	1	1	2	
Alone	2	0	0	9	0	0	0	0	0	4	1	0

*Higher values indicates a meaningful correlation; 0 indicates no correlation

Correlation analysis grouped the culinary applications that correlated the best with each other together in 4 groupings (Table 5-10). Stew and potjie grouped together; bake, roast, slap chips and crisp chips grouped together; boil, retain shape, salad, microwaved and steamed grouped together and mash was a group on its own. The frequency analysis determine the descriptive words most frequently used to describe the end products associated with the different culinary groupings and *soft* was identified as the most frequent descriptive term for potjies and stew potatoes. *Crisp* was most frequently used to describe bake, roast, crisp or slap chips. *Firm, but soft* was used to describe the culinary applications associated with boiling and salad potatoes, and *creamy* was frequently used to describe mash.

Table 5-10: Cooking method groupings and most frequently associated descriptive terms

Grouping	Cooking method	Descriptive terms used by consumers*	Dominant associated term	Current system term
Grouping 1	Potjie	Soft (44%) Smooth (32%) Small (32%)	Soft	Waxy/floury
	Stew	Soft (44%) Floury (36%) Sliced (36%) Small (36%)		
Grouping 2	Bake	Crisp (48%) Sliced (36%) Big (32%) Crunchy (32%)	Crisp	Floury
	Roast	Big (40%) Crisp (40%) Crunchy (36%) Dry (36%) Firm (32%)		
	Crisp chips	Crisp (92%) Crunchy (76%) Dry (48%) Light (32%)		
	Slap chips	Crisp (72%) Crunchy (52%) Dry (40%) Light (36%)		
Grouping 3	Boil	Soft (44%) Firm (40%)	Firm, but soft	Waxy
	Retain shape	Soft (40%) Firm (36%)		
	Salad	Crunchy (48%) Creamy (44%) Soft (40%) Firm (36%)		
	Microwave	Light (2.4%) Firm (2%)		
	Steamed	Buttery (40%) Soft (40%) Creamy (32%) Light (32%)		
Grouping 4	Mash	Buttery (72%) Creamy (64%) Fluffy (64%) Smooth (64%) Soft (64%)	Buttery/ Creamy	Floury

*figures in brackets indicates percentage of sample (n=25) associating a particular descriptive term with the particular cooking method.

5.7 Conclusion and recommendation

Potatoes that are boiled, baked or microwaved, were grouped together irrespective of the cooking method used, indicating that when using these culinary applications cultivar characteristics remain the predominant determining factor of textural characteristics. Dry matter and starch proved to be the objective measures that best declared the variance in data. It can therefore be concluded that when conducting sensory evaluation of different potato cultivars for classification purposes only one of the above mentioned culinary applications needs to be used together with dry matter and starch objective measures. Boiling will probably be the recommended choice.

Furthermore the use of consumer friendly terms for labelling purposes to simplify purchasing decisions is in line with the goals of the Marketing Committee of Potatoes South Africa. Four culinary groupings, each with their most frequently associated descriptive terms have been identified. These groupings and descriptive terms can be used in future to assist in consumer education and labelling development to increase consumer understanding, expectation and satisfaction.

It is recommended that further studies should be conducted to: a) expand the current 11 cultivar sample to include other popular cultivars to determine how the latter should be grouped using these culinary groupings, b) determine what the specific attributes/factors/qualities are that determine the grouping of cultivars, and c) what methodology can be applied within the value chain to determine the most suited culinary groupings.

5.8 Acknowledgment

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5.10 ANNEXURE 5-1

Sensory evaluation of potatoes

Date

Name:.....

Code

AROMA	None	Hint	Slight	Weak	Moderate	High	Very High	Extremely
Buttery	1	2	3	4	5	6	7	8
Earthy	1	2	3	4	5	6	7	8
Boiled vegetable water	1	2	3	4	5	6	7	8
TEXTURE: NON-ORAL	None	Hint	Slight	Weak	Moderate	High	Very High	Extremely
Hardness- k + f	1	2	3	4	5	6	7	8
TEXTURE: ORAL First bite	None	Hint	Slight	Weak	Moderate	High	Very High	Extremely
Fracturability -m	1	2	3	4	5	6	7	8
TEXTURE: ORAL Mastication / chewing	None	Hint	Slight	Weak	Moderate	High	Very High	Extremely
Mealiness	1	2	3	4	5	6	7	8
Waxy	1	2	3	4	5	6	7	8
Sticky	1	2	3	4	5	6	7	8
Moist	1	2	3	4	5	6	7	8
Coarse	1	2	3	4	5	6	7	8
Graininess	1	2	3	4	5	6	7	8
Compactness	1	2	3	4	5	6	7	8
FLAVOUR	None	Hint	Slight	Weak	Moderate	High	Very High	Extremely
Buttery	1	2	3	4	5	6	7	8
Earthy	1	2	3	4	5	6	7	8
Boiled vegetable water	1	2	3	4	5	6	7	8

Comments.....

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Chapter 6: Significance of the study, conclusions and recommendations

“A lucky person is someone who plants pebbles and harvests potatoes” – Irish proverb

6.1 Introduction

Biodiversity is an essential part of human existence which directly contributes to dietary diversity and agricultural wellbeing (Frison, et al., 2006). The importance of biodiversity has only in the last few decades become a noteworthy discussion point in many countries in relation to agricultural, food safety and security programmes. Biodiversity and the role it has in nutrition and sustainability is currently an important subject being researched by the Food and Agriculture Organization (FAO) of the United Nations in collaboration with Bioversity International (Bioversity International, 2014). By enhancing and understanding the biodiversity available at country level, crops can be used to combat and overcome hunger and malnutrition, while simultaneously preserving the environment. The FAO encourages countries to treasure and make use of their national biodiversity to lead to sustainable cultivation of biodiverse crops. One of the first nutrition indicators for biodiversity is knowledge of the nutritional value of sub-species of a specific food. It is therefore necessary that country specific nutritional analysis be conducted on crops at a sub-species level. Such data can be used in national and regional food composition tables and feed into the FAO International Network of Food Data Systems (INFOODS) data tables which will be used in the evaluation of diets and food consumption in future research studies, amongst other applications (FAO, 2010).

A significant number of potato cultivars are cultivated and consumed in meaningful amounts all over the world (e.g. it is a staple food in Ireland), making them an important food crop that can contribute to food security in many countries (Chetty, et al., 2015; Eichhorn & Winterhalter, 2005). Each cultivar has a unique nutritional profile that depends on various factors. Cultivar differences, as well as different cultivation practises, play a significant role in the textural and nutritional properties of potatoes (Booyesen, et al., 2013; Murniece, et al., 2011). Certain cooking methods can further influence the textural properties of potatoes and in turn lead to different textural properties within the same cultivar (Thybo & Martens, 1998) which creates a need for description systems.

In addition to cultivating different cultivars for sustainable ecosystem and diverse diets, consumers need to be informed of the variables associated with sub-species differences. Different nutritional profiles, i.e. starch or calcium content, may notably influence the cooking quality of potatoes. Describing the performance of potatoes once they have been prepared can be complex and difficult to communicate to consumers. Therefore culinary terms can be used when describing different

characteristics to assist consumers when making their purchasing decisions. These differences which are found between the various potato cultivars offer the consumer the opportunity to use potatoes in a variety of ways (van Marle, et al., 1997).

The aim of this study was to investigate the effect of cultivar on macronutrients and mineral content. Nutrient analysis was conducted on tubers with and without the skin. To enhance the potato classification system, the effect of culinary applications (boil, bake and microwave) on the textural properties of potatoes was evaluated. Descriptive terms to describe the intrinsic qualities of different potatoes were developed. A repeatable method of preparing deep fat fried slap chips to determine its effect on the textural properties of potatoes was developed. The purpose of the latter investigation was to determine if slap chips could be added to the existing South Africa classification system.

6.2 Significance of the study

Potato production and consumption is steadily increasing in both South Africa and the world (European Commission, 2014). Developing countries are burdened with rapidly increasing malnutrition rates (Cordeiro, et al., 2013; Haynes, et al., 2012). With explosive population growth there is a greater need to produce more nutritious food, to ensure adequate nutrition for populations. While at the same time emphasis is increasingly placed on preserving ecosystems through sustainable cultivation. Therefore Haynes (2012) suggests that an easy growing low cost, carbohydrate rich and nutrient dense crop, such as potatoes, can be promoted to overcome issues of malnutrition in these countries. An increased need for biodiverse production calls for more cultivar specific research data (Savary, et al., 2014) and this data needs to be compiled using accurate and precise scientific approaches (**Chapter 3**).

The Post-2015 Sustainable Development Goals (SDGs) goal number 2 strives to “end hunger, achieve food security, improve nutrition, and promote sustainable agriculture”, goal number 12 strives to “ensure sustainable consumption and production patterns” and goal number 15 strives to “halt biodiversity loss” (United Nations, 2015). All three of these goals are focused on ensuring that there is enough nutritious and safe food to consume for generations to come. This is where nutrient composition data can play a role. There is also a more specific need for country and crop specific nutritional analysis to better understand how the food sources available in a country can contribute to country specific nutrition solutions (Webb, 2014).

Consumer acceptance must also be considered. The textural aspects of potatoes can greatly influence how the consumer perceives quality and accepts the product. Texture is one of the main

characteristics used by consumers to evaluate potatoes (Bourne, 2002). Due to the textural differences observed in different potato cultivars (Thybo, et al., 2004) it is necessary to describe the culinary application of the product. The current classification system does not include the traditional South African potato slap chip. Therefore, this cooking method was tested to determine how slap chips fit into the classification system (**Chapter 4**). Currently the South African potato classification system groups cultivars into the following respective classes, namely waxy, waxy/floury, floury. These classes are intended to guide the consumers in terms of the culinary applications that will best compliment the intrinsic cultivar characteristics (**Chapter 5**). The system is motivated by the principal that a positive consumption experience will stimulate continued use and, therefore, continuous demand for production (Singh & Goyal, 2014).

6.2.1 Nutrient content of potato cultivars

Chapter 3 showed that there is a significant difference in the nutritional value of different potato cultivars indicating that certain cultivars can contribute more significantly to the intake of certain nutrients. Potatoes can form part of a healthy diet and make a contribution to the diet as they are a source of a variety of macro- and micronutrients. Potatoes are a source of potassium and contain low levels of sodium, which can be used to motivate the promotion of potatoes as part of a low sodium diet. In the light of the high prevalence of hypertension in South Africa which is a health threat (Day, 2014), a high potassium, low sodium diet could promote better health. Tubers are high in manganese contributing up to 60% of the total NRVs for individuals four years and older.

6.2.2 Categorising of potato cultivars

Different preparation techniques can have a significant impact on the textural properties of potatoes (Kita, 2002). In Chapter 4 no obvious grouping of potato cultivars on the basis of the intrinsic characteristics was found when potatoes were deep fat fried to produce traditional slap chips. Oiliness was the most important discriminating factor between cultivars with waxy and oily attributes grouping cultivars together, while dry matter, fried chip and earthy flavours differentiated between chips from different cultivars.

In Chapter 5 the textural properties of potatoes were evaluated by using physical and sensory attributes. Significant differences were found in dry matter and starch content and the sensory measure “fracturability with the mouth”. When using cooking methods such as boiling, baking and microwaving no significant differences were found in the textural properties of a specific cultivar. It can therefore be concluded that when testing potato tubers for textural attributes, boiling can be recommended as the cooking method of choice. New descriptive terms were developed from the sensory evaluation with the help of a focus group. The descriptive words identified in Chapter 5,

emphasizes the best suited culinary application rather than the textural properties of the tuber. The descriptive words which were derived, included; soft, crisp, firm, but soft and creamy.

6.3 Concluding remarks

To determine the dietary intake of individuals in a country, country specific nutritional values of food products are needed (Wolmarans, et al., 2009). Consuming a varied diet is the basis of good nutrition. Consuming a variety of potato cultivars can form part of more diverse diets which contribute to combating malnutrition, especially in developing countries where intakes of macro- and micronutrients are often compromised (Kraak, et al., 2012).

This study showed that there is a significant difference in the nutritional value of different potato cultivars, irrespective if analysed with or without the skin. This confirms the variation of nutrient delivery within sub-species of *Solanum tuberosum* as currently available on the South African market.

It was found that when less invasive cooking methods such as boiling, baking and microwaving are used cultivar characteristics remain the predominant determining factors influencing textural characteristics. Dry matter and starch proved to be the objective measures that best described the variance in data.

A descriptive sensory panel was used to determine that there is no clear pattern of differences between the types of cultivars (waxy, waxy/floury, floury) for any of the sensory attributes evaluated when deep fat frying was applied. It can therefore be assumed that most cultivars will be suitable for preparation in this manner. However, certain cultivars did have higher values for typical slap chip attributes.

The current South African Potato classification system classifies potatoes into three categories namely; waxy, waxy/floury and floury. These words do not clearly describe the ideal cooking methods for specific cultivars. Consumer questionnaires and a focus group session were used to develop new words that better describe the ideal preparation methods for specific cultivars. The focus group indicated that terms such as soft, crisp, firm, but soft and buttery/creamy are more descriptive in relation to preparation methods used for potatoes, than the terms in current use.

6.4 Limitations of the study

In order to have a complete dataset of the nutrient content and quality of potatoes found in the South African market, analyses should be expanded to include vitamins and updated on a continuous basis. Only eleven commonly consumed cultivars were investigated, while there are more than 80 cultivars available on the market. Apart from the cost of nutrient analysis, the number of laboratories in South Africa that can perform specialized vitamin analyses is limited.

A focus group was used to evaluate descriptive terms for potato classification. Ideally these descriptive words should be tested by a sensory panel. The present study and its findings can be used as motivation for further studies on developing descriptive terms for potato classification.

6.5 Lessons learned

Due to the diversity of this study a variety of techniques and methods had to be mastered in order to successfully complete the study. A variety of analytical methods were used during this study. In Chapter 3 lab analysis such as; ash, dry matter, nutrient analysis and sample preparation was conducted. In Chapter 4 a variety of outlets had to be visited and investigated in order to develop a preparation that was true to market conditions. A sensory panel was trained and handled during the sensory evaluation part of this project. In order to develop descriptive terms (Chapter 5) consumer survey and analytical tools were used for development and evaluation of descriptive terms.

6.6 Recommendations

Potatoes are a biodiverse crop, and a wide variety of cultivars are cultivated in South Africa. In view of these facts it would be difficult to evaluate the nutrient, as well as cooking quality of all the different cultivars in one study. Furthermore due to ever changing consumption patterns, data on different cultivars is continually required. As new cultivars are developed and made available on the South African market on-going research is needed to ensure continuity of potato consumption studies.

Potatoes are diverse in both application and nutritional quality. In order to utilise a potato to its full potential, scientific evidence must be regularly updated and the application of this information must be communicated to consumers in understandable ways.

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