

**Comparison of the eating quality of selected potato cultivars from two
production regions in South Africa and a proposed classification system for
the consumer**

LARYSSA BOOYSEN

Dissertation

M Cons Sc (Food Management)

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Co-study leader: Prof Dr Hettie C Schönfeldt

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Spreuke 3:5, 6

Vertrou op die Here met alles wat jy het. Moenie staatmaak op jou eie insigte nie. Vra na die wil van God in alles wat jy doen. Hy sal die regte pad vir jou wys.

Psalm 118:29

Wees dankbaar teenoor die Here, want Hy is goed! Sy goedheid duur vir altyd!

'Success seems to be connected with action. Successful people keep moving. They make mistakes, but they don't quit'. Conrad Hilton

To all my immediate family and friends, I thank you for your infinite support and encouragement with this study.

This work is dedicated to Mathew van der Merwe. Thank you for believing in me, knowing that I have the determination, dedication and willingness to sacrifice the little things in life and pay the price for the things that are worthwhile.



DECLARATION

I, **Laryssa Booysen**, hereby declare that the dissertation for the **Master in Consumer Science** 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.

LARYSSA BOOYSEN

25 October 2010

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ABSTRACT

Comparison of the eating quality of selected potato cultivars from two production regions in South Africa and a proposed classification system for the consumer

by

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Degree: Masters in Consumer Science (Food Management)

The eating quality of South African potato cultivars has not been determined and described scientifically. By determining the eating quality of potato cultivars, appropriate culinary applications can be identified for the South African consumer, based on the scientific information obtained. With the compilation of a databank, comprised of the eating quality of potato cultivars available in South Africa, a classification system can be developed and proposed, similar to those available in other countries.

In this study, the first objective was to determine, describe and compare the eating quality of potato cultivars from two production regions. The second objective of the study was to propose a classification system for potato cultivars for the South African consumer. The envisaged classification system will provide consumers with information regarding potato cultivars and serve as a guide to assist them with the selection of a suitable cultivar for a specific culinary application.

For this quantitative study, the focus was on two potato production regions (Limpopo and the Eastern Free State), and three potato cultivars were selected, namely BP1, Mondial and FrutiLay (a processing potato with a high dry matter content). The study was conducted in two phases. Phase 1 involved a descriptive sensory evaluation performed by a trained sensory panel. Sensory descriptors for the sensory evaluation were identified and a lexicon

was developed. A category scale was used to rate the sensory attributes. Objective evaluation was performed in Phase 2, which involved physical measurements of specific gravity, shear force resistance measurement and scanning electron microscopy.

The eating quality of potatoes obtained from these two production regions was determined, described and compared. From the results obtained it is clear that the eating quality of one production region differs from the other, as different production factors such as growing and climatic conditions exist between the regions. It is evident that both sensory and objective evaluations need to be performed in order to determine the eating quality of the various potato cultivars, as one evaluation supports the other.

In order to develop and propose a classification system for potatoes, a representative sample of potato cultivars is necessary. Therefore, seven different cultivars from the Eastern Free State region were evaluated and compared towards attaining this objective. A Partial Least Square regression modelling method was used to relate the sensory attributes and objective measurements, in order to propose a classification system for potato cultivars. Potato cultivars were grouped and suggested culinary applications were assigned to the various cultivars.

The study confirms the valuable contribution of determining the eating quality of potato cultivars for the development of a proposed potato classification system for all production regions, in order to assist the South African consumer with suggested culinary applications for potato cultivars. This classification system would not only benefit the potato industry, but the South African consumer as well.

Keywords: eating quality, potato, cultivars, potato production region, descriptive sensory evaluation, partial least square regression modelling method, potato classification system



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CHAPTER 1

THE STUDY IN PERSPECTIVE

1.1 BACKGROUND AND INTRODUCTION

The potato (*Solanum tuberosum*) is one of the world's major agricultural crops, consumed by people around the world on a daily basis. Numerous cultivars are available and more are added continually. Cultivation conditions (e.g. soil, climate, irrigation and fertilisation) vary between countries and even between regions within a country. This contributes to differences in eating quality attributes observed amongst cultivars grown in different production regions of the world.

Potatoes are regarded as one of the most popular vegetable crops in South Africa. South Africa is the fourth largest producer of potatoes in Africa and still expanding. In 2005, for example, South Africa produced approximately 1 716 453 tons of potatoes. During 2007, on 54 000 hectares of land, 1 900 000 tons of potatoes were produced. These 54 000 hectares of potatoes contributed to 4% of the total potato production in Africa. In 2008, 50 374 hectares of potatoes were planted, which produced 2 038 745 tons of potatoes (<http://www.potato2008.org>).

This study focuses on South Africa's Potato Industry. Potatoes are produced throughout the year in various regions with different climatic conditions. The major producing provinces in South Africa are the Eastern Free State, Western Free State, Limpopo, KwaZulu-Natal and Mpumalanga. Within these provinces, different production regions exist. These regions include Limpopo, North West Province, Gauteng, Mpumalanga, KwaZulu-Natal, Northern Cape, South Western Cape, Southern Cape, Eastern Cape, North Eastern Cape, Sandveld, Ceres, South Western Free State, Western Free State, Eastern Free State, Marble Hall/Groblersdal regions (National Agricultural Marketing Council Research Report, 2007).

1.2 POTATO CONSUMPTION PER CAPITA PER PROVINCE IN SOUTH AFRICA

Potato usage and consumption patterns differ in each province. Statistics are available from Potato South Africa based on the population count in a province and the consequent quantity of potatoes consumed per year (per capita), thus the "estimated per capita potato usage per province" (<http://www.potatoes.co.za>).

The estimated potato usage "per capita per province" is presented in Figure 1.1.

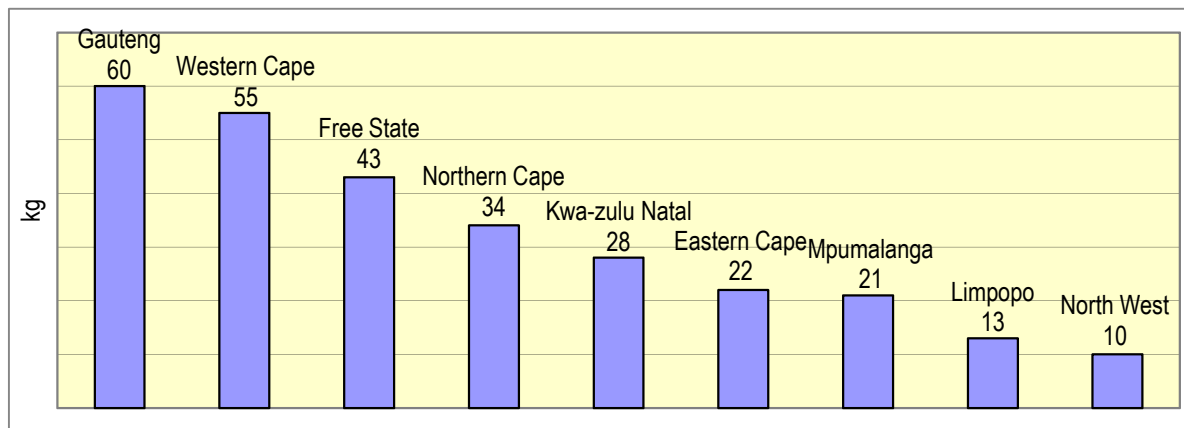


FIGURE 1.1: ESTIMATED POTATO USAGE PER CAPITA PER PROVINCE IN 2006
 (<http://www.potatoes.co.za>)

Gauteng has a population of 9 569 million residents and an estimated amount of 60 kg of potatoes is consumed per capita. The Free State province has a per capita usage of 43 kg potatoes for 2 937 million residents compared to the per capita usage of 13 kg for the Limpopo province with 5 353 million residents (<http://www.potatoes.co.za>).

There are currently approximately 40+ registered cultivars available in South Africa (<http://www.potatoes.co.za>).

1.3 CHARACTERISTICS OF SOUTH AFRICAN POTATO CULTIVARS

Each potato cultivar is assumed to have specific characteristics with regard to size, shape, cooking and eating qualities in comparison to other cultivars from the same region

(Redmond, Gormley & Butler, 2003:86). The assumption is that the eating quality of different potato cultivars grown in South Africa is unique and the sensory attributes such as appearance, aroma, flavour, texture and after-taste differ from the eating quality of potatoes produced in other parts of the world.

Potatoes are characterised according to their growing period and end-use. Each aspect will be discussed below.

1.3.1 Growing period

In South Africa, potato cultivars are characterised according to their growing period or the time taken to reach maturity. The growing or maturing periods are described as short, medium and long growing periods. The early-maturing or short growers require 70-90 days to reach maturity, while the medium-maturing growers require 90-110 days and the late-maturing cultivars require 90-150 days (Niederweiser, 2003:31).

In the early maturing cultivar group (70-90 days), Vanderplank and Buffelspoort are the most popular cultivars. The medium-growing cultivars (90 to 110 days) form the bulk of potatoes grown in South Africa, of which BP1, Mondial and Up-to-Date are currently the most popular cultivars (<http://www.nda.org>; Niederweiser, 2003:31).

1.3.2 End-use

Potatoes are also grouped according to the end-use that they are destined for. According to Niederweiser (2003:34, 68) firm potato cultivars such as Mondial and Vanderplank are favoured for making salads, because they do not slough easily, whereas the Up-to-Date cultivar is favoured for mashing and baking, because it sloughs easily. According to Heljová, Blahovec and Vacek (2005), this phenomenon of “sloughing” refers to the flaking and disintegration of the outer layers of potato tubers cooked in water, which is considered as one of the principal characteristics of potato texture. Mondial is a waxy to multi-purpose cultivar (Niederweiser, 2003:56, 66).

Approximately 18% of the potato crop is processed. The cultivars BP1 and Mondial have poor processing qualities, but are popular cultivars for household consumption (Niederweiser, 2003:35, 56). In the processing industry, cultivars that are frequently used in

the manufacturing of crisps are Darius, Hermus, Fiana, FrutiLay, Lady Rosetta, Pentland Dell and Smith's Commit. Crisps represent approximately 39.23% of the total domestic processed potato products for 2007. Vanderplank, BP1, Up-to-Date and Hertha are used in the manufacturing of fries. Frozen fries represent approximately 39.59%, while fresh fries represent around 18.61% of the total processed potato products. Canned potatoes are representative of 1.26%, mixed vegetables 0.82%, dehydrated potatoes 0.21%, other 0.17% and baby food 0.10% of the total domestic processed potato products (<http://www.nda.org>; National Agricultural Marketing Council Research Report, 2007).

1.3.3 Cultivars available on South African fresh produce markets

Figure 1.2 gives a detailed picture of the cultivars available on these markets during the 2006/2007 production season (<http://www.potatoes.co.za>).

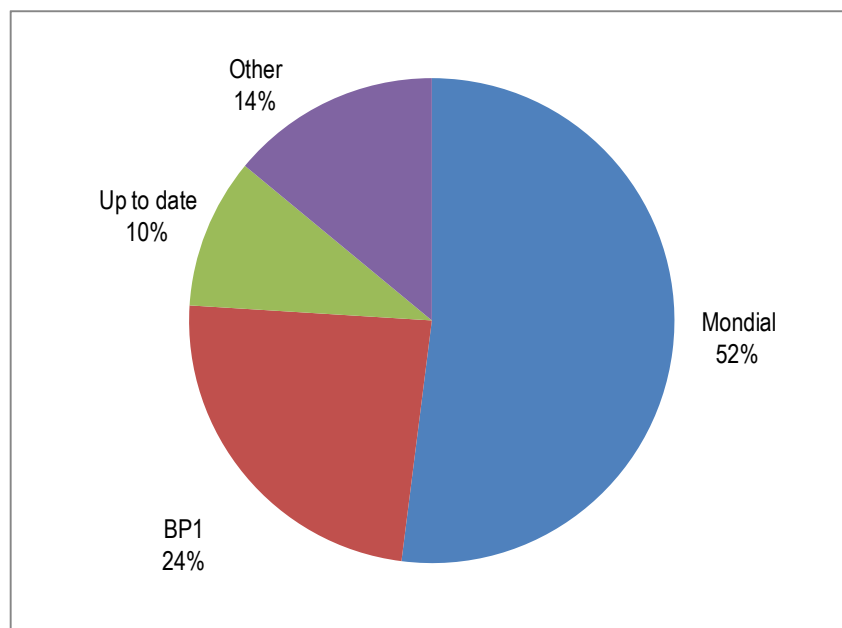


FIGURE 1.2: PERCENTAGE OF CULTIVARS AVAILABLE ON SOUTH AFRICAN FRESH PRODUCE MARKETS DURING 2006/2007 PRODUCTION SEASON (<http://www.potatoes.co.za>)

Throughout South Africa, Mondial and BP1 are the main potato cultivars available on fresh produce markets. During the 2006/2007 production season, Mondial represented 52%, BP1 24% and Up-to-date 10% of the cultivars available on fresh produce markets. Other cultivars

such as BP13, Darius, Vanderplank, Fabula, Caren, Astrid, Fiana and other minor cultivars, together represented 14% (<http://www.potatoes.co.za>; Chips, 2008:19).

This study focuses on two different potato production regions in South Africa, namely the Limpopo and the Eastern Free State regions. Different growing and climatic conditions exist in the different production regions and certain cultivars are produced more successfully in certain regions. Potatoes from the Limpopo and the Eastern Free State regions are produced with different growing conditions throughout the year.

1.4 POTATO PRODUCTION METHODS IN SOUTH AFRICA

Figure 1.3 represents the rise and fall of the gradient on the type of production used in the various production regions.

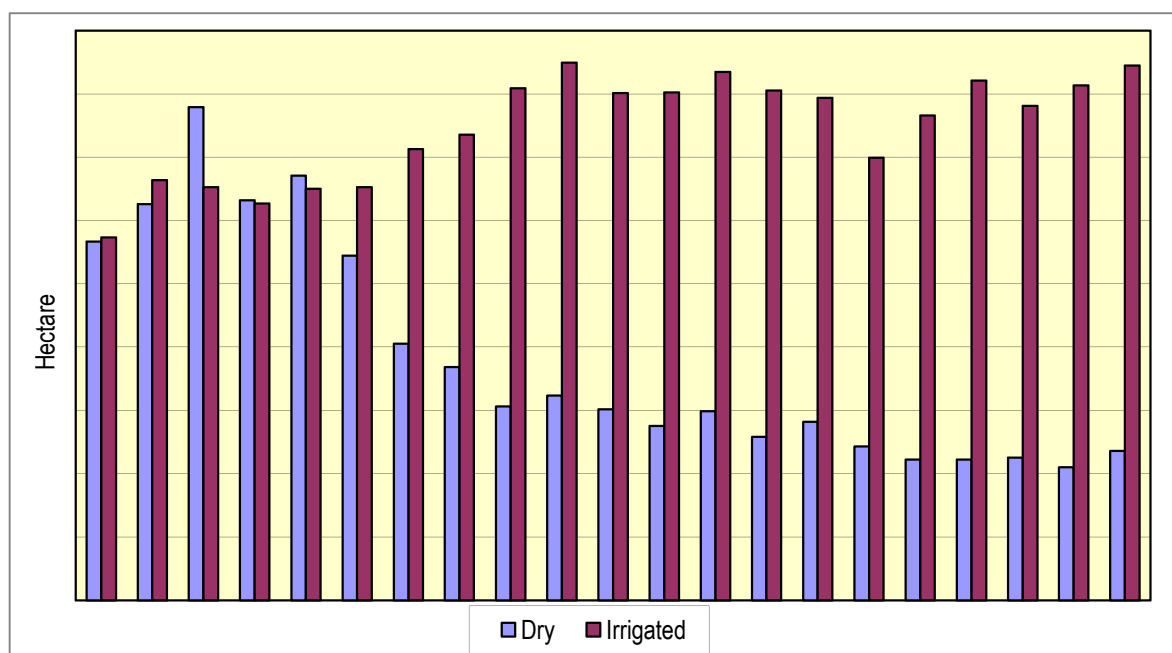


FIGURE 1.3: SOUTH AFRICAN POTATO INDUSTRY – DRY-LAND VS IRRIGATION
 (<http://www.potatoes.co.za>)

Two potato production methods, namely dry-land and irrigated growing conditions, are used to produce potato crops. During the past two decades there has been a prominent shift away from dry-land production towards production under irrigation. Presently, approximately



80% of the crop is grown under irrigation or supplemented with irrigation (<http://www.potatoes.co.za>; Chips, 2008:19).

1.4.1 Hectares planted in South Africa

Potatoes, in general, are available for production and consumption in each province in South Africa. However, in some provinces only certain cultivars are available. Figure 1.4 illustrates the hectares planted in the different regions for 2006 (<http://www.potatoes.co.za>).

Potatoes from the Limpopo region are planted during the months of March, April and May and produce potatoes for a winter harvest period, while the potatoes from the Eastern Free State region are planted during the months of September, October and November, and produce potatoes for a summer harvest period. In 2007, 9 776 hectares of potatoes were planted in the Limpopo region, while 10 311 hectares of potatoes were planted in the Eastern Free State region. Of the total potato production in South Africa, Limpopo produces 21% and the Eastern Free State 11%. During 2006 the Limpopo region produced 16% and the Eastern Free State 11% of the total potato production in South Africa (Figure 1.4) (<http://www.potatoes.co.za>; Chips, 2008:18). The two focused areas are indicated with red circles.

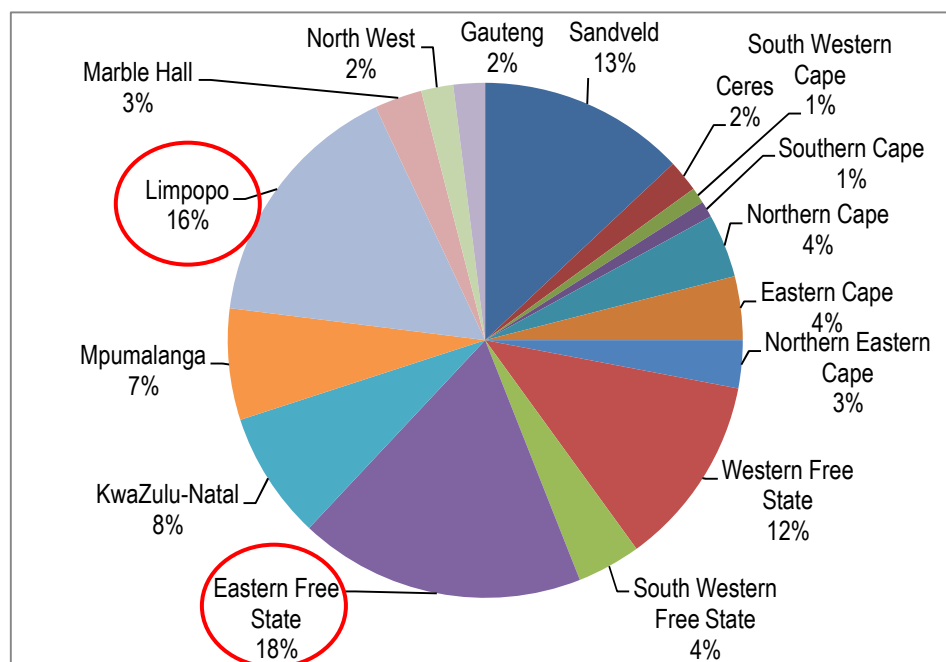


FIGURE 1.4: TOTAL HECTARES PLANTED IN 2006 (<http://www.potatoes.co.za>)

Figure 1.5 illustrates the harvest from the hectares planted in the different production regions of 2006 (<http://www.potatoes.co.za>).

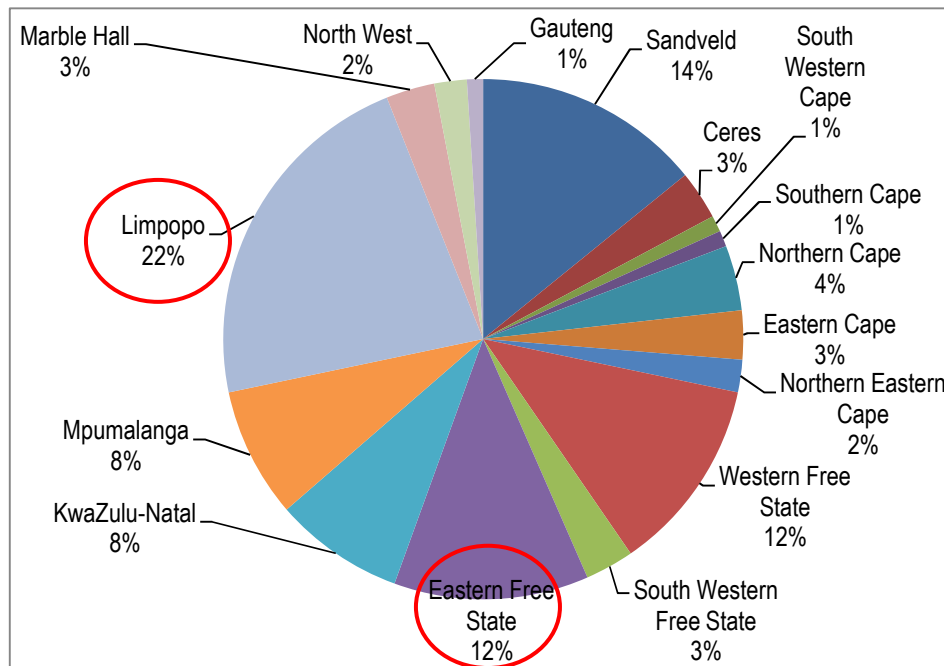


FIGURE 1.5: TOTAL HARVEST OF 2006 (<http://www.potatoes.co.za>)

During 2006 the Limpopo region represented 16% of the total hectares planted with potatoes in South Africa and produced approximately 22% of the total harvest (Figure 1.5). The Eastern Free State region represented 18% of the total acreage planted with potatoes and produced approximately 12% of the total harvest (<http://www.potatoes.co.za>).

1.5 POTATO CULTIVARS SELECTED FROM THE TWO PRODUCTION REGIONS

This study focuses on three potato cultivars, namely BP1, Mondial and FrutiLay. The FrutiLay cultivar represents a group of processing potato cultivars with a high dry matter content. This cultivar is hereafter referred to as HDM (high dry matter potato) and is used as the control. Each of these cultivars will be discussed. The BP1 cultivar will be discussed first followed by the other two cultivars.

1.5.1 The BP1 cultivar

BP1 is a cultivar that originated in South Africa in 1958, but is presently also available in neighbouring countries such as Mozambique and Zimbabwe. BP1 has a white skin and flesh colour with an oval-shaped tuber (Hils & Pieterse, 2005:42). The cultivar has a medium growing period of 90-110 days from emergence to natural foliage die-off and has a high yield potential with medium- to large-sized tubers under favourable growing conditions (Niederweiser, 2003:16).

1.5.2 The Mondial cultivar

The Mondial cultivar originated in the Netherlands and has been available in South Africa since 1987. It has a yellow skin with a light yellow flesh colour and a long tuber shape (Hills & Pieterse, 2005:139). It has a medium growing period of 90-110 days from emergence to natural foliage die-off and has a high yield potential with medium- to large-sized tubers. The keeping quality is moderate, whereas the tuber quality declines within 45 days after natural foliage die-off. When periods of heat and/or water stress are experienced in potato plants during the growing season, the keeping quality of the tubers is noticeably lessened (Niederweiser, 2003:56, 57).

1.5.3 The FrutiLay cultivar (a high dry matter potato – HDM)

The dry matter content of a potato is associated with many quality traits, such as texture, suitability for processing and susceptibility to mechanical damage or bruising. The most important determining factor of texture is the dry matter content. A correlation exists between the texture of a potato and its constituents, with the emphasis on the dry matter and starch contents, respectively (Van Dijk, Fischer, Holm, Beekhuizen, Stolle-Smiths & Boeriu, 2002b:5082). Starch is the major component of the dry matter content of potato tubers. The dry matter content of a potato tuber can be determined with the measurement of specific gravity (Dale & Mackay, 1994: 298, 304, 305).

The dry matter content of a potato determines the sensory-perceived texture of a potato (Van Dijk, Beekhuizen, Gibbens, Boeriu, Fischer & Stolle-Smiths, 2002a:5089). Potatoes, irrespective of the cultivar, with a low dry matter content will be perceived as less firm, less mealy, moist, sticky, never crumbly and grainy, whereas potatoes with a high dry matter, will

be perceived as crumbly and grainy, never moist and sticky (Van Dijk *et al.*, 2002a:5096; Van Dijk *et al.*, 2002b:5086).

1.5.4 Main cultivars planted in the two production regions

In South Africa, the cultivars Mondial, BP1 and Up-to-Date are planted primarily and are also the most favoured cultivars (<http://www.potatoes.co.za>; Chips, 2008:18, 19). The main cultivars planted in the two identified production regions are indicated in Table 1.1.

TABLE 1.1: THE MAIN CULTIVARS PLANTED IN THE TWO PRODUCTION REGIONS IN 2007 (<http://www.potatoes.co.za>)

Region	Harvest	Purpose	Main cultivars planted in 2007				Total hectares planted
			1	2	3		
Limpopo	Early	Table/processed	Mondial, 51%	Lady Rosetta, 13%	BP1, 12%		2 923
	Main	Table/processed	Mondial, 55%	BP1, 22%	UTD, 7%		6 853
Eastern Free State	Early	Table/processed	Mondial, 23%	UTD, 20%	BP1, 19%		10 168
	Main	Seed potatoes	BP1, 25%	Mondial, 25%	Astrid, 23%		143

During 2007 in the Limpopo region, the Mondial cultivar had a proportion of 51% of the total hectares planted for household or processed potatoes for the early harvest period, while a proportion of 55% was planted for table or processed potatoes for the main harvest period. A proportion of 12% of the total hectares was planted for the BP1 cultivar, during the early harvest period, whereas a proportion of 22% was planted for the main harvest period (<http://www.potatoes.co.za>).

In the Eastern Free State region, the Mondial cultivar had a proportion of 48% of the total hectares planted, which comprised 23% for table or processed potatoes and 25% for seed potato production. A proportion of 19% of the BP1 cultivar was planted for table or processed potatoes and a proportion of 25% of the total hectares were planted for seed potato production (<http://www.potatoes.co.za>).

1.6 PROBLEM STATEMENT AND JUSTIFICATION OF THE STUDY

Potatoes are a significant vegetable crop in South Africa (<http://www.potatoes.co.za>). Potatoes are suitable for a variety of preparation or cooking methods (culinary applications),

namely baking, boiling, chips, crisps, mashing, microwaving, and roasting (Bennion & Scheule, 2000:323; Jansky, 2010:210). Microwaving is a rapid cooking method that requires a minimum amount of water with a minimal loss of quality (Brown, 2011:290).

In Denmark and other countries such as Australia, Britain and Norway a classification model is in place to guide the consumer with regard to the most appropriate culinary applications, based on the eating quality of the available potato cultivars (Thybo & Martens, 1998:453). It is important for a consumer to know what the culinary applications of a particular cultivar are. For example, a mealy potato is more suitable for baking purposes and a waxy potato more suitable for making potato salad.

With the exception of the study by Dalton (1981), there is currently little scientific information available to serve as a guide to the South African consumer with regard to the cultivar purchased and the most suitable culinary applications for each cultivar. Therefore, the need exists to determine the eating quality of potato cultivars available in South Africa in order to propose a classification model for the South African consumer.

1.7 JUSTIFICATION FOR A PROPOSED CLASSIFICATION SYSTEM FOR POTATO CULTIVARS

The classification system focuses directly on the consumer and it is therefore vital for the classification system to be informative and useful. The proposed potato classification system will be based on the eating quality of the potato cultivars. This proposed classification system will illustrate the different characteristics of the cultivars and their suggested culinary applications. Such a classification system would not only benefit the potato industry, but the South African consumer as well.

The possibility to propose a classification system for South African potato cultivars for the South Africa consumer was investigated. To initiate a proposed classification system, it is required that the cooking and eating quality of South African potato cultivars are determined and described. To reach this goal of developing a South African classification system for potatoes, a databank with relevant information on the different quality attributes (including both sensory and physical attributes) regarding each of these cultivars cultivated in the potato growing regions in South Africa, needs to be compiled.

This study is the first in a series to determine and describe the eating quality of potato cultivars from the various South African production regions. The eating quality of three selected potato cultivars from two production regions were determined, described and compared, using sensory and objective evaluation tests. The proposed classification system provides consumers with scientific-based information during the decision-making process to make an informed decision regarding a specific cultivar choice for its intended culinary application (use).

1.8 PRESENTATION AND STRUCTURE OF THE DISSERTATION

The written report of the research indicates how the research developed and unfolded. An overview on the factors influencing potato production in South Africa was provided in this chapter. A description of the second and ensuing chapters of the report is given.

CHAPTER 2: LITERATURE REVIEW

In Chapter 2 the salient concepts used throughout the study are introduced. The physical structure, chemical composition and factors such as the sensory attributes of potatoes which influence the eating quality, are briefly discussed.

CHAPTER 3: RESEARCH METHODOLOGY

The research design and methodology of the study is presented in Chapter 3. This chapter addresses the quantitative data-collection techniques used. A description of the data collection and analysis is presented. An experimental research design is followed in this two-phase study. Standardised techniques methods and procedures used in Phase 1 (sensory evaluation) and Phase 2 (objective evaluation) are described. Figures are used to represent the conceptual flow of the experimental procedures. In Phase 1, the sensory data was collected using descriptive sensory evaluation, while the data of Phase 2 involved objective measurements of the physical attributes.

CHAPTER 4: RESULTS AND DISCUSSION

The collected data was analysed statistically to produce descriptive sensory and objective evaluation results. The results of this study are presented and discussed in this chapter.

The presentation and discussion of the results are according to the two phases in which the study was conducted.

CHAPTER 5: PROPOSED CLASSIFICATION SYSTEM

A proposed classification system is presented in Chapter 5. Icons were developed and designed. Information on the proposed classification system, reasons for implementing this system and information on how this system operates are provided.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations for the study are presented. Possible future research in this field of study is indicated.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This study deals with the eating quality of selected potato cultivars. The eating quality of a potato is influenced by its physical and sensory attributes, which are determined by the potato's structure and chemical composition. These attributes are discussed including other contributing factors associated with its production. Factors that contribute to the post-harvest quality of potatoes receive attention, as well as the sensory attributes that affect the eating quality thereof. Measurements to determine and describe the sensory and physical attributes pertaining to the eating quality of potatoes are included in the last part of this review.

2.2 EATING QUALITY

The quality of agricultural products, according to Johnson and Hofman (2004:125), is defined as "involving all of the attributes, characteristics, and features of a product that the buyer, purchaser, consumer, or user expects." They further stated that quality assurance "involves those planned activities designed to consistently satisfy customer expectations by defining objectives, planning activities, and controlling variability." Quality is seen as a combination of characteristics that are critical in establishing a product's consumer acceptability, including fitness for use, freedom from deficiencies and provision of satisfaction. Another definition of quality as defined by the food industry, is that quality is an integrated measure of purity, flavour, texture, colour, appearance, and workmanship (Johnson & Hoffman, 2004:125).

Physical and biological characteristics of vegetables, such as maturity, weight, size, shape, pest/mechanical and physical damage/defects, cleanliness and freshness are used by farmers to define quality. However, consumers define quality not only according to the attributes described by farmers, but more specifically in terms of taste, freshness, cooking

characteristics, colour, timely delivery and consistent supply (Johnson & Hofman, 2004:130, 131).

Intrinsic and extrinsic properties of a product determine the quality thereof. The intrinsic product properties describe the state of the product against the quality criteria enforced by the producer or user of a product. During the decision-making process of the consumer, extrinsic product properties describe the price or quality-price ratio of a product. Additional information is used to decide whether to buy or not to buy the product. Quality is assigned to a product with an evaluation of the intrinsic properties thereof. Therefore, quality refers to the suitability of a product to meet the needs and goals of the user without referring to the extrinsic product properties. For example, a different criterion in selection will be used when selecting tomatoes to prepare a soup or salad. A high level of eating quality is placed on ripe tomatoes to prepare a soup and similarly a high level of eating quality is assigned to firm tomatoes to prepare a salad. Therefore, the opposite of a low level of eating quality will occur when using ripe tomatoes to prepare a salad (Tijssens, 2004:38).

The eating quality of potatoes is determined by both physical and sensory attributes. Physical attributes are those that deal with the structure of the potato (dry matter and specific gravity) as well as the chemical composition of the potato (for example the starch composition). The physical and chemical compositions of potatoes are influenced amongst others, by the production conditions that contribute to the overall quality and sensory attributes of potatoes (Charley, 1982:20, 21). These aspects are briefly explained below.

The cooked potato texture is closely associated with the eating quality of potatoes and has been associated with the dry solid content, specific gravity, amylose, sugars and proteins. Texture and flavour mainly determines cooking quality (Chiavaro, Barbanti & Vittadini, 2005:1). Textural differences between cooked potato cultivars are mainly due to the internal pressures that developed inside the cells resulting from the swelling of the gelled starch (Kaur, Singh, Sodhi & Gujral, 2002:177). Water absorption during cooking might lead to cell separation, reduced cohesiveness and softening (Nourian, Ramaswamy & Kushalappa, 2003:257).

Apart from texture, flavour also determines the eating quality of potatoes (Chiavaro *et al.*, 2005:1). These are the fundamental sensory attributes in consumer quality and acceptance evaluations of potato cultivars. Consumers commonly base purchasing decisions of a potato cultivar mainly on the desired textural qualities (McComber, Homer, Chamberlin & Cox, 1994:2433). A combination of flavour, texture and appearance qualities influence the

consumer preference of potatoes (Canet, Alvarez, Fernandez & Tortosa, 2005:481). From a consumer's perspective, an acceptable quality potato has a creamy, white colour, a moderately dry and mealy texture, and a good, natural potato flavour. The texture of cooked potatoes is of importance as it is one of the critical quality attributes in consumer evaluation (Thybo, Szczypinski, Karlson, Donstrup, Stodkilde-Jorgenson & Andersen, 2004:92).

According to Jemison, Sexton and Camire (2008:140), potato tuber colour and appearance are important factors that influence consumer decision-making. The most preferred culinary applications for fresh potatoes are baking, mashing or roasting potatoes. Research performed by Jemison *et al.*, (2008), illustrated that potatoes' skin quality is the most important characteristic influencing preference for whole white and yellow skin cultivars for consumers. Consumers want blemish-free potatoes, free of defects, and if possible, people are influenced by seeing the flesh colour of the potato (Jemison *et al.*, 2008:140, 148).

Numerous factors contribute to the eating quality of potatoes. In the next sections these factors namely the physical and chemical composition, potato production region and other aspects relating to potato production and post-harvest conditions are discussed.

2.3 PHYSICAL STRUCTURE AND CHEMICAL COMPOSITION OF A POTATO

The physical structure and chemical composition of a potato contribute to the eating quality of potatoes. These are briefly discussed.

2.3.1 Potato structure

Textural construction includes the macrostructure, microstructure and molecular structure (Jellinek, 1985:155). A potato tuber consists of several areas as depicted in Figure 2.1. These areas include the outside skin (periderm) that contains the lenticels, the eyes, the outer storage parenchyma grouped together as the cortex, the vascular ring, and the pith and inner storage parenchyma grouped as the medulla.

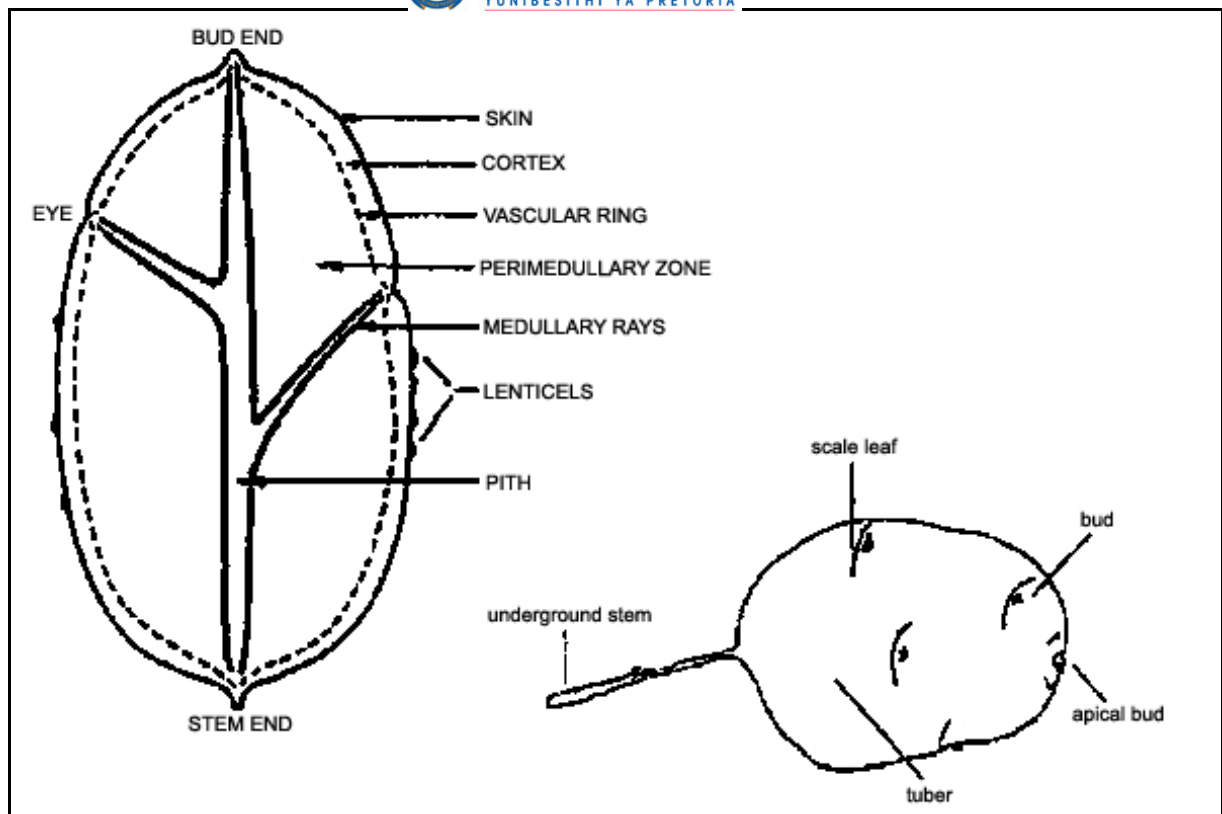


FIGURE 2.1: DIAGRAM OF A LONGITUDINAL SECTION OF A POTATO TUBER
(Rastovski, Van Es, Hartmans, Buitelaar, De Haan, Majers, Van Der Schild, Sijbring, Sparenberg, & Van Zwol, 1981)

2.3.2 Structure and chemical composition of cell wall material

The cell walls and middle lamella of potato cells typically consist of 60% pectin, 28% cellulose, 10% hemicelluloses and 2% glycoproteins. The pectic substances play a major role in intercellular adhesion and also contribute to the mechanical strength of the cell wall (Abu-Ghannam & Crowley, 2006:336). Based on observations made by Abu-Ghannam and Crowley (2006), the middle lamella breakdown, cell wall loosening, and starch gelatinisation are important factors determining texture. Differences in chemical composition of the middle lamella of various cultivars may therefore result in a distinct texture per cultivar (Van Dijk *et al.*, 2002a:5090).

Cell wall porosity and thickness are determined by pectin. Pectin plays an important role in maintaining tissue integrity as it is the main component of the potato cell wall. The pectic substances in potatoes determine the cell wall thickness. Porosity plays an important role in keeping the cells intact, especially with the intercellular cohesion (adhesion) between the

cells (Van Marle, Recourt, Van Dijk, Schols & Voagen, 1997b:1686). The cell size of the starch granules has an influence on the textural qualities of the potato. Large cells (45 μ g) tend to have a higher swelling power than smaller starch granules (15 μ g), that results in increased pressures in the potato. The increased pressures within the potato lead to cell separations, which increase the degree of mealiness of the potatoes (McComber *et al.*, 1994:2433). During the processing of potatoes, pectic material is degraded and partly solubilised into the cooking media. Important texture parameters, namely intracellular adhesion and the structure of the remaining cell walls, are greatly influenced by degradation (Van Marle *et al.*, 1997b:1686). Pectic polysaccharides from different parts of the potato cell walls illustrate differences in composition and structure. Pectic polysaccharides from the middle lamella are more easily solubilised than those present in the primary cell walls. When polysaccharides are solubilised with more harsh extractants, a higher ratio of neutral sugars to galacturonic acid is present. Comparing the cell wall material of a mealy and a waxy potato - the amounts of arabinose, rhamnose, mannose and xylose are slightly different between these two potato types (Van Marle *et al.*, 1997b:1686, 1688). According to Van Marle *et al.* (1997a:50), the extent of intercellular contacts and appearance of cell surfaces of mealy and non-mealy (waxy) potato cultivars are different. With the measurement of the solubilisation of pectic material, it was found that mealy potatoes release more pectic material, which is accompanied with more cell sloughing than non-mealy (waxy) potatoes (Van Marle *et al.*, 1997a:50).

In hemicellulose, a soluble fibre, the most common backbone monosaccharides are xylose, mannose and galactose; the most common side chains are arabinose, glucuronic acid and galactose. These are neutral sugars as they only contribute to the carbohydrate value and do not have an effect on the sweetness level (Whitney & Rolfes, 2002:99). The differences found between the pectic polysaccharides of cultivars may influence the solubilisation of pectic polysaccharides during the cooking of potatoes. During cooking, more branched pectic polysaccharides are solubilised for a mealy potato than for a waxy potato (Van Marle *et al.*, 1997b:1691, 1692).

Little is known about the differences and composition of pectic polysaccharides with respect to texture development during processing. Differences in yield and composition of pectic material were reported where the pectic material was extracted by sodium chloride (Van Marle *et al.*, 1997b:1686). In previous studies, potato cultivars showed sensitivities to pre-warming. With pre-warming, potato tissue is preheated at a moderate temperature of between 50-80 °C (Bartolome & Hoff, 1972: 266).

Cell walls of potato tubers contain many potato cells. The composition of potato cells is discussed in brief.

2.3.3 Composition of potato cells

Potato tubers consist of individual cells and starch grains are formed within these cells. Cellulose walls enclose the starch grains (Burton, 1966) within cells and surround individual cells. Figure 2.2 and 2.3 present a visual representation of potato cells and starch grains.

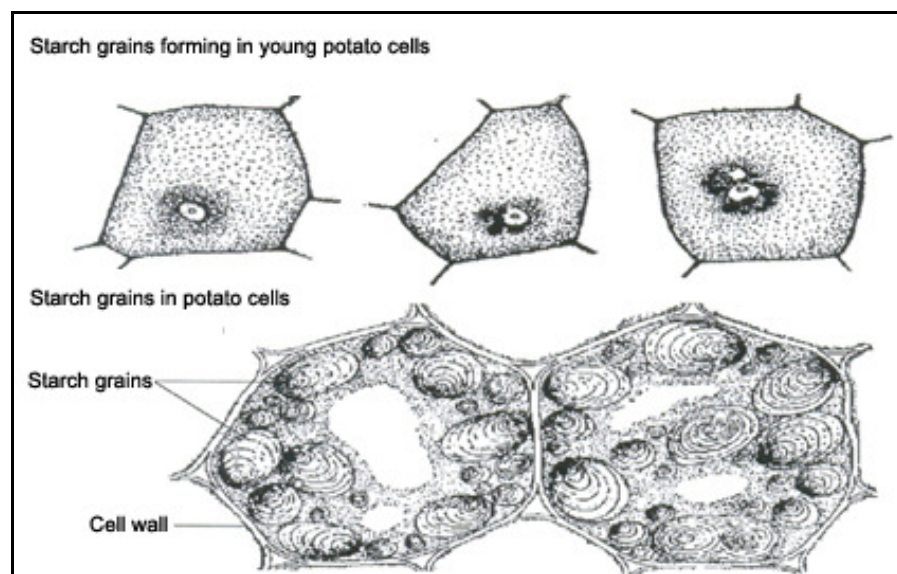


FIGURE 2.2: STARCH GRAINS FORMED INSIDE THE POTATO CELLS (Burton, 1966)

The composition and properties of the cell wall and the ionic composition influence the texture (Van Dijk *et al.*, 2002a:5083). Not only the size and amount of starch but also a number of other factors such as the rigidity and chemistry of the cell walls, the enzyme activity, minerals and water content and the heating process applied influence the texture of cooked potatoes (Povlsen, Rinnana, Van Den Berga, Andersen & Thybo, 2003:423). Water distribution in food plays a very important role and is relative to its texture (Thybo, *et al.*, 2004:91).

2.3.4 Structure and composition of potato starch grains

Starch is present as microscopic granules in the leucoplasts lining the interior of the cell walls of the parenchyma tissue (Tongsook, 2001:17). Figure 2.3 depicts starch grains in a raw potato cell.



FIGURE 2.3: STARCH GRAINS IN A RAW POTATO CELL

A raw potato tuber shows starch grains within cellulose cell wall compartments. The stored starch grains are called amyloplasts. Starch is synthesised from sucrose, a sugar formed in the leaves during photosynthesis and transported to the tuber via the phloem (vascular tissue). Potatoes' starch granules vary in size and the granule-size distribution of starch is tissue-dependent, although it is not clear if the granule-size distribution is cultivar-dependent. Starch grains are larger than most plant cells (<http://www.denniskunkel.com>).

2.3.5 Potato Starch

The starch content, pectic substances and cell size determine the potato cultivar. Starch contributes about 65-80% of the dry weight of the tuber (Tongsook, 2001:17). Textural qualities of potatoes must be described by both the starch content in the cells and the cell wall components. Dry matter content is highly associated with the texture of cooked potatoes (Thygesen, Thybo & Engelsens, 2001:470).

Starch is the predominant factor in determining the sensory-perceived texture of potatoes (Van Dijk *et al.*, 2002b:5096). The starch content is an important factor in potato texture, as this affects the way in which potato cells separate upon cooking. Textural properties of

cooked potatoes range from the sensory attributes of firmness to cohesiveness, in contrast to mealiness, sogginess, stickiness or gumminess and are caused by factors such as the starch content, pectic substances and cell size (Kaur *et al.*, 2002:177).

The amount of starch contributes to the texture. The more mature the tuber, the higher the starch content and the larger the starch grains (Thygesen *et al.*, 2001:472). A high starch content creates a dry texture synonymous with mealy potatoes, which disintegrates during boiling and mashing (Laza, 1999:21). Mealy potatoes contain a relatively large amount of starch that clearly diminishes the intracellular cohesion after cooking (Van Dijk *et al.*, 2002a:5089).

High content of pectins, divalent ions (calcium and magnesium), a high activity of pectin methyl-esterase and a low content of monovalent ions (potassium and sodium) and organic acids (citric acid and phytic acid) have been ascribed to favour the formation of pectic bonds between cells. These chemical characteristics are thus expected to be associated with high adhesion between the cells, high firmness/hardness and low mealiness that are associated with waxy potatoes (Thygesen *et al.*, 2001:470).

All plant seeds and tubers contain starch that is predominantly present as amylose and amylopectin (Paul & Palmer, 1972:690). These two starch components are discussed below.

2.3.6 The two main components of starch: Amylose and Amylopectin

The two main components of starch cells are amylose and amylopectin. Amylose and amylopectin are present in a ratio of 1:3, which seems to be fairly constant, but does increase with increasing granule size during maturation of the tuber. Amylose is a polydisperse polymer of α -1,4-linked glucosyl residues, with a slight branching, whereas amylopectin is a branched-chain glucose polymer in which the α -1,4 linkages are branched by α -1,6 linkage every 20 glucosyl residue on average. Negatively charged phosphate groups are present in potato starch. These phosphate groups partly contribute to the high degree of swelling in potato starch granules in the presence of moisture (Tongsook, 2001:17).

2.3.7 The process of starch gelatinisation

A raw starch granule is composed of α -linear (amylose) and branched (amylopectin) starch molecules. The molecular structure of amylose (Figure 2.4) and amylopectin (Figure 2.5) are presented.

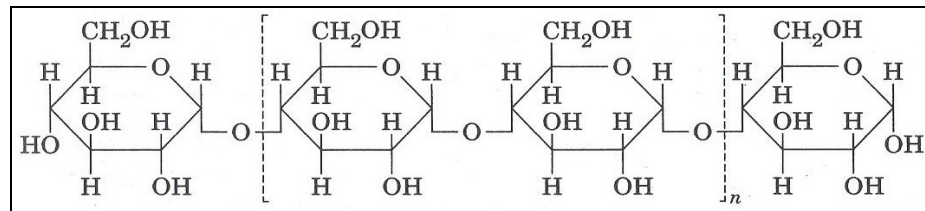


FIGURE 2.4: MOLECULAR STRUCTURE OF AMYLOSE: STRAIGHT-CHAIN, SLIGHTLY SOLUBLE STARCH FRACTION, JOINED TOGETHER BY 1, 4- α -GLUCOSIDIC LINKAGES (Charley, 1982)

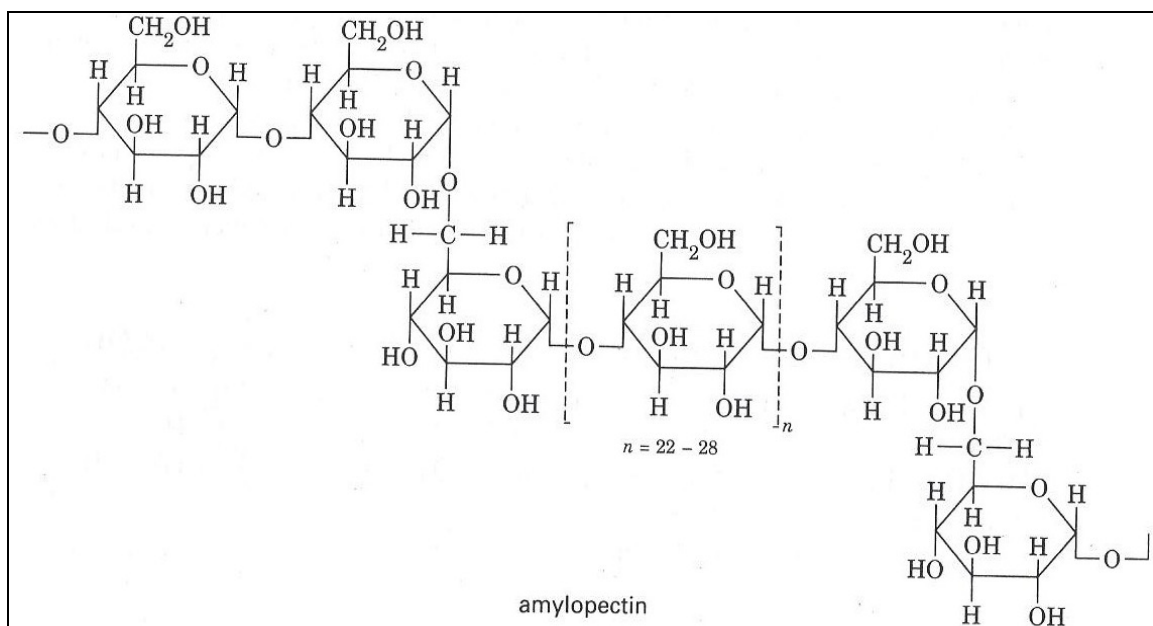


FIGURE 2.5: MOLECULAR STRUCTURE OF AMYLOPECTIN: BRANCHED FRACTION OF STARCH LINKED WITH 1, 4- α -GLUCOSIDIC LINKAGES BUT OCCASIONALLY INTERRUPTED WITH 1, 6 LINKAGES (Charley, 1982)

Starch molecules are associated with hydrogen bonding, either directly or through water hydrate bridges. This weakens the micellar network within granules by disrupting hydrogen bonds and allows water molecules to attach to the hydroxyl groups (Tongsook, 2001:19).

When an aqueous suspension of starch is subjected to heat, gelatinisation occurs when the water temperature is raised to above 50 °C, water passes from the non-starchy parts into the starch granule of the potato. The ratio of amylose and amylopectin, the two main fractions of the starch granule, influences the gelatinisation temperature of starch. The properties of the gelatinised starch are determined by the cooking time, temperature and the relative amount of starch and water present (Burton, in Tongsook, 2001:19). Figure 2.6 presents ungelatinised starch grains, that refers to amylose indicated at (a) and gelatinised starch grains, namely amylopectin indicated at (b).

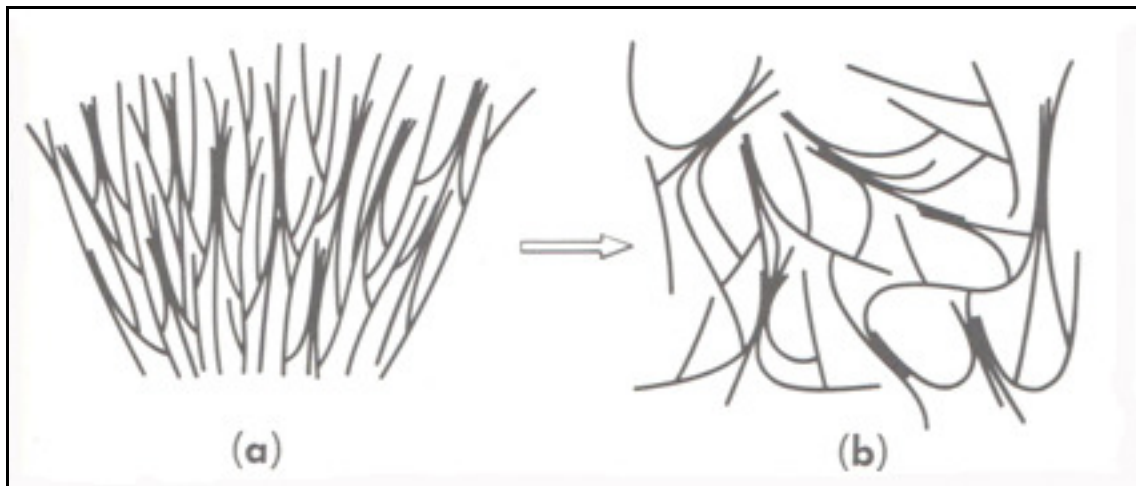


FIGURE 2.6: UNGELATINISED STARCH GRAINS IN (a) AND GELATINISED STARCH GRANULES IN (b) (Charley, 1982)

Due to a potato's high starch content it absorbs water as it cooks resulting in starch gelatinisation (Charley, 1982:501). Generally, starch gelatinisation occurs over a range of temperatures (Laza, 1999:24). Starch begins to gelatinise in the range of 64-71 °C (Campbell, Penfield & Griswold, 1980:288; Tongsook, 2001:19). Starch granules with the lowest gelatinisation temperature usually swell quickly, so that a smaller quantity of water will be available for the swelling of granules with higher gelatinisation temperatures (Laza, 1999:25).

The most important physical changes following gelatinisation is granule swelling. Potato starch exhibits exceptionally high swelling, unlike cereal starch. This is partly due to the presence of ionisable, esterified phosphate groups (Tongsook, 2001:19). When heated potato tissue cools, the crystallinity of the starch molecule lost during gelatinisation is partially regained during cooling. This phenomenon is known as starch retrogradation (Laza,

1999:25). Textural changes in cooked potatoes are mainly associated with the gelatinisation and retrogradation behaviour of starch (Kaur *et al.*, 2002:177).

Mealiness and waxiness are descriptors to categorise potatoes. When a potato is classified as mealy, it tends to separate very easily into fluffy particles that feel dry when cooked in the presence of water and it has a high amount of amylose, high density and a high starch content. Amylose is easily soluble in water and forms a slightly viscous solution (Hassid & McCready, 1943a:1154). Mealy potatoes have higher specific gravities, starch and amylose contents, as well as a higher percentage of large starch granules (diameter>50mm) than the waxy cultivars. It has been reported that tuber fragments with a higher starch content, cook softer than those containing less starch (Kaur *et al.*, 2002:177). Baking and mashing are the most appropriate cooking methods for this type of mealy potato (Bennion & Scheule, 2000). Waxy potatoes on the other hand are more compact and have a moist texture. Amylopectin fragments have a compact, branched shape that remains connected when cooked and helps the cell walls to stay intact (<http://www.cooksillustrated.com>; McWilliams, 2000:163). Potatoes that have a lower starch content than mealy potatoes will not easily separate into particles (Bennion & Scheule, 2000). Waxy potatoes are suitable for boiling and preparing potato salads.

Textural properties such as moistness and mealiness are sensory sensations. A moist mouthfeel does not necessarily relate to the moisture or starch content of the raw potato, but it is probably related to the activity of amylolytic enzymes during the cooking process. According to Van Oirschot, Rees and Aked (2003), a dry mouthfeel correlates with the remaining starch content after the cooking process.

2.3.8 Dry matter content

Dry matter describes the amount of material left after all water is removed from the potato. The dry matter content of potato tubers consists of various substances such as starch, sugars, nitrogen compounds, lipids, organic acids, phenolic compounds, mineral substances and non-starch polysaccharides. The starch content is the largest component of dry matter in potatoes (60-80%). Dry matter is an important quality parameter for potatoes (Laza, 1999:8, 25). Duration of growth is one of the main determinants of the total dry matter produced by crops (Mazurczyk, Lutomirska & Wierzbicka, 2003:173).

Crisps obtained from potatoes with a high dry matter (above 25% content) can exhibit hard textures, but crisps prepared from potatoes with a too low specific gravity (low in dry matter), absorb more oil, and are characterised by a greasy and sticky texture (Kita, 2002:173). Dry matter content of raw potatoes provides valuable information on the sensory texture of the potatoes after boiling (Thygesen *et al.*, 2001:475). Mealy potatoes tend to have a higher dry matter content than waxy potatoes (Kaur *et al.*, 2002:179). Potatoes with a low dry matter, irrespective of the cultivar, are always moist and sticky, never crumbly and grainy. The lower the dry matter content of potatoes, the firmer and less mealy they are. Potatoes with a high dry matter content are always crumbly and grainy, never moist and sticky. Thus, the dry matter content determines the perceived sensory texture of steam-cooked potatoes (Van Dijk *et al.*, 2002b:5086, 5088, 5096).

2.3.9 Effect of structural properties on texture

Texture is of utmost importance to the consumer's perception of potato quality. The sensory textural quality of cooked potatoes assists in categorising potatoes in relation to their final eating qualities into a classification system. The biological variation between potato tubers of the same cultivar is high and is known to influence the texture of cooked potatoes (Thybo *et al.*, 2004:92).

Texture is an expression of the structural, physical and mechanical properties of plant tissue. It is a fundamental quality factor of both fresh and processed foods. The structural and textural features support, facilitate and affect vital biological processes of the plant. Texture is a consequence of the relationships between the structural insoluble components and soluble chemical constituents (<http://www.old.agri.gov.il>). The texture profile is divided into mechanical, geometrical and moisture dimensions.

The mechanical properties include the sensory attributes of hardness, cohesiveness, adhesivity, density and viscosity, fracturability, chewiness and gumminess that refer to the hardness and connection of particles. Geometrical features include the particle size, hardness and the fibre orientation (Jellinek, 1985). Dry matter is closely associated with the texture of cooked potatoes. Mechanical stress (damage) deteriorates the sensory quality of potatoes in the moisture dimensions. Mechanical damage involves moisture loss of potato tubers. When the potato skin has not developed fully, it tends to damage easily and this contributes to moisture loss (Niederweiser, 2003:17).

Measurement of the dry matter content of potatoes is not adequate to forecast the taste and the sensory quality of the potato (Van Oirshot *et al.*, 2003). The dry matter content is not the only contributing factor to the mealiness of potatoes, it is associated with an increase in polarised cell walls and larger, more irregular-shaped cells, engorged with gelatinised starch after cooking (Thybo, Bechmann, Martens & Engelsens, 2000:103, 106; Van Oirshot *et al.*, 2003).

The swelling nature of a given cell wall affects texture. The swelling of a cell wall is a dominant factor, but in the tissue, it is additional to intercellular adhesion. The texture of some soft parenchyma tissues is prominently hardened by strengthening of the intercellular adhesion. If the tissue becomes clear, the intercellular adhesion is more prominent (<http://www.old.agri.gov.il>).

2.4 FACTORS INFLUENCING POTATO PRODUCTION, YIELD AND QUALITY

Agricultural production, including potato production depends on factors such as soil potential, climate, topography, water supply, nature and the sustainability of current production methods. Potato production in South Africa is mainly under irrigation. Potatoes are planted in regions with a temperate climate and with proven reliable summer rainfall, such as in the Mpumalanga Highveld and Eastern Free State region (<http://www.nda.org>). Dry-land production comprises approximately 27% of the total area planted but contributes only 17% towards total production (<http://www.nda.org>). The yield per hectare increases from dry-land production to irrigation, leading to a higher yield per hectare for irrigated potato production (<http://www.potatoes.co.za>; Chips, 2008:18).

2.4.1 Soil conditions

In South Africa, potatoes are cultivated in different regions under widely diverse conditions. Potatoes grow well on a variety of soil types, but not all soil types give optimal yields of good quality.

Several physical and chemical factors have to be considered when selecting soil for the cultivation of potatoes. A well-drained sandy loam soil of light to medium texture is preferred for potatoes. However, sandy soil has limited water-holding capacity and will only produce

good yields if the rainfall is adequate or if adequate irrigation is available. A minimum soil depth of 600 mm is required (Niederweiser, 2003:83). Cool regions where mean temperatures not normally exceed 18 °C are more favourable. Optimum soil temperature for potato growth and development ranges between 15 °C and 25 °C (Patel & Rajput, 2006:211).

A number of factors, for example the crop type, soil type, degree of compaction and moisture status, drought and waterlogging affect the crop yield. However, the major factor is rooting volume. As rooting volume increases, so will the ability of the plant to take up both the water and mineral elements necessary for plant growth and tuber formation (White, Wheatley, Ammond & Zhang, 2007:749).

2.4.2 Mineral requirements for potato soil

Plants require over 14 essential mineral elements that include both macronutrients (calcium, nitrogen, phosphorus, potassium, magnesium and sulphur) and micronutrients (iron, manganese, boron, zinc, copper and molybdenum). These mineral elements, in their ionic form, are acquired from the soil. Limits for these minerals need to be maintained for adequate nutrition and to avoid mineral toxicity levels (White *et al.*, 2007:740, 742).

Plant growth rates and nutrient availability in the soil influence the pattern and magnitude of nutrient uptake, and accumulation and partitioning of dry matter into different parts of the plant. Variations in climatic factors contribute to differences in growth patterns, and thus production potential. Early season potato varieties allocate a larger part of the available minerals to the tubers early in the growing season compared to late season varieties. This, in turn, explains the shorter growth period and lower yields of early season as compared to the late season varieties. Adequate nutrient availability and uptake to support maximum growth rate of plants are important to attain optimal production (Alva, Hodges, Boydston & Collins, 2002:1622).

2.4.3 Optimising the mineral acquisition and utilisation

Fertilisers are added to poorly developed root system within the soil to enhance the potential growth and tuber quality. The amount of fertiliser required for maximum yields will depend on environmental factors such as soil type, soil mineral concentrations and weather

conditions and agronomic factors such as longevity, growth rate and tissue mineral requirements of a potato variety. On the other hand, excessive fertiliser applications will lead to a reduced yield, mineral toxicities and environmental pollution (White *et al.*, 2007:740-742).

In most production regions, producers have succeeded in fine-tuning their fertilisation programmes to optimise yield and quality. Fertilisation guidelines based on the requirements of the potato crop and the nutrient content of the soil are readily available in South Africa (Niederweiser, 2003:71-73).

2.4.4 The process of tuber formation

The potato tuber is morphologically a modified stem with nodes and internodes (<http://www.hortweb.edu>). Tuber formation includes tuber induction, tuber initiation, tuber set, tuber bulking and tuber maturation (Struik, 2007:377). Tuberisation is a complex phenomenon and a myriad of variables such as nutrition, environment, mother tuber, genetics, leaf area, partitioning of assimilates, photoperiod, temperatures and nitrogen nutrition influences it (<http://www.hortweb.edu>; Ozygen & Palta, 2004:102). With increasing nitrogen availability, coincident with tuberisation, the vegetative growth period may be extended and tuber development delayed, which will both lead to a reduced yield. In contrast, increasing the nitrogen availability later in the season will delay the tubers' maturity, with detrimental effects on yield and tuber quality (Maggio, Carillo, Bulmetti, Fuggi, Barbieri & De Pascale, 2008:348).

The process when tubers are initiated on underground rhizomes, called stolons, is called tuber initiation. These stolon tips undergo swelling and elongation. The first biochemical sign of tuberisation is starch deposition. Following the deposition of starch, growth and development of the tuber into marketable sizes, occur by both cell division and enlargement. The tuber growth-period involves tuberisation and an increase in the dormancy during the process of tuber maturation (<http://www.hortweb.edu>; Struik, 2007:377).

2.4.5 The effect of temperature on tuber formation and growth

Temperature is one of the most important variables affecting the plant environment (Wang, Li & Wen-Quan Shi, 2005:190, 192). It affects crop growth and yield in different ways.

Photosynthesis, respiration, organ initiation and their relative growth, dry matter production and its distribution are dependent on temperature. A crop passes through successive phenological development stages and the length of these stages depends on the development rate, which is modified by temperature (Mazurczyk *et al.*, 2003:169).

Temperatures affect the process of tuber formation. The plant translates the environmental and internal signals for readiness of tuber formation. High temperatures delay, impede or inhibit tuberisation compared to lower temperatures. High temperatures can cause abnormal tuber behaviour, for example a reduction in starch content and an increase in sucrose content. The dry matter content may be low at high temperatures. Low temperatures above freezing cause the change from starch into sugars. When the carbohydrate metabolism of potato tubers experiences a cold-induced effect due to low temperatures, the level of sweetness of the potato tuber is affected. Supra-optimal temperatures may cause low dry matter concentrations which results in reduced tuber quality (Struik, 2007:381, 382).

2.4.6 Potato tuber yield and quality

Genetic variability and environmental determinants affect potato yield and quality (Maggio *et al.*, 2008:343). Maximum potato tuber yields occur when an active plant canopy is maintained until normal plant maturation. Plant nutrient concentrations and uptake rates play a major role in maintaining an active plant top (Westermann & Kleinkopf, 1985:490).

Tuber number and size distribution, dry matter content and nutrient composition are yield parameters that may greatly differ among cultivars. Tuber quality and prospective growth are affected by insufficient mineral concentrations (White *et al.*, 2005:740, 742). Tuber yield is thus influenced by cultivar, irradiance, photoperiod and temperature (Struik, 2007:380, 381).

2.4.7 The effect of a water deficiency and water stress on potato yield

Water is an increasingly scarce resource worldwide, due to factors such as an increased demand for consumption, mismanagement and pollution. Irrigated agriculture is a major consumer of water and accounts for about two thirds of the total fresh water diverted to human use (Costa, Ortuno & Chaves, 2007:1423). Successful potato production depends on sufficient water supplies during the crop's growing season. The moisture content of the plant tissues is 90-95% while the moisture content of tubers range between 70-85%

(Niederweiser, 2003:84). A potato is often considered a high water usage crop (Shock, Pereira & Eldredge, 2007:30).

Potatoes are very susceptible to water deficit. Potato plants are very sensitive to moisture stress because their root system is relatively sparse. Uptake of water by plant roots causes soil drying and subsequent increased soil water tension. On hot and sunny days, well-irrigated potato crops undergo some water stress, which affects the potato yield. Insufficient water leads to high soil moisture tension, plant stress and reduced crop yields (Patel & Rajput, 2006:210).

However, a moderate water shortage has proven to improve tuber biomass and quality. In potato, as well as most crops, water stress impairs the photosynthetic activity and consequently leads to reduced development (Maggio *et al.*, 2008:343). Water stress causes reduction of yield by reducing growth of crop canopy and biomass. This sensitivity to moisture stress can lead to dramatic fluctuations in yield due to frequent drought and poor irrigation management (Kang, Wang, Liu & Yuan, 2004:133).

2.5 POTATO PRODUCTION REGIONS

A production region is defined as an agricultural area that is subjected to certain environmental conditions. In South Africa, potatoes are grown in different seasons, in either an irrigated or dry-land region. Two main types of potato production methods occur in South Africa, namely dry-land and irrigated potato production. Each of these methods is briefly discussed.

2.5.1 Dry-land potato production

Dry-lands are usually defined in climatic terms as lands with inadequate rainfall and characterised by low (100-600 mm annually), erratic and highly inconsistent rainfall levels. The main characteristic of dryness is the negative balance between annual rainfall and evapo-transpiration rates (IFAD, 2000). Rainfall is scarce, unreliable and concentrated during a short rainy season, with the remaining period tending to be relatively dry (FAO, 2003). Dry farming is a profitable production of crops, without irrigation, of land with a low average or highly variable rainfall. To obtain maximum storage of moisture under any rainfall

condition, the soil must absorb as much water as possible when it rains, and losses by evaporation or transpiration should be kept to a minimum. Rainfall must be higher than 250 mm per year. Soil should be deep (preferably three meters) with no clay, sand, or gravel seams to interfere with capillary movement of water. The minimum feasible soil depth is 450 mm but water storage capability and drought resistance increase with increasing soil depth (Creswell & Martin, 1993:8).

2.5.2 Irrigated potato production

An irrigated region implies the provision of water or wastewater to land areas by artificial means (i.e. sprinklers) to supply in the water and nutrient needs of potatoes (<http://www.frtr.gov.htm>; <http://www.hcs.ohio-state.edu.htm>).

Irrigation is defined as supplying water to agriculture by artificial means, such as pumping water through pipes or channels onto crops, in order to assist in growing of crops in an area where rainfall is insufficient (Brown, 1907:1). The primary aim of irrigation is to complement the water available for crop production from natural sources, such as rainfall, dew, flood and ground water that seep into the root zone. Soil moisture needs to be conserved to increase soil fertility, control weeds and improve the soil's physical condition (Fasina, Awe & Aruleba, 2008:61; Josiah, Ayotamuno, Zuofa, Ofori & Kogbara, 2007:520). Irrigation requirements differ with locations, soil types and cultural practices. The number of irrigation intervals is dependent on the rainfall distribution and may differ from one season to another. Under the condition of limited water supply, higher benefits may be achieved by adopting suitable irrigation and planting techniques (Onder, Caliskan, Onder & Caliskan, 2005:76). Irrigation increases yields, the tuber number and the mean weight of the tubers, but decreases the potato tuber quality. The specific gravity of potato tubers tend to decrease as the water applied increases (Yuan, Nishiyama & Kang, 2003:153).

2.6 FACTORS THAT INFLUENCE POST-HARVEST QUALITY

Various factors have an influence or effect on the post-harvest quality of potatoes. These factors include sprouting, handling methods, storage time and temperature, formation of solanine, dry matter content and specific gravity. These factors are briefly discussed.

2.6.1 Sprouting

During tuber dormancy, no sprouting takes place. The rest period depends on the cultivar, the maturity of the tubers, soil and climatic conditions during growth and conditions during storage (Niederweiser, 2003:19). Dormancy of the tubers must be broken before sprouts can be formed. The duration of dormancy in a tuber is largely determined by the accumulation of heat units. However, the number of heat units for sprouting differs from one cultivar to another. Once dormancy is broken, the buds on the tubers develop to form sprouts. Dark and warm conditions and a high humidity promote sprouting. At this stage, the tubers are ready for planting (Niederweiser, 2003:19). Tuber starch is utilised for sprout growth, resulting in a decreased starch content and the associated sweetening of sprouting tubers.

2.6.2 Handling methods

Impact damage is a major problem in the potato industry, as potatoes have to be handled with care. Impact damage manifests in two major bruise types, namely blackspot and shatter bruising. Tuber impact sensitivity determines whether a given impact will cause a bruise. With proper conditioning and handling the amount of potatoes that are wasted, could be reduced (Baritelle & Hyde, 2003:279). The eating quality of potatoes decreases with improper handling methods.

2.6.3 Storage temperature and time, dry matter content and specific gravity

Storage temperature and duration, dry matter content and specific gravity are major contributors to the variation in the sensory attributes of the potato. Differences in aroma are determined by cultivar and storage (Thybo, Christiansen, Kaack & Petersen, 2006:173). Time and temperature are the two main factors that affect the sugar content in potatoes after harvesting.

During prolonged storage, the starch content of potatoes decreases, while the sugar content increases (Laza, 1999:17; Charley, 1982:493). However, if potatoes are stored at high temperatures (15-20 °C) the ratio of starch to sugar content increases due to increased respiration and conversion of sugars (Laza, 1999:17). Varieties with low specific gravity accumulate more sugar than varieties with high specific gravity (Burton, 1989 in Laza,

1999:12, 18). Starch grains decrease in size and show less gloss. Potatoes with a low starch content, have a relatively higher water content in the cells (Thygesen *et al.*, 2001:473).

Storage conditions can play a vital role in determining the cooking quality of the potato tuber. With prolonged storage, potato tubers are subject to both physiological changes and water losses. Physiological changes affect the integrity of the structural components of the potato cell (membranes, middle lamella, cell walls), while water losses lead to a drop in turgor pressure. Cell wall modifications and turgor changes affect the physiological properties of potatoes. Throughout the storage period the turgor pressure will slightly decrease, while specific gravity will slightly increase. Cell moisture content and its effect on turgor pressure affect tissue physiological properties more dramatically than the changes associated with ageing (Laza, Scanlon & Mazza, 2001:1, 2).

The dry matter content and the specific gravity of potatoes are related. With ageing, the average size of the starch grains and the percentage of amylase increase. Starch of mature potato tubers, accordingly with larger starch grains, gelatinise at a lower temperature (Paul & Palmer, 1972:264). Higher specific gravities, starch and amylose content as well as a higher percentage of large starch granules are associated with mealy potatoes (Singh, Kaur, Ezekiel & Guraya, 2005:1275)

As related to table potatoes, consumers should purchase smaller bags of potatoes more frequently and use them over a shorter time for a better quality potato. Any abnormal discolouration or softening could cause the consumer to reject the product (Nourian *et al.*, 2003:257).

2.6.4 The formation of solanine

With excessive exposure to light, the skin of the potato turns green due to the chlorophyll formation. Simultaneously the substance solanine, an alkaloid, is produced. Solanine results in giving the potato a bitter taste, and if taken in large amounts, can cause illnesses (McWilliams, 2000:506). Potatoes need to be stored in a cool, dark place to avoid sprouting and/or the formation of solanine that will result in an overall reduction in the physical quality of the potatoes.

2.7 CULINARY APPLICATIONS

Cooking of food (Nisha, Singhal & Pandit, 2005) improves digestibility, palatability, gives microbial safety and changes the texture of the product. According to Talburt (1987), the properties of starch and the changes in these properties during cooking explain the variations in texture and thus the eating quality in vegetative food products such as potatoes.

Cooking method or culinary application refers to the preparation of food with the application of heat. Cooking methods are divided into two categories, namely dry heat cooking and moist heat cooking. Dry heat cooking refers to any cooking technique where the heat is transferred to the food item without using any moisture. These cooking methods refer to baking, roasting and frying. On the other hand, moist heat cooking methods include any techniques that involve cooking with moisture - whether it is steam, water, stock, wine or some other water-based liquid. Therefore, moist heat cooking methods include boiling, steaming or poaching. Boiling has an influence on the cooking quality and thus eating quality of potatoes and affects the gelatinisation process of the starch molecules in the potatoes, and consequently the textural components of potatoes.

Generally, the eating quality standard for a cooked potato is a white flesh with a flaky to mealy texture. Waxy potatoes have a moist and washed-out texture due to the high moisture but low starch content. These potatoes stay firm and keep their shape during boiling. In contrast, mealy potatoes have a dry texture because of a low moisture but high starch content. During boiling, these potatoes will slough or break up easily (Chips, 2010:46, 47). The ideal eating quality of baked, mashed and boiled potatoes refers to the characteristics of a mealy and moderately dry-to-dry texture, a creamy white colour and a natural but significant potato flavour. Boiled potatoes should, however, ideally be free from excess sloughing. In baked potatoes, a crispy skin and fluffy texture is desired (Kirkpatrick, 1953:52). Dry heat with roasting normally causes the Maillard browning reaction or caramelisation to the outer skin of a potato. A soft and moist cooked potato texture results from microwaving and due to the internal pressures from unvented steam in a microwaved potato, a crisp skin is not generally produced. French fries (chips) and crisps are produced from thin slices of potatoes that are deep fried or baked until crispy (Pedreschi & Moyano, 2005:557, 558). A pleasant golden colour, a good flavour, a characteristic texture and a fried potato aroma are associated with French fries (Golubowska, 2005:847).

Various sensory attributes affect the eating quality of potatoes. These attributes refer to the attributes of texture, flavour, aroma, appearance, colour and after-taste. These sensory attributes are briefly discussed.

2.8 SENSORY ATTRIBUTES THAT AFFECT THE EATING QUALITY OF POTATOES

Specific sensory attributes contribute to the eating quality of potatoes. The sensory attribute of texture is discussed first, followed by the sensory attributes of flavour, aroma, appearance, colour, taste and after-taste.

Texture is defined as the way in which the structural components of a food are arranged in a micro- and macrostructure and the external manifestations of this structure (Nisha *et al.*, 2005:1). It refers to the structural, mechanical and surface properties of foods. It is derived from the structure of food that provides orientation to complex textural characteristics that are detected through the senses of vision, hearing, touch and kinaesthesia. In order to develop an understanding of the perceptual interplay among texture parameters and between textural properties (Szczeniak, 2002:215, 217), modalities such as visual cues and taste is required, to explore the breakdown pathways in the mouth.

It describes a substance's tissue structure and is the composite of those properties that arise from the physical structural elements and the manner in which it registers with the physiological senses (Jellinek, 1985:156). McWilliams (2000:40) refers to texture as the "mouthfeel of the food" and includes all the textural qualities of a food as experienced or perceived in the mouth. Texture is one of the most important quality attributes of potato tubers and is a quality attribute that contributes to the enjoyment and acceptance thereof. It does not only influence a consumers' preference, but also contributes to the release of volatile flavour components during chewing (Jansky, 2010:212). Therefore, in modern sensory evaluation, texture is characterised by detailed subdivisions of perceptible and pressure sensations as perceived through biting, chewing and swallowing (Jellinek, 1985:156).

Potatoes are very versatile and therefore have many culinary applications. Factors such as the dry matter content, specific gravity, amylose, sugars, protein, and nitrogen levels in tubers determine a potato's texture. The culinary uses of potato cultivars relate to their texture, for example those developed for boiling, retain their shape during cooking. Size and

structure of starch grains in raw tuber tissue is an important component of texture. As the starch gelatinises during cooking, pressure is created within the cells as it expands. Tuber moistness is therefore influenced by the proportion of tuber cells filled with gelatinised starch. A mealy texture is associated with cells filled with gelatinised starch, while the potato tubers with less starch and more loosely-held water represent a waxy texture. A moist mouthfeel is produced upon chewing the loosely held water in the latter cell type in contrast with a dry mouthfeel where the gelatinised starch in the mealy types retains water. Tubers given high mealiness scores by taste panelists were found to contain more starch and have larger cells than less mealy tubers (Jansky, 2010:212, 213).

Texture is influenced by the cell wall characteristics. Firm tissue is created during cooking by cross-linking pectin in the middle lamella with pectin methyl esterase activity. The cell wall density and the degree of solubilisation of the middle lamella and cell walls vary in cultivars but is determinant of a potato's texture. A hard, particulate mouthfeel represents thicker cell walls and middle lamella, and stronger pectic substances that may be more resistant to shear (Jansky, 2010:213).

Potatoes have a variety of preparation or cooking methods that include baking, boiling, mashing, microwaving, and roasting (Bennion & Scheule, 2000:323). Consumers' expectations are based on the intended use of the potatoes, whether a waxy or a mealy textured potato is desired. Texture has quality associations of freshness (limp lettuce, shriveled apples and stale bread are not considered fresh) and excellence in food preparation. Soft textures create health concerns but other sensory cues such as odour are indicative of spoilt food (Szczesniak, 2000:26).

Flavour is an important indicator of food quality. Flavour includes the four basic taste qualities of food, namely sweet, sour, salty and bitter, as well as aroma, which is perceived through tasting. It is the total impression of taste, odour, tactile, kinaesthetic, temperature and pain sensations perceived through tasting (Jellinek, 1985:159). A cooked potato flavour and an earthy potato flavour are important indicators of freshly cooked potatoes for consumers and second most important attribute when selecting potatoes (Jansky, 2010:210).

Flavour is produced through the interaction of a combination of three major sensory attributes, namely taste, aroma and tactile sensations (physical stimuli) (Jellinek, 1985: 159). Potato flavour is therefore determined through taste that contains non-volatile compounds; aroma that contains volatile compounds and texture that determines the mouthfeel of the potato. Aroma compounds primarily determine potato flavour, although certain non-volatile

compounds such as sugars and amino acids serve as precursors for the formation of thermally produced volatiles, which could act as flavour potentiators (Thybo *et al.*, 2006:174). Flavour compounds are produced through plant genotype, production environment and storage environment. These influence the level of aroma compounds and the enzymes that react with them to produce flavour compounds. Raw potatoes contain mainly sugars, amino acids, RNA, and lipids. Potato plants synthesise flavour precursors. These precursors react to produce the Maillard reaction compounds including sugar, lipid and RNA degradation products during the cooking process that contribute to flavour. The flavour intensity of raw potato decreases during storage. Potatoes with the smallest initial amount of free fatty acids oxidised the most, while the material containing the most unsaturated free fatty acids is less oxidised during the storage (Hallberg & Lingnert, 1990:206, 208, 209; Jansky, 2010:209).

TABLE 2.1: COMPOUNDS REPORTED TO HAVE A STRONG IMPACT ON COOKED POTATO FLAVOUR (Jansky, 2010:211)

Compound Origin Flavour	Compound Origin Flavour	Compound Origin Flavour
2,-4-decadienal lipid degradation earthy, fatty	Lipid degradation	Earthy, fatty
c4-heptenal lipid degradation cold boiled potato	Lipid degradation	Cold boiled potato
1-octen-3-ol lipid degradation earthy, mushroom	Lipid degradation	Earthy, mushroom
Alkyl pyrazines Maillard reaction/sugar	Maillard reaction/sugar degradation	Earthy, roasted, nutty, buttery
Decanal Maillard reaction/sugar	Maillard reaction/sugar degradation	Fruity, fatty, floral
2- and 3-methylbutanal Maillard reaction/sugar	Maillard reaction/sugar degradation	Fruity
Phenylacetaldehyde Maillard reaction/sugar	Maillard reaction/sugar degradation	Green
Terpenes (α -copaene, β -	Raw tuber	Fruity, floral
Methoxypyrazines	Raw tuber/soil microbes	Musty, earthy
Methional	Sulfur amino acid	Cooked potato
Dimethyl trisulfide, Dimethyl disulfide	Sulfur amino acid	Cooked onion

Aroma is a distinctive, yet intangible quality attribute perceived by the olfactory sense. It is the total odour impression received through the olfactory receptors (Jellinek, 1985: 159). A strong, usually pleasant smell and is of significant importance when food is served. The overall acceptability of the product is dependent on the appropriateness of the aroma of the food. For example, when potato tuber tissues are sliced and/or heated, aroma compounds

develop. Hundreds of aroma compounds are produced with cooked potatoes. Lipid degradation and the Maillard reaction and/or sugars produce the most important aroma compounds during heating. Sugars and amino acids are thus important in the development of flavour compounds in chips (Jansky, 2010:211, 212).

At high baking temperatures potato tubers produce a complex array of volatile compounds, including lipid degradation products, Maillard reaction products, sulphur compounds, and methoxypyrazines. The Maillard reaction, together with pyrazines, produces the most important and characteristic components of a baked potato flavour. Therefore, a strong positive relationship exists between pyrazines and organoleptic quality in both baked potatoes and potato chips. Water loss in boiled potatoes is minimal compared to baked potatoes. The interior of boiled potatoes warms quickly but the tuber temperature never exceeds 100 °C. The major aroma components of boiled potatoes are derived from lipid degradation, the Maillard reaction, and the degradation of methionine. The amino acid methionine intermediates with the Maillard reaction and Strecker degradation reaction that produces methional, a major aroma compound. Different levels of methional vary among cultivars and production environments. When tissues are disrupted during slicing in preparation for boiling, more opportunities are provided for lipoxygenase to come into contact with its substrates. A lipid oxidation product, c4-heptanal, is another important contributor to a boiled potato aroma, which produces an earthy aroma at low levels. Respectively, an off-flavour in potato flakes and boiled potatoes is produced with lipid oxidation products after they are refrigerated (Jansky, 2010:211, 212).

Tuber temperature increases consistently in all parts reaching 100 °C within a few minutes of each other with microwaving. In comparison, with oven baking, the potato skin remains cooler than the interior of the tuber due to evaporative cooling. Therefore, the rate of water loss is higher in baked potatoes, as no crust develops due to evaporative cooling at the tuber surface and the loss of volatile compounds through co-distillation as water evaporates. Microwave-baked potatoes tend to be more bland than oven-baked or boiled potatoes as lower levels of volatiles are found. Therefore, microwave-baked potatoes receive lower ratings in sensory analyses for a baked potato flavour (Jansky, 2010:211, 212).

The volatility of aroma is related to the temperature of the food – the higher the temperature, the more evident the aromatic compounds become when evaluating food. It is thus important to serve food at its standard serving temperature when presented for sensory evaluation. Consumer satisfaction is ensured with a cooked potato and/or an earthy potato

aroma, which is familiar with a cooked or baked potato served at high temperatures of between 50–60 °C (McWilliams, 2000:38).

Appearance refers to the visual properties of a product and includes attributes such as size, shape, colour, texture, gloss and transparency (Lawless & Heymann, 1998:73). A golden colour and a crispy texture are associated with French fries while a crispy skin and fluffy texture are associated with baked potatoes (Golubowska, 2005:847; Kirkpatrick, 1953:52). Consumers are on the lookout for fresh and unsoiled potatoes without any signs of bruises or sprouting in order to get value for money. Shapes and sizes of potatoes vary, from being regularly uniform in shape and size compared to irregular in shape and sizes. Potatoes can be bought as small-sized tubers, i.e. baby potatoes, to be used in “potjiekos”, medium-sized tubers that accompany meat and/or vegetables for a main meal, or even large tubers for the preparation of French fries.

Colour contributes to the aesthetic appreciation of food and influences the perception of taste, but is not directly a taste component of flavour (Jansky, 2010:211). Dark-coloured products are produced with the Maillard reaction with the interaction of reducing sugars (glucose and fructose) and amino acids at high temperature. Foods' attributes are associated with colour and is an index to quality for identification and grading (Charley, 1982:3). When a consumer has to decide on the colour of a potato, the perception of colour according to Francis (1995:149), interacts with other sensory attributes such as aroma, texture and flavour. With the interaction of the senses, it will determine whether a white or yellow potato is chosen for the intended use. For example, it is more likely that a white potato will be chosen when serving potatoes with sour cream or when potato salad is prepared. A yellow potato is more likely to be chosen when preparing a stew, as it will compliment the taste and appearance of the stew, for example a chicken curry stew.

Taste refers to five basic human taste components, namely bitter, sour, sweet, salty and umami, and these are used with descriptive sensory evaluation. Potato tubers contain all these taste components, except for salty. Bitter-tasting potatoes contain glycoalkaloids and phenolic compounds. However, glycoalkaloids positively contributes to potato flavour. Potato skin has high levels of glycoalkaloids and phenolic compounds. Therefore, potatoes cooked with the skin on are more bitter than those cooked after peeling. Moreover, when potatoes are consumed with the skin on, small tubers may taste more bitter than large tubers (Jansky, 2010:210).

A sour or bitter taste in potato tubers is produced through organic acids. Organic acids are produced by the incomplete oxidation of sugars, as well as the deamination of amino acids, ascorbic acid and polyphenolic acids. Even though starch is tasteless, it influences texture during cooking and can interact with the flavour compounds. Potato tubers contain low levels of sugars, mainly glucose, fructose, and sucrose, which may contribute directly or indirectly to flavour. Precursors for umami compounds are ribonucleotides, which also act as flavour enhancers. Although raw potatoes are low in ribonucleotides, relatively high levels of 5' ribonucleotides are released by the enzymatic hydrolysis of RNA when tubers are heated during cooking. According to Jansky (2010:210), a boiled potato flavour is produced through the products of interactions of the synergistic effect when 5' ribonucleotides interact with amino acids, especially glutamate. Sugars may also contribute to umami taste characters in the form of glutamate glycoconjugates (Jansky, 2010:210, 211).

After-taste is a taste that persists in the mouth when the substance that caused it is no longer present in the mouth. Another definition of after-taste is that it is the continuation of a sensory quality perceived during the presence of the stimulus (Lawless & Heymann, 1998:805). Consumers normally associate an after-taste as being negative towards a product.

The sensory attributes of importance for this study are aroma, texture, flavour, and after-taste. A sensory panel was trained for the evaluation of the sensory attributes of the potato cultivars.

2.9 DESCRIPTIVE SENSORY EVALUATION

Descriptive sensory evaluation is a scientific discipline used to evoke, measure, analyse and interpret those reactions to characteristics of food and materials as they are perceived through the senses of sight, smell, taste, touch and hearing (Institute of Food Technologists, Sensory Evaluation Division 1995:211; Lawless & Heymann, 1998:2). In descriptive sensory evaluation, a sensory profile is created. This translates the analysed cognitive and sensory data, including perception of the food item, into descriptive attributes. The assumption is that the combined attributes used to describe the product will provide a complete impression of the product as perceived (Frewer, Risvik & Schifferstein, 2001:26).



2.9.1 A trained sensory panel

Sensory evaluation of texture involves taste panels that give their impressions of textural attributes (Blahovec, Esmir & Vacek, 2000:2). Product heterogeneity, physiological factors, psychological factors such as motivation, concentration, stress, hunger and thirst and disagreement using a scale, indicate level differences of sensory assessors. However, level differences are common for highly trained panels, as panel members have different sensitivity levels for certain attributes. The panel is introduced to the underlying textural principles involved in the structure of the product in order to understand the concepts of the product (Thybo & Martens, 1998:454). Panel members are trained using a sensory descriptive texture profile in order to produce reliable results, an increased discriminative ability and reproducibility of the results (Thybo & Martens, 2000:283).

For this study, training on the product is provided by presenting a representative sample of a potato to each panel member on which their sensitivity and ability to discriminate between the different sensory attributes are increased.

The potato's structure and chemical composition is of importance for this study as it plays a vital role in the sensory attributes and eating quality of a potato. Physical attributes determine and describe the textural and structural attributes of a potato. The physical attributes of a potato affect the eating quality of potatoes. Various methods are used to determine and describe these attributes. These methods are briefly discussed.

2.10 METHODS TO DETERMINE THE PHYSICAL ATTRIBUTES OF POTATOES THAT AFFECT THE EATING QUALITY OF POTATOES

The need for rapid methods to determine a potato's texture caused a growing interest in the use of spectroscopic screening methods such as nuclear magnetic resonance (NMR), the so-called magnetic resonance imaging (MR-imaging) or near infrared (NIR) spectroscopy (Thybo *et al.*, 2000:103, 104).

NMR-relaxation is a rapid non-invasive method to determine the distribution of water in foods, in addition to correlate with the dry matter content (Thybo *et al.*, 2004:91). MR-imaging correlates with the sensory texture quality of cooked potatoes. MR-images determine structural features within a raw potato that are of significance for the sensory

experience of cooked potatoes. MR-imaging also measures water properties, e.g. the abundance and the spatial distribution of free and bound water inside the biological materials. An MR-image shows differences in colour intensity and structure between varieties and thus variations in water distribution and restraint. The darker the tissue, the more free is the present water – for this reason the water content within the potato tuber is unevenly, spatially distributed. Specific gravity, which is highly correlated with the dry matter content, is not reflected with a MR-image (Thybo *et al.*, 2004:91, 92, 95, 98). NIR spectroscopy proved to be a good predictor of a potato being waxy, moist, firm and mealy, or crumbly, grainy and sticky (Thybo *et al.*, 2000:104).

Objective methods used to determine and describe the physical, textural and structural attributes for this study are specific gravity, scanning electron microscopy, shear force measurements and the dry matter content. Each of the methods will be discussed briefly.

2.10.1 Specific gravity

Specific gravity is the ratio of the density of a food (or other substance) to that of water (McWilliams, 2000:62). A potato that floats in a container filled with water is less dense, has a lower specific gravity and the probability of the potato to retain its shape after cooking is good – thus a waxy potato. If a potato sinks in a container filled with water, the potato is dense, tends to be mealy and sloughs easily. Mealy potatoes have a higher specific gravity, a higher starch content with lower cell adhesion - and are thus more suitable for baking purposes (Charley, 1982:505; McWilliams, 2000:63).

2.10.2 Scanning electron microscopy

Texture provides a measure of properties such as lightness, granulation, uniformity, density, roughness, regularity, linearity, frequency, phase, directivity, coarseness, randomness, fineness and smoothness (Thybo *et al.*, 2004:92).

An image analysis is based on a resolution of the structure in the image, the so-called texture of the image. There is no common accepted definition for image texture. Image texture is viewed as a regular pattern that fills fragments of image surface. Such fragments have two main properties: there is significant variation in intensity levels between nearby pixels and there is homogeneity at some spatial scale larger than the resolution of the image (Thybo *et*

al., 2004:92). Scanning Electron Microscopy (SEM) is a method to describe the surface structure of a solid by measuring the angle and energies of electrons scattered by the atoms (<http://www.everyscience.com>).

Cultivar differences exist regarding size distribution of starch grains and appearance of cells. The most important variation in image features of potatoes is characterised to be a contrast between potatoes having a low volume fraction of cell walls (large cells), a small number of cells and starch grains, and large numbers of elongated cells (Martens & Thybo, 2000:474).

2.10.3 Shear force resistance

Shear force resistance (Chiavaro *et al.*, 2005) refers to the force required to shear through a raw and/or a cooked potato. A high resistance to shear force (thus resisting deformation) has been associated with a mealy texture and represented a high dry matter content (McComber *et al.*, 1994; Thybo *et al.*, 2000 & Van Dijk *et al.*, 2000 in Gibson, 2006:50).

2.10.4 Dry matter content

The dry matter content (or water content) in potatoes is very important determinant to potato texture and has been found to predict various texture attributes. A traditional gravimetric method is used to determine the dry matter content of potatoes. This method is widely used to describe and control texture at harvest and in processing units. However, this method can only be used for quality control (Thybo, Andersen, Karlsson, Hdonstrup & Stodkilde-Jorgensen, 2003:315). With texture profile analysis (TPA), a Halogen Moisture Analyser, from Mettler Switzerland is recommended to use to determine the dry matter content (Kaur *et al.*, 2002:178).

2.10.5 Cooking time

Cooking time refers to the duration of time taken for potato tubers to change from a raw to a cooked stage until the desired softness of the potato tuber is achieved.



2.10.6 Cooking gains/losses

Cooking losses/gains refer to the amount of moisture gain or loss for potato tubers during the cooking process.

Therefore, sensory attributes and a range of objective methods can be used to determine and describe the physical, textural and structural attributes of potatoes. The methods of specific gravity, scanning electron microscopy and shear force measurement, cooking time, cooking gains/losses performed in the study, contributed to the sensory-perceived texture of the potatoes.

2.11 CONCLUDING SUMMARY

In this chapter, the eating quality of potatoes was discussed. The literature review revealed that the eating quality of potatoes are influenced by the sensory and physical attributes, which in turn are determined by the structure and chemical composition of potatoes. The contributing factors to the composition of potatoes namely the potato production region and other associated influences during the production process were pointed out. The factors that have an effect on the post-harvest quality of potatoes were included as these have been proven to contribute to the eating quality of potatoes as well. Attention is given to the culinary applications and sensory attributes that affect the eating quality of potatoes.

In the last part of the chapter, descriptive sensory evaluation and methods to determine the physical attributes of potatoes received attention. The next chapter discusses the methodology of the study.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 INTRODUCTION

The aim of the study was to determine and describe the eating quality of three selected potato cultivars from two production regions in order to propose a classification system for culinary applications of South African potato cultivars.

This study's focal point was on both the sensory and physical attributes in order to provide information to describe the attributes of the three potato cultivars and act as indication of the eating quality. The eating quality of the selected potato cultivars from the two production regions (Limpopo and Eastern Free State) was based on quantitative descriptions obtained from sensory evaluation tests and supported by data obtained from physical measuring techniques. To reach this aim, the study was executed in two phases to determine and describe the eating quality of the three selected potato cultivars. In Phase 1 the descriptive sensory evaluation was performed, while the second phase involved the objective evaluation.

This chapter describes the research methodology followed in each phase of this study and includes the research design, the research objectives, conceptualisation, operationalisation and data collection.

3.2 RESEARCH DESIGN

A quantitative research approach was followed as it involved quantitative measurements by means of allocating numbers to measured characteristics. In this exploratory and descriptive study, an experimental research design was implemented. The reason for an exploratory study is to gain new insights into a topic (Babbie & Mouton, 2001:80). In this study, the eating quality of three South African potato cultivars was scientifically determined and described. In the experimental approach variables are controlled through an experimental design, with the implication that the phenomena of "cause and effect" can be described (Walliman, 2005:118). In this study, the eating quality was determined with the measurement and descriptions of the sensory characteristics of the three different potato

cultivars. This was done by means of descriptive sensory evaluation, where aroma, texture, flavour and after-taste were determined and described. Objective evaluation of the physical attributes of the potato cultivars were performed by means of physical measurements. The physical measurements included measuring of specific gravity of raw potatoes, while shear force measurement and scanning electron microscopy were performed on both raw and cooked potatoes. Each of the physical measurements measured an aspect that was descriptive of the textural attributes of the selected potato cultivars. An experimental design requires specific and standardised measurements and observations (Babbie & Mouton, 2001:49, 118, 209). Both descriptive sensory evaluation and physical measurements as objective evaluation were performed in order to compare the eating quality of the potatoes from two potato production regions in South Africa. To achieve experimental control, all procedures were standardised for the preparation of the potato samples used in the sensory evaluation tests and the objective evaluation.

3.3 UNIT OF ANALYSIS

Three selected potato cultivars, namely BP1, Mondial and a Frutilay (a processing potato with a high dry matter content), from two potato production regions (Limpopo and Eastern Free State), were used as the units of analysis.

3.4 RESEARCH AIM AND OBJECTIVES

The research aim was to determine, describe and compare the eating quality of the selected cultivars from two South African production regions. To reach the aim, the following research objectives were formulated for the study:

1. To determine, describe and compare the **sensory attributes** of the three selected potato cultivars from two South African production regions in order to compare the eating quality of the selected potato cultivars.

The sensory attributes of aroma, texture, flavour and after-taste are applicable in the study and were determined and described.

2. To determine, describe and compare the **physical attributes** of three selected potato cultivars from two South African production regions in order to compare the eating quality of the selected potato cultivars.

The physical attributes of specific gravity, shear force resistance, scanning electron microscopy (SEM), cooking time, cooking gains/losses are applicable and were determined.

3. To determine and compare the relationship between the sensory and the physical attributes of the three selected potato cultivars from two South African production regions.
4. To propose a classification system, based on the eating quality, for culinary applications of the selected potato cultivars from the two production regions.

3.5 ASSUMPTIONS

The following assumptions were applicable in this study:

1. Potatoes from each cultivar from a region were considered alike.
2. Potatoes from one production region were considered representative of one region only.
3. Potatoes from a region were exposed to the same cultivation and growing conditions.
4. The trained sensory evaluation panel evaluated each sample (of the two production regions) objectively and consistently.

A conceptual framework for this experimental research study on the sensory and objective attributes is presented in Figure 3.1. The conceptual framework indicates the steps followed during the process to answer the research objectives in order to determine the eating quality of potato cultivars. The design broadly outlines the steps and methods that were followed throughout the study.

3.6 CONCEPTUAL FRAMEWORK AND EXPERIMENTAL DESIGN

In Figure 3.1, the conceptual framework for the study is presented. The two phases of the study are depicted in the figure. Sensory evaluation was conducted in Phase 1, while the objective evaluation was performed in Phase 2 of the study. Factors that may affect the eating quality, such as the production region and the three cultivars used for the sensory evaluation, namely BP1, Mondial and HDM, are indicated at the top. The sensory attributes of aroma, texture, flavour and after-taste were evaluated. Objective evaluation was performed using physical measurement tests such as specific gravity, shear force resistance and scanning electron microscopy. The measurements of the sensory and physical attributes of the potatoes resulted in the description of the eating quality of the various cultivars. The combined data set on the eating quality of the different potato cultivars resulted in the proposed classification system.

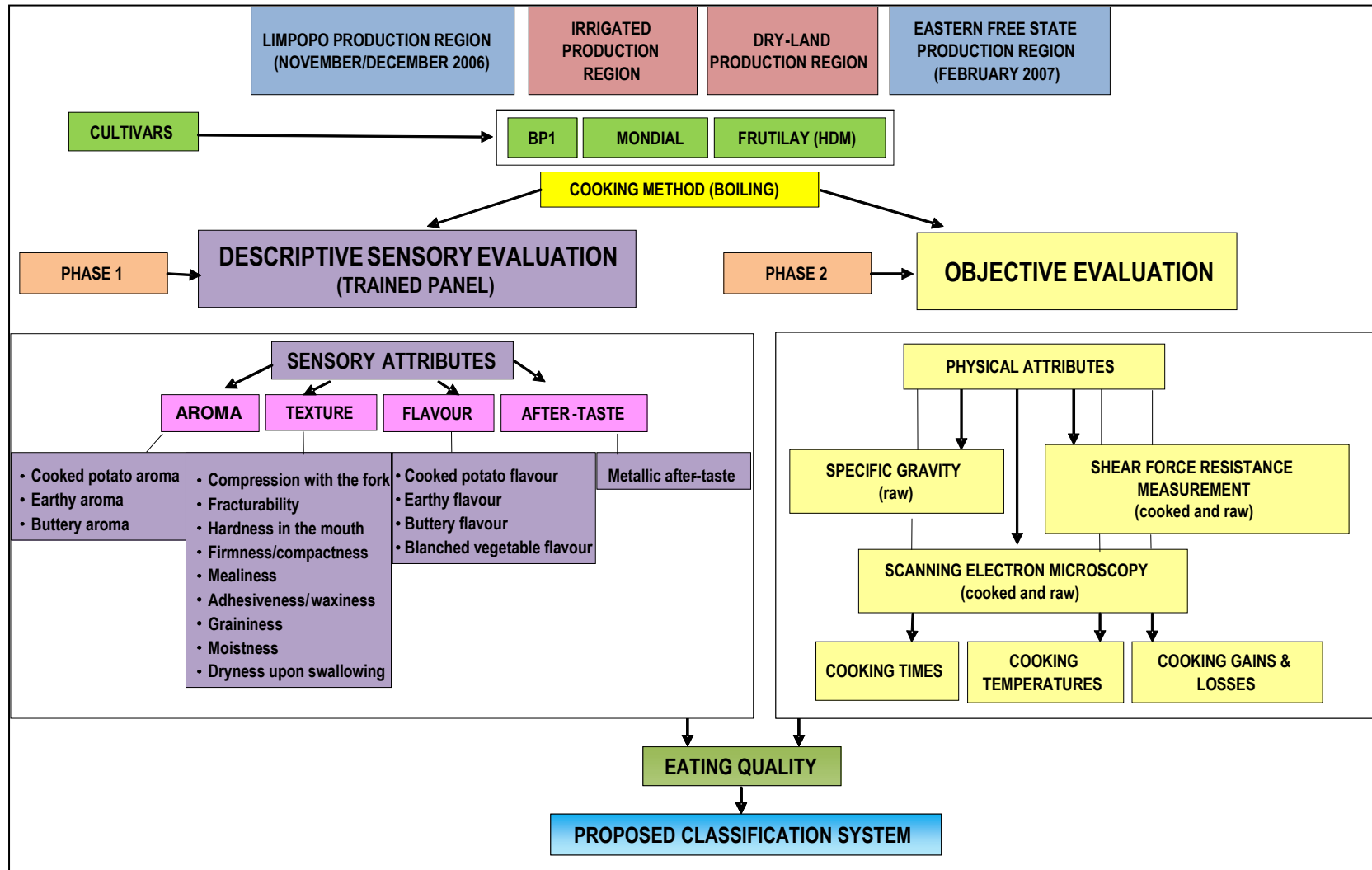


FIGURE 3.1: CONCEPTUAL FRAMEWORK AND EXPERIMENTAL DESIGN FOR THE STUDY



3.7 CONCEPTUALISATION

Conceptualisation is the refinement and specification of the theoretical concepts (Babbie & Mouton, 2001:640). The concepts that were of importance for this study are highlighted in bold:

Eating quality refers to fundamental sensory attributes in consumer quality and acceptance evaluations. Quality is a fundamental aspect or attribute of a sensory experience, which is distinguishable in non-quantitative terms from others in the same sensory field. Quality in a food are those attributes that influence a consumer's satisfaction with the product and represent consumption value to him/her (Schröder, 2003:86). The eating quality of potatoes relate to the attributes appearance, aroma, texture, flavour, after-taste and colour (Chiavaro *et al.*, 2005:1). A detailed description of the sensory and physical attributes is given in Chapter 2 (see 2.4 and 2.8).

A **cultivar** is variety of a plant that has been created or selected intentionally and maintained through the cultivation thereof (<http://www.ventria.com>).

The **sensory attributes** of **aroma**, **texture**, **flavour** and **after-taste** are evaluated. Within the sensory attribute of aroma, the dimensions of a cooked potato aroma; an earthy potato aroma and a buttery aroma are evaluated. The texture sensory attribute contains the textural section of first bite that includes the textural dimensions of compression with a fork, fracturability, hardness in the mouth and firmness/compactness. The textural section of mastication includes graininess, adhesiveness/waxiness, mealiness, moistness and dryness upon swallowing. The flavour sensory attribute includes the dimensions of a cooked potato flavour, an earthy potato flavour, a buttery flavour and a blanched vegetable water flavour. The sensory attribute of an after-taste is also evaluated.

Objective evaluation involves the physical measurements to describe the physical and textural attributes of the potato cultivars. The physical measurements included specific gravity, shear force resistance measurements and scanning electron microscopy observations and evaluations.

Specific gravity entails the ratio of the density of a food (or substance) to that of water (McWilliams; 2001:62).

Shear force resistance refers to the force required to shear through a sample of a raw and/or a cooked potato with measurable tensile strength (McWilliams, 2000:64).

Scanning electron microscopy refers to a scanning electron microscope to give a qualitative visualisation of the texture that shows the degree of cell adhesion and cell wall softening (Martens & Thybo, 2000:471).

Cooking time is the duration of time taken for potato tubers to change from a raw to a cooked stage.

Cooking losses/gains refer to the amount of moisture loss or gain for potato tubers during the cooking process.

3.8 OPERATIONALISATION

Operationalisation refers to the way in which the concepts in the conceptual framework were measured (Babbie & Mouton, 2001:128). The eating quality of the potato cultivars was determined by means of descriptive sensory evaluation techniques as well as with objective evaluation measures. Each of these two groups of evaluation methods is briefly discussed.

3.8.1 Descriptive sensory evaluation

Sensory attributes of quality guide the consumer in the selection of food. The selection, acceptance and digestibility of a food item is largely determined by its sensory properties. The sensory texture quality is of importance in cooked potatoes, as this is one of the most critical quality attributes in consumer evaluation of potatoes. The biological variation between identical potato tubers is high and it is known to influence the texture of cooked potatoes (Thybo *et al.*, 2004:92). Evaluation of sensory properties is affected by individual preference. According to Pomeranz and Meloan (1994:758) individual preference is influenced by factors ranging from social, cultural, religious patterns, psychological factors, variations in climate and in the general physical status of the individual concerned.

In descriptive sensory evaluation, human subjects who are specifically trained for the purpose are used to identify, describe and quantify the sensory attributes of a food (Piggott,

Simpson & Williams, 1998:6). A descriptive sensory panel has been trained at the Agricultural Research Council, Irene in Pretoria for this study. The trained panel rated specific sensory attributes or inherent elements of the cooked potatoes on an 8-point category rating scale (Lawless & Heymann, 1998:806) as used by (Thybo & Martens, 1998:458).

3.8.1.1 Selection and training of the descriptive sensory panel

Panelists were selected from the trained ARC panel based on their ability to provide similar responses to similar products on repeated occasions with taste and smell acuity, interest in the project and availability for the duration of the study. A trained panel encompasses discriminative ability, reproducibility of the responses, agreement among assessors and the selection of reliable and relevant attributes (Thybo & Martens, 1998:454). The panel consisted of ten (10) members and was chosen to participate in the development of the sensory profiles (descriptors) for the different potato cultivars.

The sensory attributes, applicable to the study, were identified to aid the evaluation process of the three selected potato cultivars BP1, Mondial and FrutiLay (a processing potato with a high dry matter content – further referred to as HDM) used as the control.

The descriptive sensory training sessions took place over four consecutive days (see Figure D2 – Addendum D). The sensory attributes applicable to the study were introduced to the panel during the training sessions. Panel members developed descriptors and definitions of the sensory attributes of the potato cultivars (Thybo & Martens, 1998:458). Thorough training was provided to the panel for comprehensive understanding of the attributes.

The trained panel from the Agricultural Research Council (ARC), Irene evaluated the potato samples according to standardised descriptive sensory evaluation methods. The panellists were retrained to increase their sensitivity and ability to discriminate between the sensory attributes of the different potato cultivars.

3.8.1.2 Development of the lexicon

An evaluation form (lexicon) that describes the sensory attributes of the potato cultivars by means of descriptive sensory evaluation was specifically developed (see Table B1 - B4, Addendum B). Slight differences occurred in the sensory attributes evaluated in the Limpopo region and the Eastern Free State region. The sensory attributes evaluated were

adapted on the lexicon form used with the training and consequent evaluation of the potato cultivars in the Limpopo region to the Eastern Free State region.

3.8.1.3 Scaling and score sheet used during the descriptive sensory evaluation

Scaling involves the allocation of numbers by sensory panelists to quantify sensory experiences (Lawless & Heymann, 1998:209). A category scale is a method of measurement in which the subject is asked to rate the intensity of a particular stimulus by assigning it a value (category) on a limited, usually numerical level of data (ordinal data) (Meilgaard, Civille & Carr, 2000:43). The intensities of the attributes are quantified on a scale of any length possible e.g. 1-7, 1-9, 0-100 (Lea, Neas & Rodbotten, 1998:4). Category scales are commonly used in descriptive analysis, which is a limited set of words or numbers with equal intervals between categories.

An 8-point category scale was used to measure the intensity of each of the different sensory attributes of the different potato cultivars (see see Table B2 and B4 – Addendum B). One (1) on the category scale denotes the least intense condition (e.g. no potato aroma) and eight (8) denotes the most intense condition (e.g. extremely intense potato aroma). Each sensory attribute (aroma, texture, flavour and after-taste) was measured according to Thybo and Martens (1998:458).

Panellists were requested to use half of the potato sample (approximately 25g of 50 g) with the descriptive sensory evaluation on the textural section of ‘first bite’ (see Addendum B). The rationale behind the evaluation of half of the sample is for a thorough textural evaluation of the sample in the mouth, on the tongue and on the palate.

3.8.2 Objective evaluation

The stimulus in texture perception is predominantly mechanical in nature. Therefore, most of the instrumental methods of texture evaluation (Nisha *et al.*, 2005) are based on mechanical tests. Measurement tests were carried out using standardised methods and equipment (McWilliams, 2000:59) as required in experimental studies of this nature. The objective evaluation resulted in objective data that was obtained in a laboratory under controlled conditions.

In this study specific gravity, shear force resistance measurements and scanning electron microscopy were used as physical measurements to supplement the data obtained from the sensory evaluation. The physical measurements measured specific textural attributes of the different potato cultivars. Objective evaluation in Phase 1 included cooking time, cooking losses and cooking gains that contributed to understanding the physical dynamics of the concept “eating quality.”

3.8.2.1 Specific gravity

The standardised method by Gibson (2006) was used to determine the specific gravity of the potatoes. Specific gravity was measured by using a Mettler Toledo PB3002-s scale (Switzerland, 2000). Specific gravity was calculated by the under-water-weight method (Es & Hartmans as published by Rastovski *et al.*, 1981). The under-water-weight (UWW) refers to weight of a potato batch under water in grams as a calculation of the weight of the same potato batch above water. The formula of specific gravity was used to obtain the specific gravity of the potatoes.

$$\text{Thus, specific gravity (SG) is} = \frac{\text{dry weight}}{\text{dry weight} - (\text{under-water-weight})}$$

According to McComber *et al.* (1994), the measured value of specific gravity indicated whether the potatoes were either mealy or waxy. Lower specific gravity values are indications of more waxiness. A waxy potato with a low specific gravity (1.070) retains its shape well but a mealy potato has a higher specific gravity (1.115) and sloughs readily (McWilliams, 2000:63).

3.8.2.2 Shear force resistance

Shear force resistance (Chiavaro *et al.*, 2005) refers to the force required to shear through a raw and/or a cooked potato. Physical texture analysis (shear force resistance) measurements were performed on potato core samples. Cylindrical raw and cooked potato samples with a 12.5 mm core diameter were cored parallel to the length of the potato. The Warner Bratzler shear device mounted on a Universal Testing Machine (Instron 4500, Series IX, Version 5, Massachusetts) was used. A speed of 60 mm.min⁻¹ with a 1kN load cell was applied. Eight cores per sample were tested. The reported value in kg represented the average of the peak force measurements of each sample (Gibson, 2006:20).

A high resistance to shear force (thus resisting deformation) has been associated with a mealy texture and represented a high dry matter content (McComber *et al.*, 1994; Thybo *et al.*, 2000 & Van Dijk *et al.*, 2000 in Gibson, 2006:50).

3.8.2.3 Scanning electron microscopy

Scanning electron microscopy was performed by means of an image analysis. An image analysis is based on the resolution of the structure in the image, the so-called texture of the image (Thybo *et al.*, 2004:92). This method was used to determine the size and distribution of the starch grains from raw and cooked BP1 and Mondial samples from the Limpopo and Eastern Free State production regions. The image texture illustrates the textural and structural properties of the BP1 and Mondial potato cultivars by means of scanning electron microscopy. According to Martens and Thybo (2000), differences between the cultivars could be seen with respect to the cell size and distribution of the starch grains by using electron microscopy as well as the variation in the cell sizes of cooked potato samples.

Concepts of importance for the study were operationalised and illustrated in the conceptual framework (Figure 3.1). Data collection for this study was performed in two phases. The two-phase experimental procedure is presented and described briefly.

Phase 1 refers to the sensory evaluation performed on the three cultivars from the two production regions. A brief description of the method and equipment used in this phase is presented in Figure 3.2 followed by the experimental procedure of the objective evaluation performed in Phase 2 of the study, presented in Figure 3.3.

3.9 EXPERIMENTAL DESIGN: PHASE 1

An experimental design needs to be controlled to steer away from various forms of errors (Babbie & Mouton, 2001:645). For consistency during the data collection, methods and equipment used in the research process were standardised to eliminate any deviation in the methods of data collection. A pilot study was performed to ensure this. The sample preparation and the sensory evaluation procedures were developed and standardised before commencing with the data collection for the study. Therefore a structured plan of the experimental procedure to determine the eating quality of potato cultivars was developed.



Descriptive sensory evaluation was performed in Phase 1 of the study. Figure 3.2 presents the flow diagram of the experimental procedure, followed by the sensory evaluation in order to determine the eating quality of the potato cultivars.

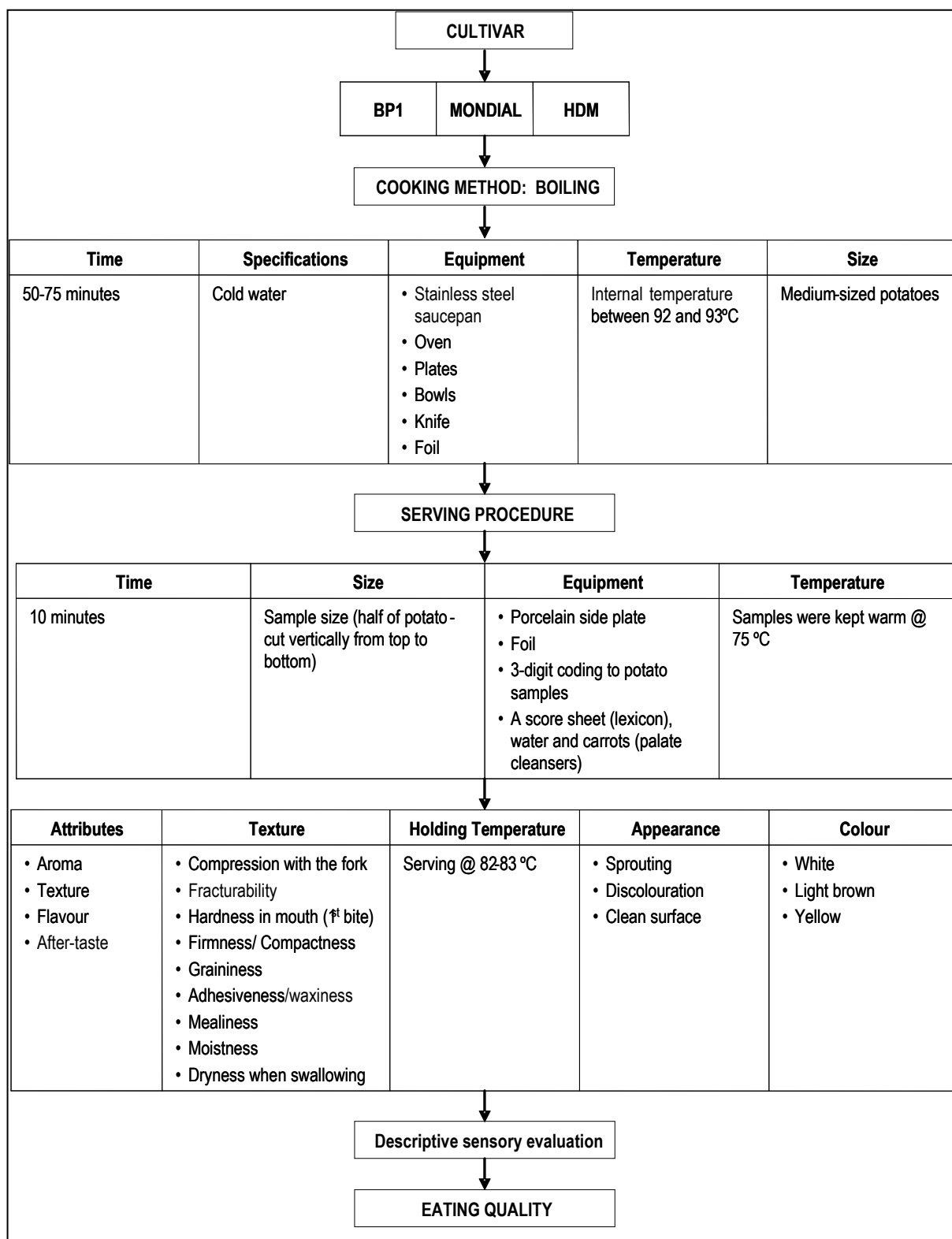


FIGURE 3.2: FLOW DIAGRAM FOR THE EXPERIMENTAL PROCEDURE OF PHASE 1



3.9.1 Experimental procedure

The sensory evaluation took place over five consecutive days. Validity of the study's results was ensured through repetitions (Stone & Sidel, 1993:111). Four repetitions of each cultivar were applied during the sensory evaluation. The handling and storage, the sample selection, the preparation and cooking of the potatoes as well as the serving procedure for the sensory evaluation are briefly discussed.

3.9.1.1 Handling and storage of the potato cultivars

The samples were transported from the two regions (Limpopo and Eastern Free State) in dark paper bags to the laboratory (see Figure D1 – Addendum D). At the laboratory, the samples were placed in crates in a dark, ventilated room with a moderate room temperature. Most of the soil was removed with the transportation of the samples and to prolong the keeping quality, the excess soil was not removed (Gibson, 2006:16).

3.9.1.2 Sample selection for the sensory evaluation

Three potato cultivars, namely BP1, Mondial and HDM were selected from the Limpopo and the Eastern Free State regions in South Africa, for the sensory evaluation and objective evaluation that involved physical measuring tests (see Figure D3 – Addendum D).

The potato samples from both the Limpopo and Eastern Free State regions were drawn from different farmers at the same physiological age and were harvested on the same day. Similar storage conditions were applied to both regions' potato samples.

3.9.1.3 Sample selection for the preparation of the potatoes

Simple random sampling was used when selecting cultivar samples for cooking (Walliman, 2005:276). Samples were selected each day, and then randomised with the cooking. Six (6) medium-sized potatoes from each cultivar were selected, weighing between 180 and 240 g each for the sample preparation. Control in sample preparation is compulsory if results obtained with the sensory evaluations are to be meaningful (McWilliams, 2000:14). The potatoes were washed and scrubbed to remove any soil or dirt present. The potatoes were weighed raw (see Figure D4 – Addendum D).

3.9.1.4 Cooking method and time

Medium-sized potatoes were placed into two-litre stainless steel saucepans and boiled in their skins. Water at room temperature was added to cover the potatoes. The boiling process started at room temperature. The saucepan was covered with a lid (to prevent excessive moisture loss) during the cooking process.

Water was replenished, when required, to ensure that the potatoes were constantly covered with water. The boiling time varied slightly between the different cultivars but ranged between 50 and 75 minutes. The core temperature was measured with a hand-model Kane-Mane probe equipped with a T-type thermocouple. The potatoes were cooked until soft. An indicator of softness was when a core temperature of between 92 and 93 °C was reached (see Figure D5 – Addendum D). The thermocouple also had to slide through the potato with no resistance.

The potatoes were removed from the heat and were weighed to determine moisture loss or moisture gain. The potatoes were transferred to a pre-heated glass bowl and kept warm at 75 °C in calibrated Miele (H217) ovens for 10 minutes. After the resting period, the potatoes were cut into sample sizes (half of the potato) vertically from top to bottom. See Figure 3.3 below.

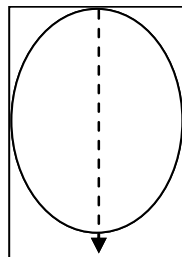


FIGURE 3.3: ILLUSTRATION OF THE CUTTING PROCEDURE FOR THE SENSORY EVALUATION

3.9.1.5 Standardisation of serving procedure for sensory evaluation

Sample sizes (half of a potato in the skin) were served to each panel member for evaluation. The approximate mass of each sample varied according to the size of the potato but was more or less 50 g each. Each sample was wrapped in aluminium foil, shiny side in and coded with a three-digit code (see Figure D6-D8 – Addendum D). Samples were kept warm

at 75 °C in calibrated Miele (H217) ovens for 10 minutes before serving it to the panel within 3 to 5 minutes.

The serving temperature was controlled and samples were served at a serving temperature of between 82 and 83 °C. The coded potato samples were served to the panel on pre-heated porcelain side plates on a white tray (see D9 – Addendum D). Uniformity of each sample (volume served and serving temperature) was ensured. Samples were randomised to exclude any bias due to the positioning effect.

Trained panel members received a sensory evaluation form (a developed lexicon form) (see Table B2 and B4 – Addendum B) to perform the descriptive sensory evaluation test. The lexicon resembled the list of the sensory attributes that had to be evaluated. Panel members were provided with water and carrots, which served as palate cleansers between evaluation sessions (see D10 – Addendum D).

Descriptive sensory evaluation was performed under infrared light conditions. Reason for the different colour of light used was to eliminate all factors that could influence the panellists' evaluation of the potato samples based on their colour.

Phase 2 of the study involved objective evaluations. Three objective evaluation tests were carried out in Phase 2 by using physical measurement tests to acquire objective data from the potato cultivars. Accuracy of measurements is a key aspect of control in food experimentation (McWilliams, 2000:14).

3.10 EXPERIMENTAL DESIGN: PHASE 2

Objective evaluation was performed in Phase 2 of this study. Figure 3.4 presents a flow diagram of the experimental procedure followed during the objective evaluation in order to determine the eating quality of the potato cultivars.

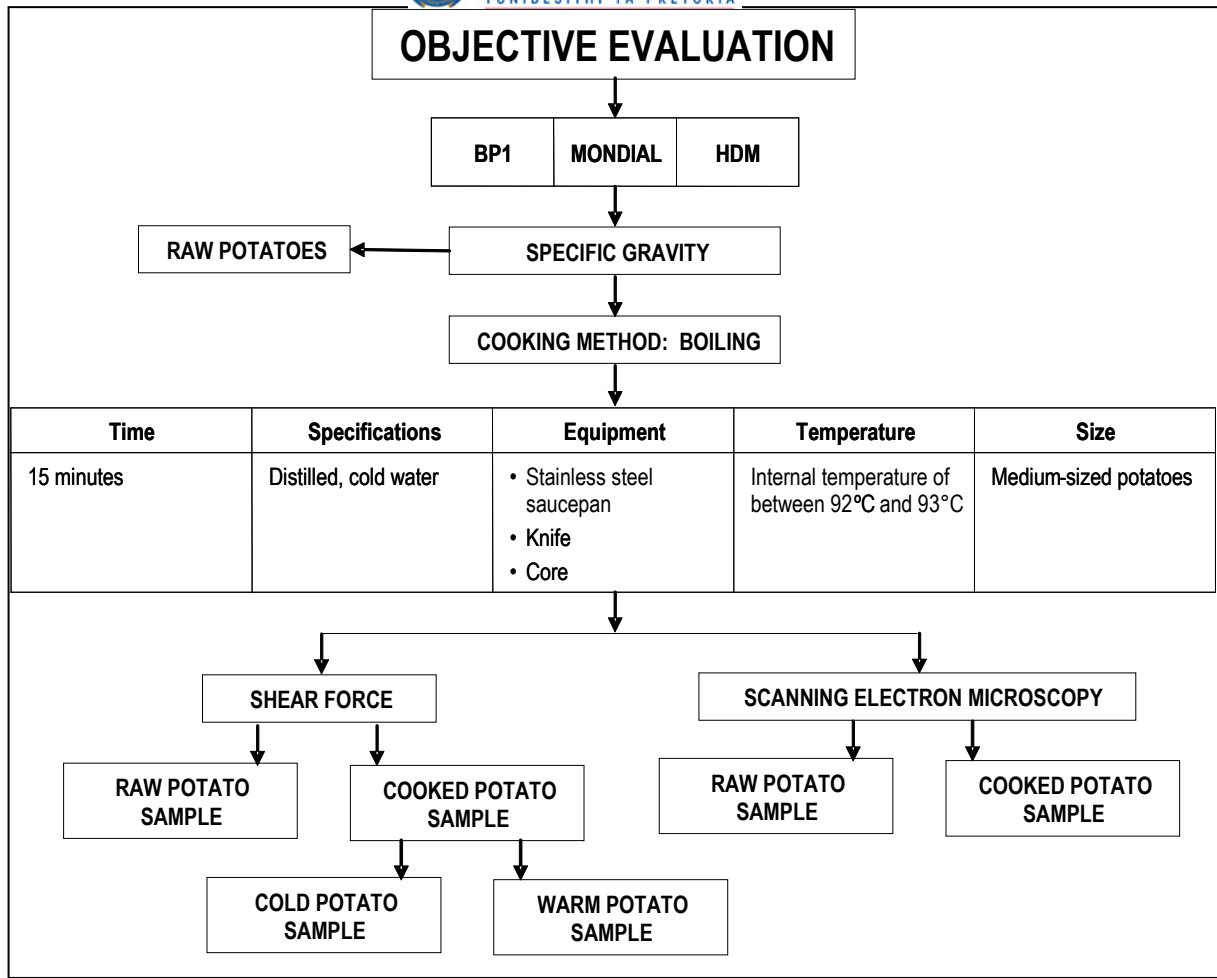


FIGURE 3.4: FLOW DIAGRAM OF EXPERIMENTAL PROCEDURE FOR PHASE 2

In Figure 3.4 the potato cultivars, specifications and equipment used are indicated. The objective measurements performed included specific gravity measurements on raw potato samples; shear force resistance measurements and scanning electron microscopy of both raw and cooked potato samples.

3.10.1 Specific gravity

Specific gravity was determined within 24 hours of harvesting. The specific gravity was repeated on a weekly basis for four consecutive weeks. Specific gravity was measured in order to determine the correlations, if any, between the initial specific gravity and the results from the other objective measures, as well as to determine if a significant difference was observed in the specific gravity of the batches over time (Gibson, 2006:17). According to

Thygesen *et al.* (2001) a high specific gravity measurement has been associated with a high dry matter content and a more mealy potato.

Two to three potatoes were selected as a sample batch. From the sample batch, the potatoes' dry weight and under-water-weight were determined (see 3.8.2.1). This process was repeated ten times with different sample batches for each of the three cultivars (Gibson, 2006:17).

3.10.2 Shear force resistance

Ten potatoes were selected from each cultivar from both localities. Potato cores were placed in two-litre stainless saucepans covered with 500 ml distilled water at room temperature and boiled for 15 minutes uncovered on a stovetop. The remaining water was drained after the cooking. Eight randomly selected cores from both raw and cooked samples at a warm temperature of 65 °C (within 15 minutes of cooking) and a room temperature of 22 °C (an hour after cooking) from each batch were analysed. Core temperature was measured before and after analysis with a hand model Kane-Mane probe equipped with a T-type thermocouple (Gibson, 2006:20). The shear force measurements of the potato samples were performed within two (2) hours after cooking (Gibson, 2006:20; Martens & Thybo, 2000; Nisha *et al.*, 2005). The cores were placed in sealable plastic bags to prevent dehydration.

3.10.2.1 Shear force resistance measurements on cooked potato samples

Cylindrical raw and cooked potato samples with a 12.5 mm core diameter, cored parallel to the length of the potato, were sheared perpendicular to the core using a Warner Bratzler shear device mounted on a Universal Testing Machine (Instron 4500, Series IX, Version 5, Massachusetts). Eight cores per sample were tested. The speed was 60 mm.min⁻¹ with a 1kN load cell (Gibson, 2006:20).

Load maximum, displacement at maximum and thick-max were determined for a shear force measurement value. Load maximum indicated the maximum force required to shear through the sample, displacement at maximum load and thick-max indicated the maximum force required over the thickness of each specimen (kg/mm). Only load maximum measurements in a raw, cooked (warm) and cooked (cold) state were used for this study (Gibson, 2006:21).

The test, as mentioned above, was done to determine the softening from a raw to a cooked state as well as comparing softening between the two cultivars. Softening of each sample was recorded in two stages from raw to cooked while still warm, as well as from raw to cooled once cooked, was recorded (Gibson, 2006:21).

3.10.3 Scanning electron microscopy

Preparation of the samples for scanning electron microscopy was performed by Nicolette Gibson and standardised methodology was used. From each cultivar, five potatoes were selected. Each potato was cut longitudinally into two cubes, 1 cm³ each. One cube per potato was cooked (in a two-litre stainless steel saucepan with 500 ml distilled water, uncovered on a stovetop for 15 minutes at a temperature of 94 °C) and the other was kept raw. After cooking, the cubes were placed in plastic bags to prevent dehydration after which they were processed for scanning electron microscopy (Gibson, 2006:19).

The cubes were cut lengthwise into approximately 20 mm long 1 mm² cubes and fixated in 2 ml fixation medium. The fixation medium consisted of 2 ml 2.5% formaldehyde, 2 ml 2.5% glyceraldehyde, 10 ml Na/K buffer and distilled water (Gibson, 2006:19).

After 24 hours, the samples were dried overnight in a Bio-Rad Critical Point Dryer (E3000, Watford, England). After drying, the samples were coated with gold by a Polaron Sputter Coater (E5200C Watford, England). Scanning electron microscopy (SEM) was performed by a JEOL Scanning Electron Microscope (JSM-840 JEOL, Tokyo, Japan). The size of the starch grains were determined from the photographs taken by the SEM (Gibson, 2006:19).

3.11 DATA ANALYSIS

The objective and sensory evaluation data collected was analysed statistically with analysis of variance (ANOVA), multivariate- and correlation analysis, principal component analysis (PCA) and partial least squares regression (PLS). The statistical software programme GenStat® (Payne, Murray, Harding, Baird, & Soutar, 2007) was used. Each of these statistical methods is briefly discussed.

3.11.1 Analysis of variance (ANOVA)

Analysis of variance (ANOVA) is a way to deal with several treatments or levels. ANOVA is one of the most common statistical procedures performed in quantitative descriptive analysis where more than two products are compared, using scaled responses. ANOVA is a method for finding variation that can be attributed to some specific cause, against the background of existing variation due to other causes. The sources of variance in a data set are separated.

A ratio of the factor variance to the error variance is constructed with ANOVA. A significant F-ratio for a given factor implies that at least one of the individual comparisons among means is significant for that factor. The F-ratio is an indicator of noise (Lawless & Heymann, 1998:701-703, 804). The one-way ANOVA test was applied with Fisher's protected t-test least significant difference at 5% level of significance.

An ANOVA analysis was used to calculate the differences, if any, between the sensory attributes (aroma, texture, flavour and after-taste) of the three cultivars, within each production region as measured on the 8-point category scale.

3.11.2 Multivariate analysis

Multivariate statistical methods, such as principal component analysis (PCA) and partial least square regression modelling (PLS), refer to methods that are applied to data sets that contain both dependent and independent variables. For example, the data sets in which one or more of the variables are special or of more interest relative to some others – one would be able to detect broader patterns of interrelationships among products and among sensory characteristics (Meilgaard *et al.*, 1991:276 & Lawless & Heymann, 1998:586).

3.11.3 Correlation analysis

Correlation analysis measures the strength of linear relationships between two variables. It can be used to identify groups of responses that vary in similar ways. The strength of the relationship (expressed in the correlation coefficient as "r") of the data arising from two different sources, for example consumer ratings and descriptive data from a trained panel, can be determined with correlation analysis (Meilgaard *et al.*, 1991:276). The correlation coefficient is dependent on the range and number of samples used. A concomitant change

between the variables may occur because the variables are causally related, for example, a decrease in a sensory attribute will cause a subsequent decrease in another sensory attribute. A change in one may not be linearly related to the other (Lawless & Heymann, 1998:398, 741).

A correlation matrix was constructed to determine possible correlations between the sensory attributes of the three potato cultivars within each production region. These correlations were performed to determine the inter-relationship between the various sensory attributes of the potato cultivars.

3.11.4 Principal component analysis (PCA)

Principal component analysis (PCA) is applied to data in order to identify the main variations that explain the data, and therefore often simplifies the interpretation of the descriptive sensory data that transforms the set of original correlated descriptors into a new set of principal components.

Through PCA, the correlation structure of a group of multivariate observations is analysed and the axis along which maximum variability of the data occurs is identified and referred to as principal component 1 (PC 1). The second principle (PC 2) is the axis along which the greatest score of the remaining variability lies, subject to the constraint that the axis must be perpendicular (at right angles) to each other (Meilgaard *et al.*, 1991:277).

The inputs to a PCA comprise attribute ratings that describe a set of products. Given many attributes, some will be correlated, meaning that an attribute that received a high rating, could also receive either a high or low rating on other attributes (Lawless & Heymann, 1998:608, 735).

PCAs were used in this study to illustrate inter-relationship (association) of the sensory attributes with the potato cultivars.

3.11.5 Partial least squares regression (PLS)

A univariate regression method is used to understand the effect of one independent or predictive variable on a dependent variable. Multivariate regression is necessary to

understand the effect of all measured variables of interest. Partial least squares (PLS) is a multivariate regression method that handles multicollinearity (excessive correlation) and small sample sets (Helland, 1988; Manne, 1987).

PLS is used to compare blocks of variables, or relate one or several response variables (Y) to several correlated explanatory variables (X). This method aims to identify the underlying factors, or linear combinations of the explanatory variables, which best model the dependant variables (Smith, Leighton, Morey & Schönfeldt, 2009:31).

PLS regression consists of relating X and Y matrices in one single estimation procedure. PLS component 1 (PLS 1) is used to predict one dependent variable, and PLS component 2 (PLS 2) to predict several dependent variables, from a set of independent variables.

In this study, PLS regression was used to understand the relationship between the sensory attributes of boiled potatoes to six objective measurements, with the objective of determining the most important physical measurements that influence the sensory profiles of the potatoes (Smith *et al.*, 2009:31).

3.12 RELIABILITY AND VALIDITY

It is a fundamental requirement of scientific research to demonstrate that measures to ensure both reliability and validity were adhered to. Each of these aspects is briefly discussed.

3.12.1 Reliability

Reliability of a measurement procedure is the stability or consistency of the measurement. Therefore, a reliable measurement procedure will produce identical measurements if the same variable is measured under the same conditions yielding consistent numerical results each time it is applied (De Vos *et al.*, 2005:162, 163). Reliability is not concerned with what is being measured, but how well it is being measured.

Therefore, reliability in quantitative research is the extent to which the measurements of a test remain consistent over repeated tests of the same subject under identical conditions. An

experiment is thus reliable if it yields consistent results of the same measure (Lawless & Heymann, 1998:3).

In order to achieve reliability in the study, the following measures were taken:

A pilot study was conducted to ensure that the methods and techniques used in the sensory evaluation and for the objective tests were standardised. The measuring instruments used in the physical tests were calibrated. Established measures were used. Standardised sensory evaluation procedures were followed and a standardised category scale was used (Lawless & Heymann, 1998:15).

The panel members were paid volunteers and were recruited and selected based on their participation in previous research projects at the Agricultural Research Council (ARC), Irene, prior to further training on a specific product. The trained panel evaluated the potato samples according to standardised descriptive sensory evaluation methods. They were trained to increase their sensitivity and ability to discriminate between the sensory attributes of the different potato cultivars. All the samples were evaluated by the panel according to the methods described in the Annual Book of the American Society for Testing and Materials Standards (ASTM, 1989). The descriptive sensory evaluation tests took place under controlled conditions in the sensory laboratory of the ARC, Irene.

The sensory analysis facilities at the ARC, Irene were constructed according to ASTM design guidelines for sensory facilities, with all the elements required for an efficient sensory evaluation program. The physical milieu was quiet, air-conditioned, free from intrusions and no odours from the food preparation area were present.

The sample preparation and serving procedures were standardised and adhered to throughout the study as discussed in paragraph 3.9.5 and 3.9.6. The potatoes from each study, as described earlier, came from farms in the specific production region. Four repetitions of each cultivar were applied to obtain statistical reliability and validity in this study.

3.12.2 Validity

Validity refers to the extent to which an empirical measure accurately reflects the concept it is intended to measure by producing a value that is close to the “true value”, as defined by the

independent measurement, from another instrument that has been appropriately calibrated (Lawless & Heymann, 1998:4; De Vos *et al.*, 2005:160 and Babbie & Mouton, 2001:123).

In this study, standardised measuring instruments and procedures were used, as well as standardised sensory evaluation procedures to ensure measurement validity.

Construct validity Construct validity is based on the logical relationships among variables. It determines the degree to which an instrument measures the theoretical construct accurately. Construct validity is concerned with the meaning of the instrument, what it measures, how and why it operates as it does (De Vos *et al.*, 2005:162; Babbie & Mouton, 2001:123).

The thorough literature overview and the conceptualisation ensured a thorough understanding of the concepts being measured.

Content validity Content validity is concerned with the sampling adequacy or representativeness of the study's content as an instrument. The measuring device covers a full range of meanings or forms within the concepts being measured (De Vos *et al.*, 2005:161; Babbie & Mouton, 2001:123).

The eating quality was determined through the sensory attributes of aroma, texture, flavour and after-taste. For the sensory evaluation, an 8-point standardised category scale was used (Lawless & Heymann, 1998:220). For statistical reliability and validity, replications within a research study need to take place (Stone & Sidel, 1993:111).

A trained panel was used to rate and evaluate the eating quality of the selected potato cultivars from the two potato production regions. The trained panel was thoroughly trained regarding the use of a sensory evaluation form (lexicon) and the evaluation of the various sensory attributes (McWilliams, 2000:516). All dimensions of eating quality were included and experts in the subject field assisted in the development of the lexicon.

Internal validity Internal validity is a measure of the level of sophistication of the design and extent of control in an experiment. The values of the data gained should genuinely reflect the influences of the controlled variables (Walliman, 2005:434).

Every effort was made to evaluate the differences in the cultivars from the two production regions by randomising the potatoes obtained. A trained descriptive sensory panel was used for the sensory evaluation with four repetitions thereof.

Face validity Face validity is a subjective measurement as it only “looks” as if it measures what it is supposed to be measuring. Face validity measures the superficial appearance and face value (De Vos *et al.*, 2005:161, 162). The sensory evaluation forms used in this study portrays the measurements of the intended sensory attributes clearly (see Addendum B).

The multiple measurements of the sensory and objective evaluation performed, contributed to triangulation of measurements that further enhanced the validity of the study.

3.13 ETHICS

Ethical approval was obtained for the study from the Ethics Committee of the Faculty of Natural and Agricultural Sciences, University of Pretoria. Reference number: EC090209-009. See Addendum (A).

Each panel member participated on a voluntary basis and signed a consent form before the study commenced. A legal document was signed by the potato farmers to certify that the products supplied were safe for human consumption and not harmful in any way to the consumers. The preparation, cooking and presentation methods of the samples were according to the hygiene and safety regulations set out by the American Standardised Testing Materials (ASTM). These regulations were strictly followed by the Agricultural Research Council (ARC), Irene.

3.14 CONCLUDING SUMMARY

The chapter outlined the research methodology followed in the two phases of the study. The experimental design of each phase was described that included the procedures followed to determine the eating quality of potatoes by means of descriptive sensory evaluation and objective evaluation. Some techniques regarding the analysis of the data were highlighted. It was also essential to illustrate how reliability and validity of the study was maintained due



to the nature of the research design. The next chapter focuses on the results and discussion of the results.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter the results of the study will be presented and discussed. This will be done according to the two phases in which the study was conducted. Phase 1 consists of the results and discussion of the descriptive sensory evaluation followed by the results and discussion of the objective evaluation of Phase 2.

4.2 DESCRIPTIVE SENSORY ANALYSIS

Results obtained from the sensory evaluation tests were analysed using descriptive statistics. Analysis of variance (ANOVA) was carried out on the results of all 17 sensory attributes measured in the study obtained from both the Limpopo and the Eastern Free State region. The aim of the sensory evaluation tests was to establish whether any significant differences exist among the eating quality of the three selected potato cultivars within each of the production regions (Limpopo and Eastern Free State), as well as an evaluation-comparison between the two potato production regions. The statistical results of the data on the sensory attributes of the potato cultivars from the Limpopo region will be discussed, followed by the results from the Eastern Free State region's potato cultivars.

A one-way ANOVA test was applied with Fisher's protected t-test least significant difference at 5% level of significance between cultivar means, as the data was acceptably normal and cultivar variances homogeneous. The sensory data of the Limpopo region was an unbalanced design, as shown in Table 4.1. When comparing actual means statistically, score values is not meaningful as discreet data becomes continues data (Payne *et al.*, 2007).

TABLE 4.1: EXAMPLE OF THE UNBALANCED DESIGN OF THE SENSORY ATTRIBUTES FROM THE LIMPOPO REGION

SENSORY ATTRIBUTE: COOKED POTATO AROMA			
Cultivar	Prediction	n	Standard error
BP1	4.792	120	0.07434
Mondial	4.723	120	0.07465
HDM	4.375	40	0.12875

The repetitions of each cultivar differs with n=120 for the BP1 cultivar; n=120 for the Mondial cultivar and n=40 for the HDM cultivar and represents an unbalanced design according to the analysis of variance (ANOVA).

4.3 DESCRIPTIVE SENSORY ANALYSIS RESULTS OF POTATO CULTIVARS FROM THE LIMPOPO REGION

The mean values of the three selected cultivars from the Limpopo region for the sensory analysis are presented in Table 4.2. Within a region, selected sensory attributes showed significant differences among the cultivars, as obtained with GenStat® (Payne *et al.*, 2007). The sensory attributes of aroma, texture, flavour and after-taste were evaluated and are presented.

The lexicon used in the sensory evaluation (see Chapter 3, Table 3.1) determines the order of discussion of the sensory attributes. The sensory attributes of aroma, texture, flavour and after-taste were evaluated and the attributes that proved significant differences between the selected cultivars are presented. The results of the aroma sensory attribute are presented first, followed by the results of the texture, flavour and after-taste sensory attributes.

TABLE 4.2: MEAN VALUES OF THE SENSORY ANALYSIS OF THREE POTATO CULTIVARS FROM THE LIMPOPO REGION

ATTRIBUTE	p-value	BP1 cultivar	Mondial cultivar	HDM cultivar
AROMA				
Cooked potato	0.020	4.79 ^a	4.72 ^a	4.38 ^b
Potato/earthy	< 0.001	2.18 ^b	2.88 ^a	2.20 ^b
Buttery	< 0.001	2.53 ^a	1.80 ^b	2.65 ^a
TEXTURE				
Compression with the fork	< 0.001	3.06 ^b	2.75 ^c	3.80 ^a
Fracturability	< 0.001	2.62 ^b	2.14 ^c	3.28 ^a
First bite				
Hardness in mouth (first bite)	< 0.001	2.92 ^b	2.66 ^c	3.53 ^a
Firmness/compactness (mouth)	< 0.001	3.06 ^b	2.75 ^c	3.80 ^a
Mastication/chewing				
Graininess	< 0.001	2.71 ^b	2.18 ^c	2.53 ^a
Adhesiveness/waxiness	< 0.001	2.55 ^b	3.05 ^a	2.93 ^a
Mealiness	0.025	2.46 ^b	2.82 ^a	2.68 ^{ab}
Moistness	< 0.001	3.04 ^a	3.07 ^a	2.35 ^b
Dryness upon swallowing	< 0.001	2.73 ^c	2.97 ^b	3.70 ^a
FLAVOUR				
Cooked potato	0.308	4.64	4.59	4.40
Earthy/potato	<0.001	2.12 ^b	2.72 ^a	2.10 ^b
Buttery	<0.001	2.38 ^a	1.73 ^b	2.53 ^a
Blanched vegetable water	<0.001	1.90 ^b	2.34 ^a	2.03 ^b
AFTER-TASTE				
Metallic	0.011	1.68 ^b	1.99 ^a	1.84 ^{ab}

abc means in a row with different superscripts differ significantly
1 = lowest score of attribute; 8 = highest score of attribute

4.3.1 Aroma

The variation in the aroma sensory attribute is mainly caused by the cultivar type and storage (Thybo *et al.*, 2006:173). Significant differences occurred in all three of the aroma dimensions, namely *cooked potato aroma*, *potato/earthy aroma* and *buttery aroma*.

Cooked potato aroma The sensory attribute described as *cooked potato aroma* differed significantly with the p-value of $p = 0.020$. BP1 (4.79^a) and Mondial cultivars (4.72^a) had the most intense *cooked potato aroma* compared to the HDM cultivar (4.38^b). Methional, an aroma component, is identified as a boiled potato odour. This aroma component is formed during the boiling process of potatoes (Thybo *et al.*, 2006:174) and is more pronounced in both the BP1 and the Mondial cultivars.

Earthy potato aroma There was a significant difference in the *earthy potato aroma* sensory attribute between the different cultivars with a p-value of <0.001. The Mondial cultivar had

the most intense *earthy aroma* (2.88^a) compared to the HDM cultivar (2.20^b) and the BP1 cultivar (2.18^b).

Buttery aroma The sensory attribute of a *buttery aroma* had a probability of <0.001, which means that there was a significant difference between the cultivars. BP1 and HDM cultivars scored the highest ratings for the sensory attribute of a *buttery aroma* (2.53^a – 2.65^a) followed by the Mondial cultivar (1.80^b).

4.3.2 Texture

Texture describes a substance's tissue structure (Jellinek, 1985:155). Texture parameters include hardness, compactness and firmness. The changes in the textural properties of potatoes are due to the associated changes in the physico-chemical properties and structure of the cell wall. The texture of cooked potatoes depends on the cooking conditions as a result of various factors such as starch gelatinisation, pectin degradation, cell wall breakdown and cell separation (Nourian *et al.*, 2003:261).

The textural component comprised of various sensory attributes that included *compression with the fork* and *fracturability*. The textural section of "first bite" followed, which included *hardness in the mouth with the first bite* and *firmness/compactness*. The section of "mastication/chewing" followed, which included *graininess*, *adhesiveness/waxiness*, *mealiness*, *moistness* and *dryness upon swallowing*. Significant differences occurred in sensory attributes of *compression with the fork*, *fracturability*, *hardness in the mouth with the first bite*, *firmness/compactness*, *graininess*, *adhesiveness/waxiness*, *mealiness*, *moistness* and *dryness upon swallowing* as presented in Table 4.2.

Compression with the fork A significant difference was found for the sensory attribute of *compression with the fork* with a probability of <0.001. The HDM cultivar (3.80^a) had the most intense *compression with the fork* rating followed by the BP1 cultivar (3.06^b) and in turn followed by the Mondial cultivar (2.75^c).

Fracturability The sensory attribute of *fracturability* was found to be significantly different between the different cultivars, with a p-value of <0.001 among the cultivars. The HDM cultivar had the most intense score (3.28^a) for *fracturability*, followed by BP1 cultivar (2.62^b) that differed significantly from the Mondial cultivar. The Mondial cultivar (2.14^c) had the lowest intensity for *fracturability*.

4.3.2.1 First bite

The sensory attribute of first bite differed significantly among the three cultivars.

Hardness in the mouth with the first bite The *hardness in the mouth with the first bite* sensory attribute had a probability of <0.001 , which indicated a significant difference between the cultivars. The HDM cultivar (3.53^a) differed significantly from BP1 (2.92^b), which, in turn, differed significantly from the Mondial cultivar (2.66^c). The HDM cultivar had a more intense “*hardness in the mouth with the first bite*” rating than both the BP1 and Mondial cultivars. Waxy potatoes are more compact and remain intact and such a potato will not easily separate into particles as with mealy potatoes (McWilliams, 2000:163; Bennion & Scheule, 2000). An easy to bite, tender, firm but soft texture seems to be the most acceptable to the consumer (Jellinek, 1985:156), which in this instance, are the BP1 and the Mondial cultivars.

Firmness/compactness Firmness is a term used to describe the structure of a potato, which is described by the textural construction (macro-, micro- and molecular structure) or granular make-up of a potato (Jellinek, 1985:155). The sensory attribute of *firmness/compactness* was significantly different among the cultivars with a probability of <0.001 . The HDM cultivar had a higher *firmness / compactness* (3.80^a) rating than the BP1 cultivar (3.06^b), which, in turn, was significantly higher than the Mondial (2.75^c) cultivar. Thus, the HDM cultivar had the highest intensity rating for *firmness/compactness*. This greatly influences the assigned culinary applications for the various potato cultivars in the classification model.

4.3.2.2 Mastication/chewing

The sensory attributes of mastication included *graininess*, *adhesiveness/waxiness*, *mealiness*, *moistness* and *dryness upon swallowing*, and statistical differences among the cultivars were established for these attributes. The sensory attributes that showed significant differences between the cultivars, are discussed.

Graininess For the sensory attribute of *graininess*, the probability of $p < 0.0001$ was found for the “*mouthfeel*” of the potatoes. The three cultivars differed significantly from each other with the HDM cultivar having the highest graininess (2.53^a). This differed significantly from the BP1 cultivar (2.71^b), which in turn was higher than the Mondial cultivar (2.18^c). Texture is a composite of those properties that arise from the structural elements of food and the manner in which it registers with the physiological senses. According to Thybo and Martens

(1998:454), somasthetic perception refers to the skinfeel by the tactile senses (mealiness and graininess) and is higher in potatoes with a high starch content.

Adhesiveness/waxiness The p-value of <0.001 shows a significant difference between the cultivars for the *adhesiveness/waxiness* sensory attribute. Mondial (3.05^a) and the HDM (2.93^a) cultivars did not differ significantly from each other, whereas the BP1 cultivar (2.55^b) was significantly lower in adhesiveness/waxiness than the other two cultivars. Adhesiveness appears to be dependent on the form of the moisture present in the potato (Thygesen *et al.*, 2001:474). According to McWilliams (2001), a compact and moist texture is associated with waxy potatoes with the presence of amylopectin molecules (<http://www.cooksillustrated.com>). Starch-filled cells separate individually or in clusters, as explained by Paul and Palmer (1972:264), which characterises mealy potatoes, as contrasted with waxy potatoes, where cells adhere. Mealy potatoes have higher specific gravities, starch and amylose contents, as well as a higher percentage of large starch granules (diameter >50 μ m) than waxy cultivars. It has been reported by Kaur *et al.* (2002:177), that tuber fragments with a higher starch content, cook softer than those containing less starch.

Mealiness The sensory attribute of *mealiness* was found to be significantly different between the three cultivars, with a probability of 0.025. Mondial cultivar (2.82^a) was significantly higher in mealiness than the BP1 cultivar (2.46^b) that had the lowest intensity for *mealiness*, followed by the HDM (2.68^{ab}) cultivar that was in between the two scores. Starch present in potato tubers plays an important role in the cooking quality, as it absorbs water and swells, creating internal pressures that can lead to cell separation, reduced cohesiveness and softening. A mealy texture according to Nourian *et al.* (2003:257) is caused by the predominance of cell separation. Mealy potatoes tend to have a higher dry matter content than waxy potatoes (Kaur *et al.*, 2002:179). According to Shomer, Vasiliver and Lindner, (1995), the permeability of the cell wall to starch is what greatly affects potato texture.

Moistness *Moistness* is an important sensory attribute in potatoes. A p-value of $p < 0.001$ was obtained, which proved a significant difference between the cultivars. The Mondial cultivar (3.07^a) and the BP1 cultivar (3.04^a) had the highest intensity for *moistness* compared to the HDM cultivar (2.35^b). The BP1 (3.04^a) and the Mondial (3.07^a) cultivars did not differ significantly from each other. The moistness of a potato according to Van Oirshot *et al.* (2003) is probably related to the activity of amylolytic enzymes during the cooking

process. The remainder of the starch content correlates with a dry mouthfeel after cooking (Thybo *et al.*, 2004:95).

Dryness upon swallowing The sensory attribute of *dryness upon swallowing* was significantly different with a probability of <0.001 . The highest rating for *dryness upon swallowing* was scored by the HDM cultivar (3.70^a), which differed significantly from the Mondial cultivar (2.97^b) and in turn from the BP1 cultivar (2.73^c). According to McComber *et al.* (1994), mealy potato cells filled with gelatinised starch, have a greater water retention level, which creates a dry characteristic mouthfeel. This dry mouthfeel is associated with the sensory attribute of *mealiness* and thus the feeling of dryness when a potato has been swallowed.

4.3.3 Flavour

Flavour is the total impression of taste, odour, tactile, kinesthetic, temperature and pain sensations perceived through tasting (Jellinek, 1985:159). The four flavour dimensions, namely an *earthy potato flavour*, a *buttery potato flavour*, a *blanched vegetable water potato flavour* and a *metallic after-taste* differed significantly among the three cultivars. Each of these sensory attributes is discussed.

Cooked potato flavour No significant difference was established among the cultivars for the *cooked potato flavour* sensory attribute with a probability of 0.308. Methional, a sulphur amino acid, may produce a cooked potato flavour (Jansky, 2010:211).

Earthy potato flavour The *earthy potato flavour* sensory attribute with a probability of <0.001 indicated a significant difference between the cultivars. The Mondial cultivar (2.72^a) had the highest rating for the sensory attribute of an *earthy potato flavour* compared to the HDM (2.10^b) and BP1 (2.12^b) cultivars. No significant difference was found between the BP1 cultivar (2.12^b) and the HDM cultivar (2.10^b). An *earthy potato flavour* seems to be more pronounced in the Mondial cultivar. A compound namely methoxypyrazines that is found in raw potato tubers and soil microbes, produces an earthy potato flavour (Jansky, 2010:211).

Buttery potato flavour The sensory attribute of a *buttery potato flavour* had a p-value of <0.001 . Two cultivars, namely HDM (2.53^a) and BP1 (2.38^a), showed no significant difference between them. The Mondial cultivar (1.73^b) differed significantly from the other two cultivars. Aroma compounds primarily determine potato flavour. Thybo *et al.* (2006:166)

indicated that the aroma compounds linalool, methional, nonanal and decanal are correlated to potato flavour.

Blanched vegetable water flavour A probability of <0.001 was established for the sensory attribute of a *blanched vegetable water flavour*. The Mondial cultivar (2.34^a) was the most intense with the *blanched vegetable water flavour* sensory attribute. No significant difference was found between the HDM cultivar (2.03^b) and the BP1 cultivar (1.90^b).

4.3.4 After-taste

The sensory attribute of a metallic after-taste differed significantly among the three cultivars.

Metallic after-taste For the sensory attribute of *metallic after-taste*, the p-value of 0.011 that indicates a significant difference among the cultivars. The Mondial cultivar (1.99^a) differed significantly from the BP1 cultivar (1.68^b). However, no significant difference was found between the HDM cultivar (1.84^{ab}) on the one hand and the BP1 cultivar and the Mondial cultivar on the other. According to Thybo *et al.* (2006:174) non-volatile compounds, such as sugars and amino acids, serve as precursors for the formation of thermally produced volatiles, as well as certain nucleotides, which could act as flavour potentiators. The Mondial cultivar had a slightly higher metallic after-taste.

4.4 PRINCIPAL COMPONENT ANALYSIS OF THE POTATO CULTIVARS FROM THE LIMPOPO PRODUCTION REGION

Principal component analysis (PCA) was performed to graphically illustrate the correlations among the different sensory attributes of potato cultivars from the Limpopo production region. Figure 4.1 gives a detailed depiction of the PCA biplot loadings of the sensory attributes and is an indication of the correlation structure of the sensory attributes. In the PCA, mean values of each individual sensory attribute was used to evaluate each potato cultivar on the sensory attributes of aroma, texture, flavour and after-taste.

In such plots, points closest together are most similar, and those far apart are dissimilar with respect to the sensory attributes. The lines connecting the sensory attributes indicate the strength of the correlations among the attributes. Thus, two lines very close together indicate

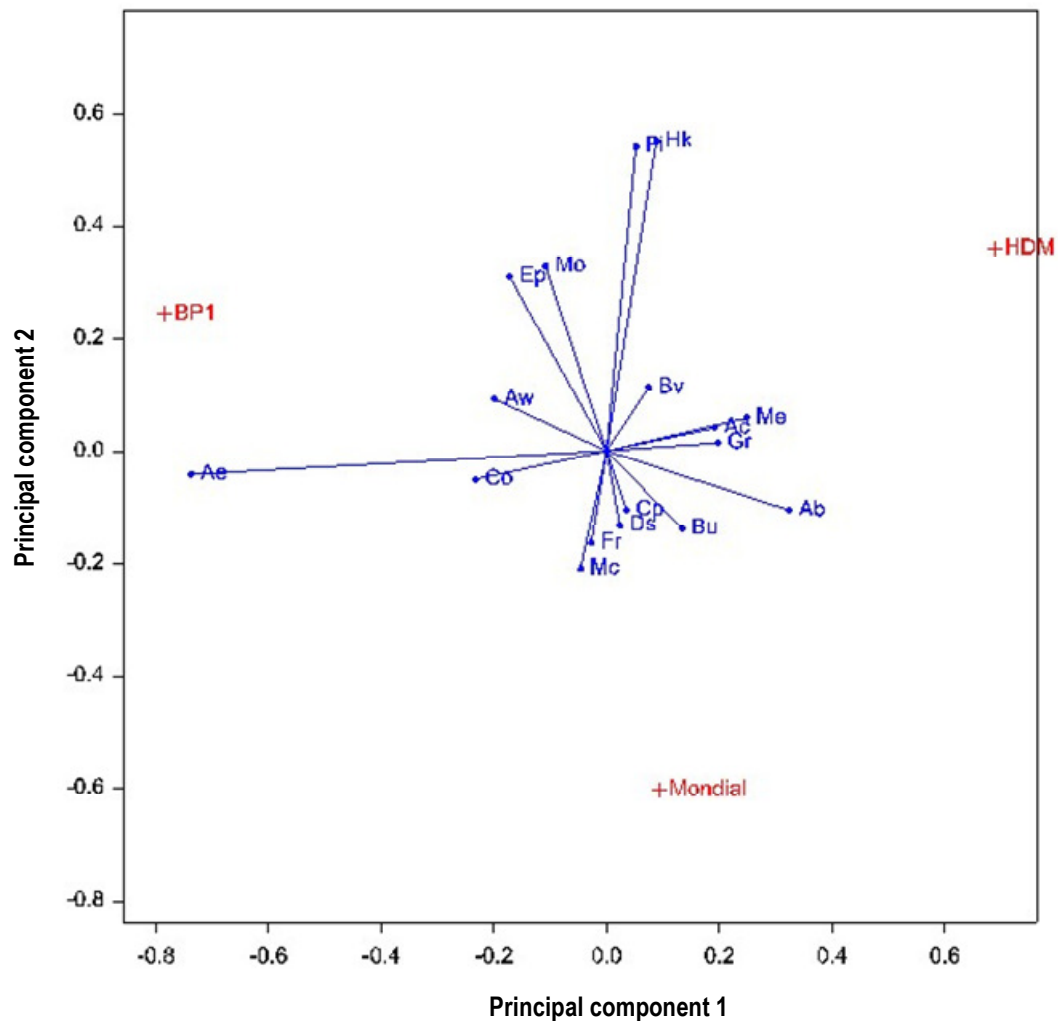
that those two attributes are positively correlated, while lines opposite each other indicate that they are negatively correlated. For example, it indicates that *hardness in the mouth* (Hk) is highly correlated with *firmness* (Fi) and that both are negatively correlated with *metallic after-taste* (Me).

A detailed illustration of the positioning of the various cultivars, relative to their sensory attributes that rated being the most intense in each cultivar, is presented. The lines farthest away from the midpoint of the axis (horizontal and vertical), explain most of the variation in the data. The points (sensory attributes) closest together are most similar, and those far apart are dissimilar. Two lines very close together indicate that those two attributes are positively correlated, while lines opposite to each other indicate that they are negatively correlated.

PC 1 accounts for 66.5% of the total variance in the sensory attributes of the different potato cultivars, while PC 2 accounts for 33.5% of the variation in the sensory data. In the principal component biplot (Figure 4.1) abbreviations are assigned to the sensory attributes descriptive of each cultivar. These are given below.

In the Limpopo region, the BP1 cultivar is mostly associated with an earthy potato aroma and with the sensory attributes of moistness, earthy potato flavour and adhesiveness/waxiness. Compression with the fork, a metallic after-taste, fracturability, dryness upon swallowing, a cooked potato flavour, a buttery flavour as well as a buttery aroma is associated with the Mondial cultivar, while the HDM cultivar is associated with graininess, a cooked potato aroma, mealiness, a blanched vegetable water flavour, hardness in the mouth and firmness/compactness.

The cooked potato aroma and compression with the fork sensory attributes are positively correlated, thus $p < 0.001$ ($p = -1.000$ and $r = -0.999$) including a positive correlation with the sensory attribute of mealiness, thus $p < 0.0093$ ($p = -1.000$ and $r = 0.9999$). An earthy potato aroma and graininess are positively correlated with $p < 0.05$ ($p = 0.0078$ and $r = -0.999$) but are negatively correlated with mealiness and a cooked potato aroma. Fracturability is positively correlated with hardness in the mouth, thus $p < 0.05$ ($p = 0.0052$ and $r = -0.9955$). A cooked potato flavour and moistness are positively correlated, thus $p < 0.05$ ($p = 0.0017$ and $r = -1.0000$).



Ab = Buttery aroma, Ac = Cooked potato aroma, Ae = Earthy potato aroma, Aw = Adhesiveness/waxiness, Bu = Buttery flavour, Bv = Blanched vegetable water flavour, Co = Compression with the fork, Cp = Cooked potato flavour, Ds = Dryness upon swallowing, Ep = Earthy potato flavour, Fi = Firmness/compactness, Fr = Fracturability, Gr = Graininess, Hk = Hardness in the mouth, Mc = Metallic after-taste, Me = Mealiness, Mo = Moistness

FIGURE 4.1: PRINCIPAL COMPONENT BILOT OF THE POSITIONS OF POTATO CULTIVARS FROM THE LIMPOPO REGION RELEVANT TO THEIR SENSORY ATTRIBUTES

The sensory evaluation results of the potatoes from the Eastern Free State region follow.

4.5 DESCRIPTIVE SENSORY ANALYSIS RESULTS OF THE POTATO CULTIVARS FROM THE EASTERN FREE STATE PRODUCTION REGION

A one-way ANOVA test was applied with Fisher's protected t-test least significant difference at 5% level of significance among cultivar means, as the data was acceptably normal and cultivar variances homogeneous. Within a region, selected sensory attributes showed significant differences as obtained with GenStat® (Payne *et al.*, 2007). The sensory data of the Eastern Free State region was a balanced design, as shown in Table 4.3.

TABLE 4.3: EXAMPLE OF A BALANCED DESIGN OF THE SENSORY ATTRIBUTES FROM THE EASTERN FREE STATE REGION

SENSORY ATTRIBUTE: COOKED POTATO AROMA			
Cultivar	Prediction	N	Standard error
BP1	4.139	36	0.1609
Mondial	4.275	40	0.1527
HDM	4.432	44	0.1456

With the sensory evaluation of the Eastern Free State region, the repetitions of each cultivar were similar with n=36 for the BP1 cultivar, n=40 for the Mondial cultivar and n=44 for the HDM cultivar, which are representative of a balanced design according to the analysis of variance (ANOVA). However, the sensory data presented 12 missing values among the three cultivars. According to Healy and Westmacott (1956), and (Payne *et al.*, 2007), the EM algorithm applied by Genstat is used to handle the missing data.

Table 4.4 presents an ANOVA analysis of the sensory attributes for three selected potato cultivars from the Eastern Free State region. Each sensory attribute that was significantly different within the different sensory attributes of aroma, texture, flavour and after-taste are discussed.

TABLE 4.4: MEAN VALUES OF THE SENSORY ANALYSIS OF THREE POTATO CULTIVARS FROM THE EASTERN FREE STATE PRODUCTION REGION

ATTRIBUTE	p-value	BP1 cultivar	Mondial cultivar	HDM cultivar
AROMA				
Cooked potato	0.401	4.14	4.28	4.43
Earthy potato	0.001	3.50 ^a	2.88 ^b	2.39 ^c
Buttery	0.005	1.34 ^a	1.73 ^b	1.82 ^a
TEXTURE				
Compression with the fork	0.033	2.77 ^a	2.6 ^{ab}	2.41 ^b
Fracturability	0.801	4.83	4.95	4.77
First bite				
Hardness in mouth (first bite)	0.017	3.22 ^{ab}	2.83 ^b	3.42 ^a
Firmness/compactness (mouth)	0.045	3.47 ^{ab}	3.05 ^b	3.61 ^a
Mastication/chewing				
Graininess	0.365	2.61	2.78	2.91
Adhesiveness/waxiness	0.319	2.58	2.33	2.30
Mealiness	0.334	2.78	2.95	3.16
Moistness	0.129	3.06	2.68	2.93
Dryness upon swallowing	0.828	3.39	3.53	3.41
FLAVOUR				
Cooked potato	0.813	4.28	4.40	4.32
Earthy/potato skin	0.157	2.97	2.55	2.75
Buttery	0.275	1.61	1.85	1.80
Blanched vegetable water	0.751	2.56	2.53	2.68
AFTER-TASTE				
Metallic	0.425	1.86	2.00	1.77

^{abc} means in a row with different superscripts differ significantly;
1 = lowest score of attribute; 8 = highest score of attribute

4.5.1 Aroma

With the aroma sensory attribute, the sensory attributes of a *cooked potato aroma*, an *earthy potato aroma* and a *buttery aroma* were evaluated. An *earthy potato aroma* and a *buttery aroma* showed significant differences among the cultivars. However, no significant difference was found for the sensory attribute of a *cooked potato aroma*.

Cooked potato aroma The sensory attribute of a *cooked potato aroma* had a p-value of 0.401, which indicated that no significant difference was found among the cultivars.

Earthy aroma The *earthy aroma* sensory attribute had a probability of <0.001, which indicates a significant difference between the cultivars. Three cultivars, BP1, Mondial and the HDM differed significantly from each other. The BP1 cultivar had the most intense *earthy potato aroma* (3.50^a), followed by the Mondial cultivar (2.88^b), with the HDM cultivar (2.39^c)

having the lowest intensity of this specific sensory attribute. The acceptance of the aroma of a food contributes to the overall acceptability of a food product (McWilliams, 2000:38).

Buttery aroma A significant difference was found between the cultivars for the sensory attribute of a *buttery aroma*, with a probability of $p = 0.005$. The HDM and the Mondial cultivars scored the highest ratings for the sensory attribute of a *buttery aroma* ($1.82^a - 1.73^a$) with the BP1 cultivar (1.34^b) scoring the lowest. The buttery aroma was more pronounced for the HDM and Mondial cultivars. As stated by Thybo *et al.* (2006:166), aroma compounds linalool, methional, nonanal and decanal are correlated to potato flavour.

4.5.2 Texture

Texture is a function of the potato structure (Abu-Ghannam & Crowley, 2006:335). During cooking, texture softens as a result of different chemical and physical changes that take place. The main structural change during the cooking process is the breakdown of the middle lamellae that leads to easy separation of the cells (Nisha *et al.*, 2005). Within the textural component, the sensory attributes of *compression with the fork*, *hardness in the mouth with the first bite*, and *firmness/compactness* showed significant differences. An evaluation of each sensory attribute follows.

Compression with the fork The *compression with the fork* sensory attribute had a probability of 0.033, which denotes a significant difference between the cultivars. *Compression with the fork* was most intense with the BP1 cultivar with a rating of (2.77^a), while the HDM cultivar had the lowest rating of (2.41^{ab}) for the *compression with the fork* sensory attribute compared to the Mondial cultivar (2.60^a).

Fracturability The sensory attribute of *fracturability* had a p-value of 0.801 that indicated that no significant difference was found among the cultivars.

The textural section of “first bite” is presented, which included the sensory attributes of *hardness in the mouth with the first bite* and *firmness/compactness*, followed by the section of “mastication/chewing” that included *graininess*, *adhesiveness/waxiness*, *mealiness*, *moistness* and *dryness upon swallowing*. Significant differences were established and are discussed.

4.5.2.1 First bite

Hardness in the mouth with the first bite A probability of 0.017 was obtained for the sensory attribute *hardness in the mouth*, which indicated a significant difference. The HDM cultivar (3.42^a) was the most intense with the *hardness in the mouth* sensory attribute. The BP1 cultivar (3.22^{ab}) did not differ significantly from the Mondial cultivar. The Mondial cultivar (2.83^b) differed significantly from the HDM cultivar and scored the lowest rating for *hardness in the mouth with the first bite* sensory attribute. Incomplete gelatinisation of starch in the presence of water, according to Chiavaro *et al.* (2005), is likely to be related to the hardness among the cultivars. The hardness of a cultivar type might also be related to the changes in the potato cell wall and middle lamella during the heating process, as in the case of the HDM cultivar.

Firmness/compactness in the mouth The sensory attribute of *firmness/compactness in the mouth* had a p-value of 0.045, which indicated a significant difference among the cultivars. The HDM cultivar had a score of (3.61^a), which indicated the highest intensity for the *firmness/compactness* sensory attribute, and the BP1 cultivar had a score of (3.47^{ab}) that did not differ significantly from the HDM cultivar. The Mondial cultivar differed significantly from the HDM cultivar with the lowest score of (3.05^b) for the sensory attribute *firmness/compactness*. Low temperature blanching in the range of 55-75 °C has been shown to improve firmness of cooked vegetables, reducing the physical breakdown and sloughing and providing an excellent and safe way of preserving texture. According to Abu-Ghannam and Crowley (2006:336), it has been proposed that the enzyme pectin methyl esterase (PME), present in fruit and vegetables, plays a role in this firming effect at low blanching temperatures, as illustrated by the HDM cultivar.

4.5.2.2 Mastication/chewing

The last section of the textural component of “mastication/chewing” included the sensory attributes of *graininess*, *adhesiveness/waxiness*, *mealiness*, *moistness* and *dryness upon swallowing*. No statistical differences were established among the cultivars.

Graininess The sensory attribute of *graininess* had a probability of 0.365, which showed no statistical differences among the cultivars.

Adhesiveness/waxiness The sensory attribute of *adhesive/waxiness* had a probability of 0.319. No statistical differences were found between among the cultivars.

Mealiness The sensory attribute of *mealiness* had a probability of 0.334. No statistical differences were established among the cultivars.

Moistness The sensory attribute of *moistness* had a probability of 0.129. No statistical differences between the cultivars were found.

Dryness upon swallowing The sensory attribute of *dryness upon swallowing* had a probability of 0.828. No statistical differences were established among the cultivars.

4.5.3 Flavour

The four flavour dimensions included a *cooked potato flavour*, an *earthy potato flavour*, a *buttery potato flavour*, and a *blanched vegetable water potato flavour*. No significant differences were established among the cultivars for the four flavour components.

Cooked potato flavour The sensory attribute of a *cooked potato flavour* had a probability of 0.813, which showed that no statistical differences were found among the cultivars.

Earthy potato flavour The sensory attribute of an *earthy potato flavour* had a probability of 0.157. No statistical differences were established among the cultivars.

Buttery flavour The sensory attribute of a *buttery flavour* had a probability of 0.275, which showed that no statistical differences were found among the cultivars.

Blanched vegetable water flavour The sensory attribute of a *blanched vegetable water flavour* had a probability of 0.751. No statistical differences were established among the cultivars.

4.5.4 After-taste

The sensory attribute of a metallic after-taste did not differ significantly among the three cultivars.

Metallic after-taste The sensory attribute of a *metallic after-taste* did not differ significantly among the three cultivars as a probability of 0.425 was established. No statistical differences were found among the cultivars.

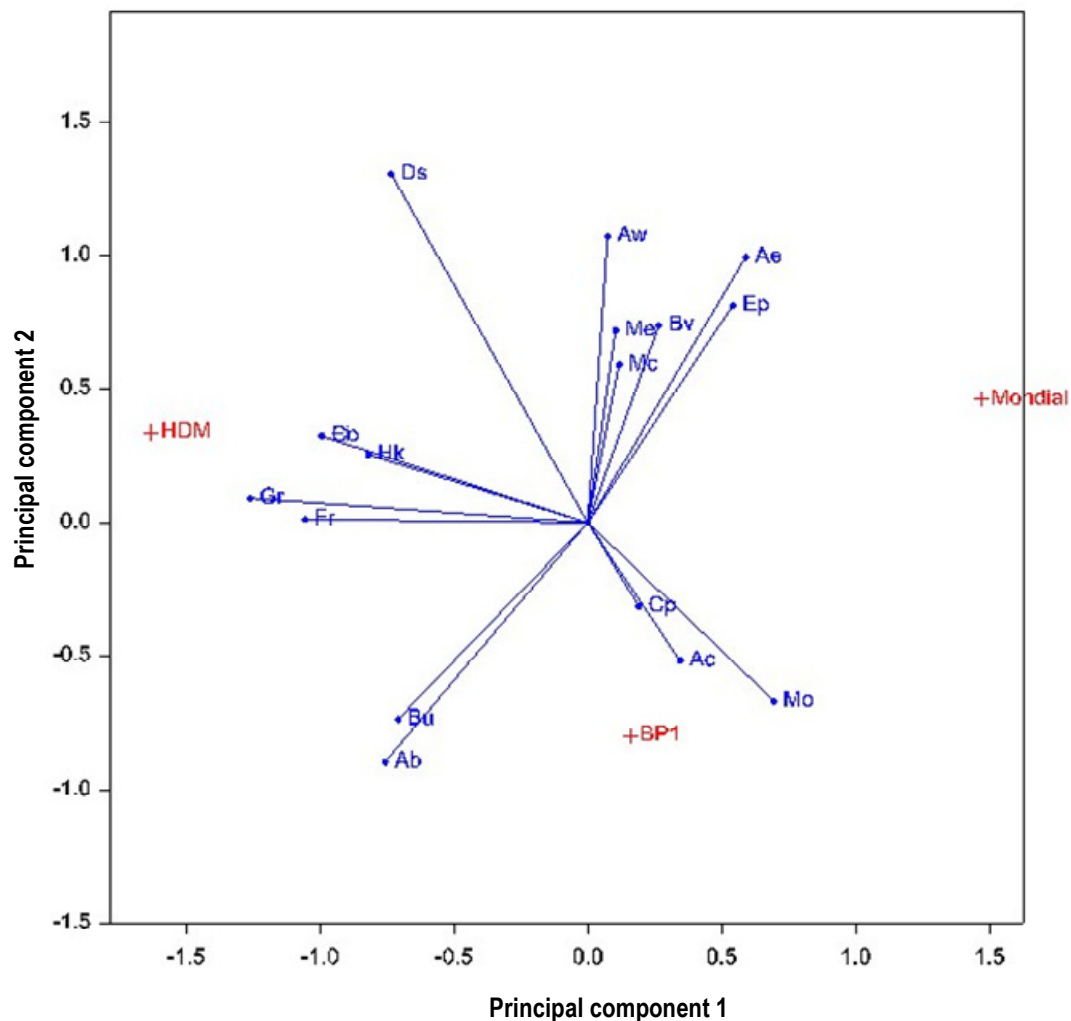
4.6 PRINCIPAL COMPONENT ANALYSIS OF THE POTATO CULTIVARS FROM THE EASTERN FREE STATE PRODUCTION REGION

Principal component analysis (PCA) was performed to graphically illustrate the correlations between the different sensory attributes. In the PCA, mean values of each individual sensory attribute was used to evaluate each potato cultivar on the sensory attributes of aroma, texture, flavour and after-taste.

In such plots, points closest together are most similar, and those far apart are dissimilar, with respect to the sensory attributes. The lines connecting the sensory attributes indicate the strength of the correlations between the attributes. Thus, two lines very close together indicate that those two attributes are positively correlated, while lines opposite each other indicate that they are negatively correlated.

A detailed illustration of the positioning of the various cultivars (BP1, Mondial and HDM), relative to their sensory attributes (rated being the most intense in each cultivar), is presented in Figure 4.2. The lines far-off explain most of the variation in the data from the midpoint of the axis (horizontal and vertical). A positive correlation is where two lines (sensory attributes) are very close to each other and are thus most similar. Those far apart are dissimilar, while a negative correlation is indicated with lines opposite each other. A variation of 83.5% in the data of the sensory attributes of the different potato cultivars is explained in PC 1, with PC 2 explained 16.5% of the variation in the sensory data.

Abbreviations are used to identify the positioned sensory attributes in Figure 4.2, and are given below for the convenience of the reader.



Ab = Buttery aroma, Ac = Cooked potato aroma, Ae = Earthy potato aroma, Aw = Adhesiveness/waxiness, Bu = Buttery flavour, Bv = Blanched vegetable water flavour, Co = Compression with the fork, Cp = Cooked potato flavour, Ds = Dryness upon swallowing, Ep = Earthy potato flavour, Fi = Firmness/compactness, Fr = Fracturability, Gr = Graininess, Hk = Hardness in the mouth, Mc = Metallic after-taste, Me = Mealiness, Mo = Moistness

FIGURE 4.2: PRINCIPAL COMPONENT BILOT OF THE POSITIONS OF POTATO CULTIVARS FROM THE EASTERN FREE STATE REGION RELEVANT TO THEIR SENSORY ATTRIBUTES

The sensory attributes of a buttery flavour, a buttery aroma, compression with the fork, a cooked potato aroma and moistness are associated with the BP1 cultivar. In contrast to the BP1 cultivar, the HDM cultivar is associated with fracturability, graininess, hardness in the mouth, firmness/compactness and dryness upon swallowing, while the Mondial cultivar is associated with the sensory attributes of adhesiveness/waxiness, mealiness, a metallic after-taste, a blanched vegetable water flavour, an earthy potato aroma and an earthy potato flavour.

In this instance, the PCA biplot of the Eastern Free State region does not agree with the results of the ANOVA analysis, as it was shown that the Mondial cultivar had a more intense buttery flavour than to the BP1 cultivar as opposing with the results from the PCA biplot (Figure 4.2) that the BP1 cultivar had a more intense buttery flavour.

The sensory attributes of moistness, a cooked potato flavour and a cooked potato aroma are positively correlated, thus $p < 0.05$ (with $p = 0.0267$ and $r = 0.9991$) but are negatively correlated with dryness upon swallowing. A buttery aroma is positively correlated with a buttery potato flavour with $p < 0.05$ ($p = 0.0330$ and $r = 0.9987$). Hardness in the mouth is positively correlated with firmness, thus $p < 0.05$ (with $p = 0.0045$ and $r = 1.0000$) including a positive correlation for the dryness upon swallowing and a cooked potato flavour sensory attributes with $p < 0.05$ ($p = 0.0330$ and $r = 0.9987$). An earthy potato aroma and an earthy potato flavour are positively correlated, thus $p < 0.05$ (with $p = 0.0354$ and $r = 0.9985$), but are negatively correlated with a buttery aroma and a buttery flavour.

4.7 COMPARISON OF THE POTATO CULTIVARS FROM THE TWO PRODUCTION REGIONS

The sensory evaluation results of the potato cultivars of each production region are compared first, followed by the comparison of the objective measurements of the two production regions in order to determine whether differences exist in the eating quality of the cultivars from the two production regions.

4.7.1 Comparison of the sensory attributes of the cultivars from the Limpopo production region

The sensory attributes of the cultivars BP1, Mondial and the HDM from the Limpopo region are compared in Figure 4.3.

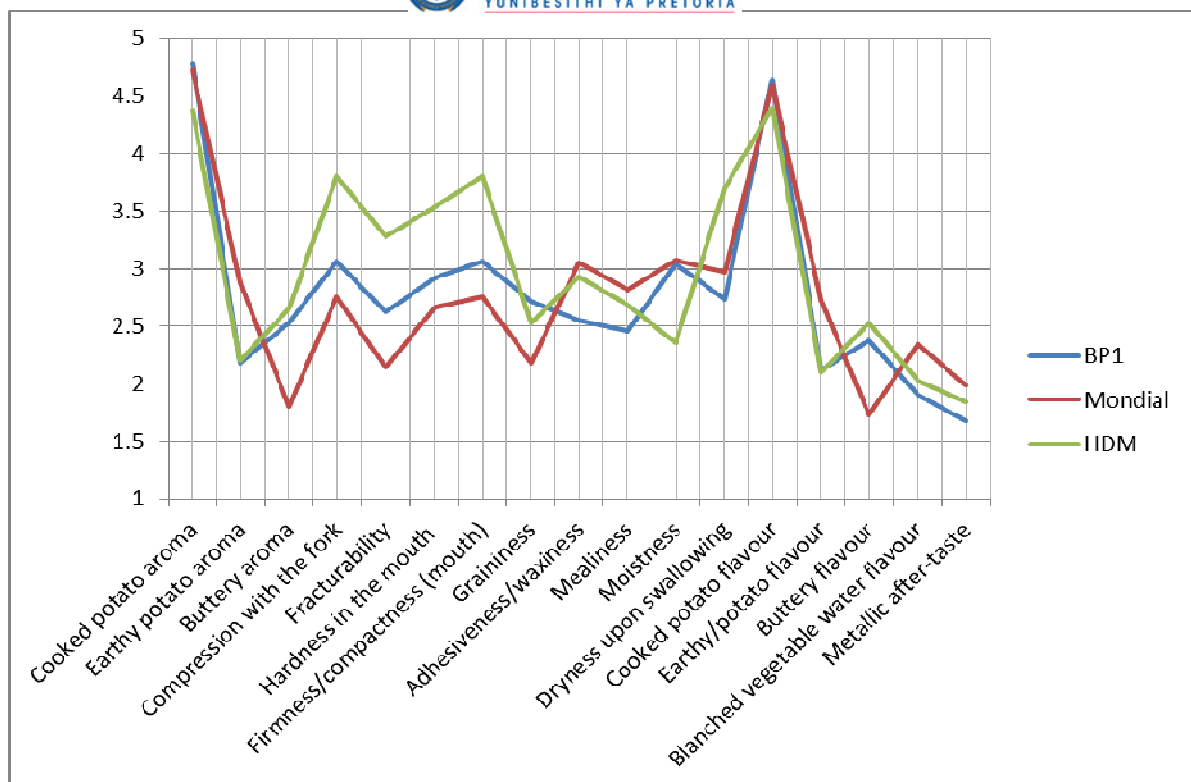


FIGURE 4.3: COMPARISON OF THE SENSORY ATTRIBUTES OF THE CULTIVARS FROM THE LIMPOPO PRODUCTION REGION

The Mondial cultivar had the most intense ratings for the sensory attributes of earthy aroma, adhesiveness/waxiness, moistness and an earthy potato flavour. BP1 and HDM cultivar scored the highest ratings for buttery aroma and the compression with the fork. Fracturability, hardness in the mouth, firmness/compactness, graininess, dryness upon swallowing and a buttery flavour are the sensory attributes in which the highest ratings are scored by the HDM cultivar. According to Van Marle *et al.* (1997b:1686), the total cell wall material and amount and composition of solubilised pectic material for a potato cultivar (mealy versus waxy) differs.

4.7.2 Comparison of the objective measurements of the cultivars from the Limpopo production region

A comparison of the objective measurements, including specific gravity, shear force measurement, load maximum and percentage softening, was performed for BP1, Mondial and HDM cultivars from the Limpopo region, and is presented in Table 4.5.

TABLE 4.5: COMPARISON OF THE OBJECTIVE MEASUREMENTS OF THE CULTIVARS FROM THE LIMPOPO PRODUCTION REGION

	p-value	BP1	Mondial	HDM
Specific gravity	<.001	1.065 ^b	1.060 ^c	1.088 ^a
Load maximum shear force, raw	<.001	3.297 ^b	3.066 ^c	4.134 ^a
Load maximum cooked, warm	0.061	0.270	0.270	0.380
Percentage softening cooked, still warm	0.676	91.860	90.900	90.770
Load maximum cooked, cooled	0.027	0.328 ^b	0.298 ^b	0.443 ^a
Percentage softening cooked, cooled	0.746	90.070	90.340	89.160

^{abc} means in a row with different superscripts differ significantly

Significant differences were found for specific gravity, load maximum shear force for raw potato samples as well as load maximum cooked, then cooled, among the different cultivars from the Limpopo region. No significant differences were established for load maximum cooked, warm, percentage softening cooked, still warm and percentage softening cooked, then cooled. The objective measurements that proved significant differences between the cultivars are discussed.

Specific gravity The objective measurement of *specific gravity* had a p-value of <0.001 that indicated a significant difference among the cultivars. The HDM cultivar had a score of (1.088^a), which indicated the highest score for *specific gravity*, followed by the BP1 cultivar (1.065^b) and the Mondial cultivar (1.060^c) for the objective measurement of *specific gravity*.

Load maximum shear force, raw A significant difference was found for the objective measurement of *load maximum shear force*, in a raw state with a probability of <0.001. The HDM cultivar (4.134^a) had the highest score for the *load maximum shear force, raw* followed by the BP1 cultivar (3.297^b) and in turn followed by the Mondial cultivar (3.066^c).

Load maximum cooked, cooled The objective measurement of *load maximum cooked, and then cooled* was found to be significantly different between the different cultivars, with a p-value of 0.027 among the cultivars. The HDM cultivar had the most intense score (0.443^a) for *load maximum cooked, cooled* followed by BP1 cultivar (0.328^b) and the Mondial cultivar (0.298^b) that did not differ significantly from each other.

4.7.3 Comparison of the sensory attributes of the cultivars from the Eastern Free State production region

In Figure 4.4, the sensory attributes of the BP1, Mondial and HDM potato cultivars from the Eastern Free State region are compared.

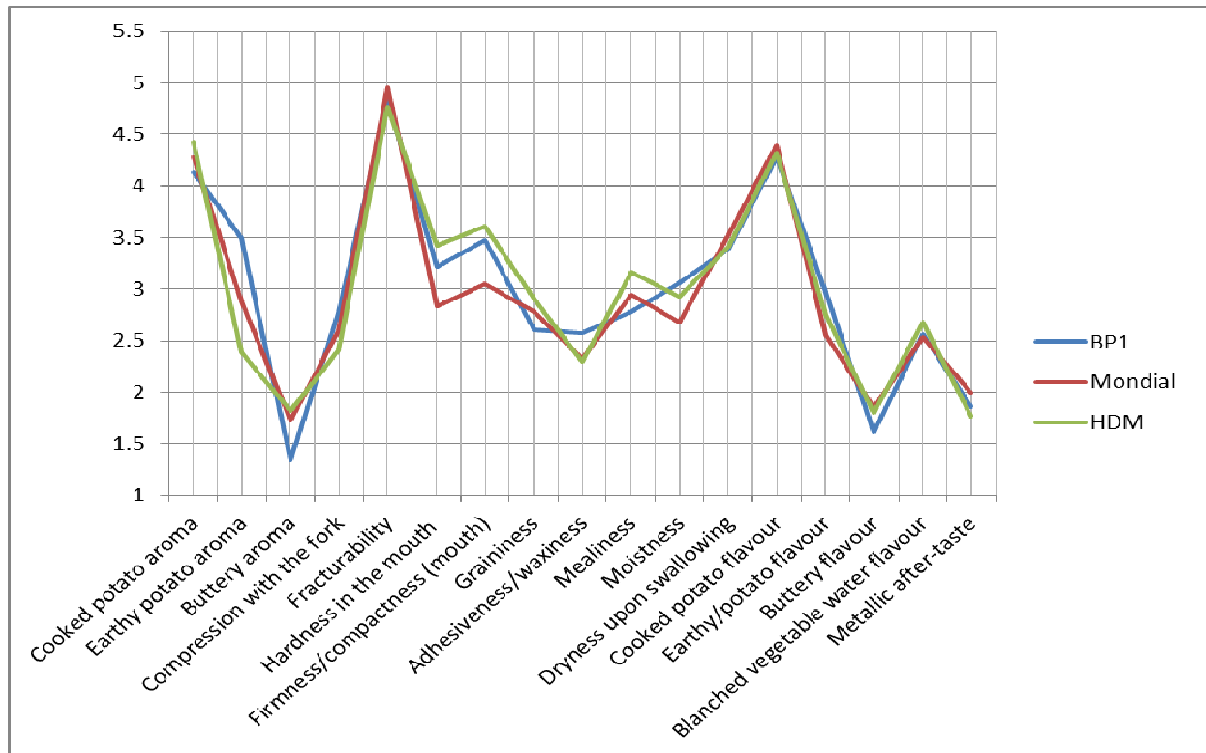


FIGURE 4.4: COMPARISON OF THE SENSORY ATTRIBUTES OF THE CULTIVARS FROM THE EASTERN FREE STATE PRODUCTION REGION

The sensory evaluation's results for the Eastern Free State region are presented in Figure 4.4. The BP1 cultivar obtained the highest ratings for the sensory attributes of an earthy potato aroma and compression with the fork. The HDM cultivar had the most intense ratings for hardness with the first bite and firmness/compactness, while the Mondial cultivar scored the lowest ratings for the sensory attributes of hardness with the first bite and firmness/compactness.

4.7.4 Comparison of the objective measurements of the cultivars from the Eastern Free State production region

Objective measurements of specific gravity, shear force measurement, load maximum and percentage softening were performed for BP1, Mondial and HDM cultivars from the Eastern Free State region and are presented in Table 4.6.

TABLE 4.6: COMPARISON OF THE OBJECTIVE MEASUREMENTS OF THE CULTIVARS FROM THE EASTERN FREE STATE PRODUCTION REGION

	p-value	BP1	Mondial	HDM
Specific gravity	<.001	1.078 ^b	1.079 ^b	1.097 ^a
Load maximum shear force, raw	<.001	4.519 ^b	4.091 ^c	5.140 ^a
Load maximum cooked, warm	0.497	0.309	0.313	0.365
Percentage softening cooked, still warm	0.769	92.89	92.26	93.11
Load maximum cooked, cooled	0.278	0.322	0.38	0.433
Percentage softening cooked, cooled	0.317	92.74	90.68	91.65

^{abc} means in a row with different superscripts differ significantly

Significant differences were found for specific gravity and load maximum shear force for raw potato samples. No significant differences were established for Load maximum cooked, warm, percentage softening cooked, still warm, load maximum cooked, cooled and percentage softening cooked, then cooled. The objective measurements that proved significant differences between the cultivars are discussed.

Specific gravity The objective measurement of *specific gravity* had a p-value of <0.001 that indicated a significant difference among the cultivars. The HDM cultivar had a score of (1.097^a), which indicated the highest score for *specific gravity*, followed by the BP1 cultivar (1.078^b) and the Mondial cultivar (1.079^b) that did not differ significantly for the objective measurement of *specific gravity*.

Load maximum shear force, raw A significant difference was found for the objective measurement of *load maximum shear force*, in a raw state with a probability of <0.001. The HDM cultivar (5.140^a) had the highest score for the *load maximum shear force, raw* objective measurement followed by the BP1 cultivar (4.519^b) and in turn followed by the Mondial cultivar (4.091^c).

Objective one (1) and objective two (2) as presented in chapter 3 (see paragraph 3.4) were carried out and are presented in paragraph 4.2-4.6 in this chapter. Objective one (1) aimed

to determine, describe and compare the sensory attributes namely aroma, texture, flavour and after-taste of the three cultivars within in each region, in order to compare the eating quality of the potato cultivars from the two production regions. Objective two (2) aimed to determine, describe and compare the physical attributes namely specific gravity, shear force resistance and scanning electron microscopy of the three cultivars within in each region, in order to compare the eating quality of the potato cultivars from the two production regions.

In order to determine whether differences (if any) exist in the eating quality of the two production regions, a comparison of the eating quality of the cultivars from these two production regions will be presented, followed by a visual representation of the two production regions.

4.8 PRINCIPAL COMPONENT ANALYSIS OF THE POTATO CULTIVARS FROM BOTH PRODUCTION REGIONS FOR A REGION-TO-REGION COMPARISON

A multivariate analysis, namely a principal component analysis (PCA) was performed for both production regions in order to establish whether different production regions and growing conditions have an effect on the sensory attributes of the cultivars with a region-to-region evaluation among the cultivars.

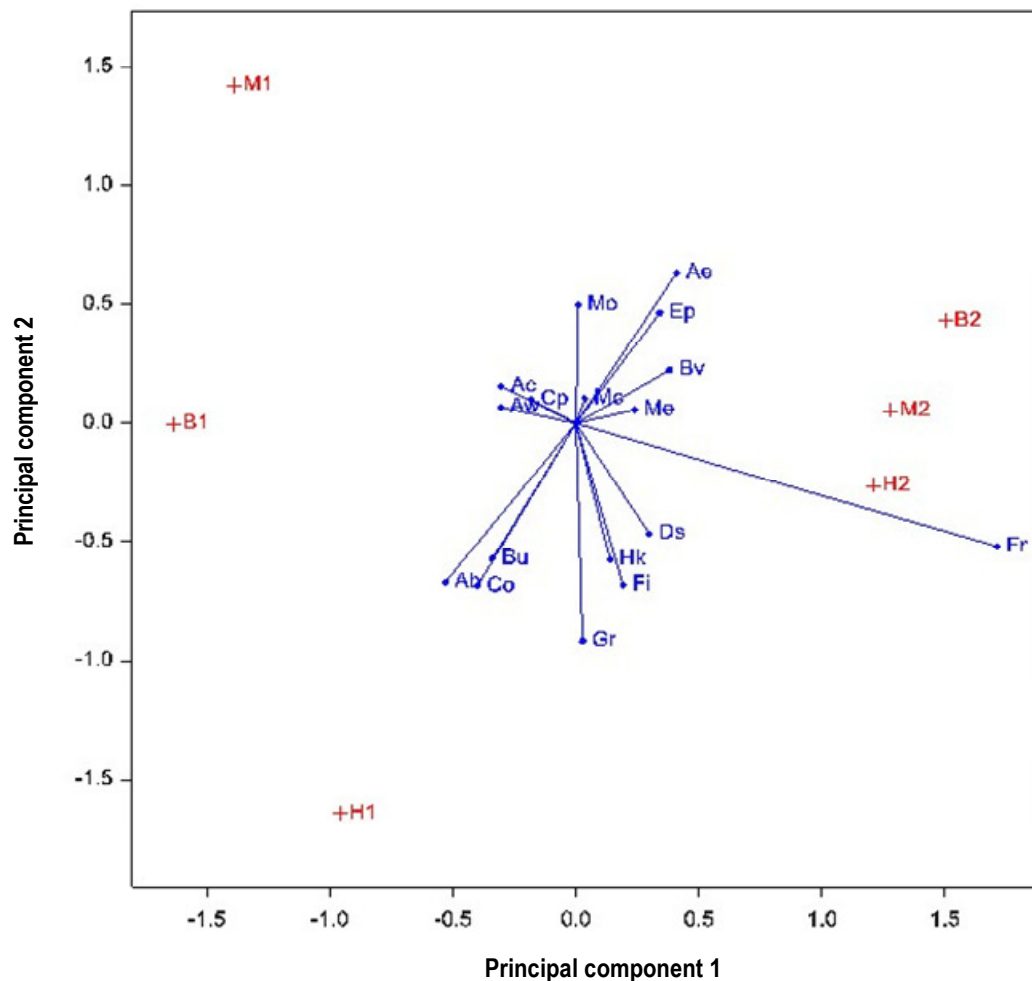
Figure 4.5 shows the positioning of the potato cultivars relevant to their sensory attributes, from both production regions. The Limpopo region is indicated as Region (R1), thus the cultivars in the region are indicated as M1 for the Mondial cultivar, followed by the BP1 cultivar indicated as B1 and the HDM cultivar as H1. Region (R2) represents the Eastern Free State region and similar indicators apply for the various cultivars referring to the BP1 cultivar as B2, the Mondial cultivar as M2, and the HDM cultivar as H2.

Figure 4.5 represents a detailed illustration of the positioning of the various cultivars, from the two production regions, relative to their sensory attributes, which rated being the most intense in each cultivar. PC 1 explains 60.1% of the variation in the data of the sensory attributes of the different potato cultivars while PC 2 explains 27.4% of the variation in the sensory data of both regions. In this biplot it is evident that the first PC contrasts the two regions. The three cultivars of Region 2 (Eastern Free State region) appear on the right-hand side while the three cultivars of Region 1 (Limpopo region) appear on the left-hand side. It is also clear that the cultivar differences in Region 2, the Eastern Free State region,

with dry-land growing conditions, are less apparent with B2, M2, H2 very close together, than under irrigation with M1, B1 and H1 which are much further apart. The Mondial cultivar from the Limpopo region is characterised by having the sensory attributes of moistness, a cooked potato flavour, a cooked potato aroma and adhesiveness/waxiness whereas the BP1 and the HDM cultivars are associated with a buttery aroma, compression with the fork and a buttery flavour as seen in Figure 4.5.

In the Eastern Free State region, the BP1 cultivar has the sensory attributes of an earthy potato aroma, a metallic after-taste and an earthy potato flavour, while sensory attributes of a blanched vegetable water flavour, mealiness and fracturability are associated with the Mondial cultivar. According to Van Marle *et al.* (1997a:53), the uronic acid, arabinose and galactose are present in higher concentrations in the cooking medium of a mealy potato. The glucose found in the cooking medium is most likely originated from the starch and not from cellulose, which is not solubilised upon cooking.

The HDM cultivar is characterised by the sensory attributes of dryness upon swallowing, hardness with the first bite, firmness/compactness and graininess. The changes in potato texture of the cultivars are due to the changes in structure and chemical composition. As stated by Abu-Ghannam and Crowley (2006:336), the rigid structure of the raw potato is mainly due to the pectic substances, celluloses and hemicelluloses. According to Van Marle *et al.* (1997b:1691), the differences found between the pectic polysaccharides of the cultivars may influence the solubilisation of pectic polysaccharides during the cooking of potatoes. Part of the cell wall material solubilised during cooking originated from the middle lamellae. The solubilised material is relatively more branched and higher methylated and acetylated for mealy potatoes than for waxy potatoes.



Ab = Buttery aroma, Ac = Cooked potato aroma, Ae = Earthy potato aroma, Aw = Adhesiveness/waxiness, Bu = Buttery flavour, Bv = Blanched vegetable water flavour, Co = Compression with the fork, Cp = Cooked potato flavour, Ds = Dryness upon swallowing, Ep = Earthy potato flavour, Fi = Firmness/compactness, Fr = Fracturability, Gr = Graininess, Hk = Hardness in the mouth, Mc = Metallic after-taste, Me = Mealiness, Mo = Moistness

R1 = Region 1, Limpopo region; R2 = Region 2, Eastern Free State region; B1 = BP1 cultivar from the Limpopo region; M1 = Mondial cultivar from the Limpopo region; H1 = HDM cultivar from the Limpopo region; B2 = BP1 cultivar from the Eastern Free State region; M2 = Mondial cultivar from the Eastern Free State region; H2 = HDM cultivar from the Eastern Free State region

FIGURE 4.5: PRINCIPAL COMPONENT BILOT OF THE POSITIONS OF POTATO CULTIVARS FROM BOTH PRODUCTION REGIONS RELEVANT TO THEIR SENSORY ATTRIBUTES

The results of the scanning electron microscopy performed for the BP1 and Mondial cultivar are presented and discussed below.

4.9 SCANNING ELECTRON MICROSCOPY

Scanning electron microscopy (SEM) of the cultivars BP1 and Mondial of the Limpopo production region were executed in the raw and cooked stages to establish whether a physical, observable difference exist between the cultivars. With an image analysis, the texture provides a measure of properties such as lightness, granulation, uniformity, density, roughness, regularity, linearity, frequency, phase, directivity, coarseness, randomness, fineness and smoothness (Thybo *et al.*, 2004:92).

Photographs produced by a scanning electron microscopy show starch granules within the cell walls and the cells of the potatoes in the raw state and the gelatinised starch fraction in the cooked state.

The two cultivars are depicted in a raw and a cooked stage. The scanning electron microscopy of the two cultivars in the two stages, namely raw and cooked stages, are depicted from Figure 4.6 to Figure 4.7. As the HDM cultivar was only used as a control sample for the sensory evaluation, no scanning electron microscopy was performed on this specific cultivar. In order to present a clear-cut image, the image of the BP1 cultivar is enlarged (x1000) times and the image of the Mondial cultivar (x200) times enlarged.

4.9.1 Scanning electron microscopy on raw potato samples

Differences between the raw potato samples of the two potato cultivars, BP1 and Mondial, are depicted in Figure 4.6 and Figure 4.7.

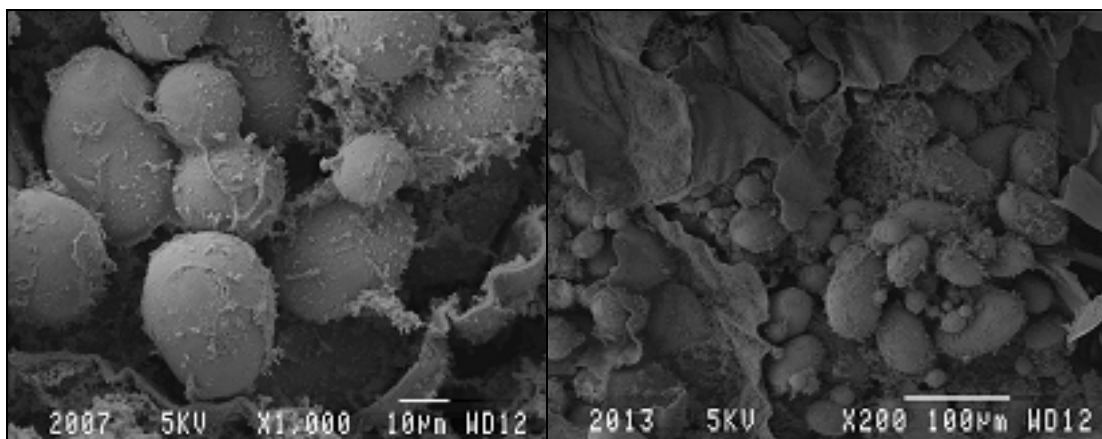


FIGURE 4.6: BP1 - RAW SAMPLE

FIGURE 4.7: MONDIAL - RAW SAMPLE

A microtome method is used to accurately measure the size of a granule. Starch granules are present with the BP1 and the Mondial cultivar. The starch granules found in the Mondial cultivar are slightly larger than the actual BP1 cultivar. According to Singh *et al.* (2005), in Gibson (2006), larger starch granules will have higher swelling power that cause increased pressure within the cell. With larger starch grains, the starch content is high and a more mature potato tuber can be expected (Thygesen *et al.*, 2001:472).

As a result of the assumed larger size of the starch granules, the Mondial cultivar would have a higher dry matter content (Gibson, 2006:44). If a higher mealiness is experienced (Thybo *et al.*, 2000; Van Dijk *et al.*, 2002a), a high dry matter content is present. Thus, cultivars with a high dry matter content will be expected to have bigger starch granules.

Cell size has an influence on the textural qualities of the potato (McComber *et al.*, 1994). The amount of starch determines the texture. A mealy potato has a high starch content that disintegrates during boiling and mashing, as the intracellular cohesion is diminished after cooking (Laza, 1999:21; Van Dijk *et al.*, 2002a:5089). According to Thybo *et al.* (2000) and Van Dijk *et al.* (2002b), a higher dry matter content is associated with a more mealy product and that suggests that the Mondial cultivar from the Limpopo region would be more mealy than the BP1 cultivar (Gibson, 2006:45). An abundant intracellular cohesion between the starch granules predicts a waxy texture for a potato (Martens & Thybo, 2000 & Thybo *et al.*, 2002 in Gibson, 2006:45).

4.9.2 Scanning electron microscopy on cooked samples

The photographs taken of the cooked potato samples from the different cultivars indicate differences between the cultivars.

Cooked samples of the BP1 and Mondial cultivars used for the scanning electron microscopy are presented below. Figure 4.8 represents the sample for the BP1 cultivar while Figure 4.9 represents the sample for the Mondial cultivar.

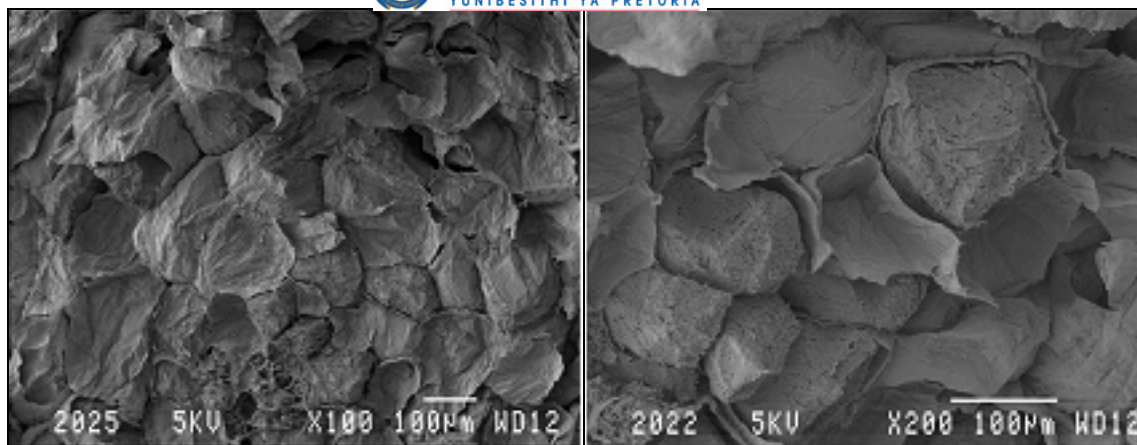


FIGURE 4.8: BP1 - COOKED SAMPLE

FIGURE 4.9: MONDIAL - COOKED SAMPLE

There appeared to be a difference in the degree of the swelling of the starch as well as with the separation of the gelatinised starch from the cell walls (as seen in Figures 4.6 and 4.7).

The BP1 cultivar seemed to undergo a higher degree of swelling of the starch than the Mondial cultivar while the Mondial seemed to have a higher degree of separation of gelatinised starch from the cell walls. Taking a closer look at the Mondial cultivar's starch granules in a raw state, they were examined to be larger (See Figure 4.7) (Gibson; 2006:45). Singh *et al.* (2005) reported that larger starch granules have a higher swelling pressure and degree of swelling but the direct opposite was discovered with the Mondial cultivar. Cells are intact and a thriving intercellular cohesion between the cells exists, predicting a waxy texture for both of the cultivars (Thybo & Martens, 2000; Thybo *et al.*, 2002). Waxy potatoes are more compact and have a moist texture. This potato will not easily separate into particles and has a lower starch content than mealy potatoes (McWilliams, 2000:163). Mealy potatoes have higher specific gravities, starch and amylase contents as well as a higher percentage of large starch granules (diameter>50mm) than waxy cultivars (Kaur *et al.*, 2002:17).

The cells of the cooked BP1 cultivar seems to be more closely compressed and wrinkled, which might indicate that a higher mealiness than the Mondial cultivar could occur within this cultivar (Thybo & Martens, 2000 in Gibson, 2006:45). According to Van Oirshot *et al.* (2003), mealiness is associated with an increase in polarised cell walls and larger, more irregular shaped cells, engorged with gelatinised starch after cooking. The predictions based on the SEM results that the Mondial cultivar would be more mealy than the BP1 cultivar, were contradicted. However, further scientific tests and methods need to be developed to accurately measure and analyse these results. (Gibson, 2006:45).

To facilitate a complete presentation of the characteristics of the selected potato cultivars, including both the sensory and objective evaluations' results of the two regions, a partial least squares (PLS) regression method was applied.

4.10 INTERPRETATION OF THE PARTIAL LEAST SQUARES (PLS) REGRESSION MODEL ON TWO PRODUCTION REGIONS

PLS regression modelling (Vargas, Crossa, Sayre, Reynolds, Ramirez & Talbot, 1998) was applied to the two production regions and the three potato cultivars, which were planted in both regions to determine whether there are regional and/or cultivar differences. In the biplot, the Y=dependent variables were the sensory attributes of 17 mean values per cultivar, and the X=independent variables were six mean objective measurement values per cultivar. The PLS regression was applied to relate the sensory attributes to the objective measurements (Peppard, Ramus, Witt, & Siebert, 1989; Toscas, Shaw & Beilken, 1999) and to identify the most important attributes differentiating between the potato cultivars as well as between the two regions. The six objective measurements that were performed assisted in the characterisation of the different potato cultivars. All the sensory attributes and objective test values used in the PLS regression model were taken as the means for each cultivar (Smith *et al.*, 2009:32, 33).

The first dimension of the PLS regression model explains most of the variation in all the data, followed by the second dimension. A biplot of the Y and X matrix loadings indicates points for the 17 sensory attributes, the six objective measurements, and the three cultivars in two regions in Figure 4.10. In such plots, points close together are more similar and those farthest apart are dissimilar.

In Table 4.7 below, the summary of the percentage variance (first and second dimension of the PLS regression model) for the sensory attributes (dependant variables) and the objective measurements (independent variables), is presented.

TABLE 4.7: PERCENTAGE VARIANCE EXPLAINED, RANKED ACCORDING TO THE FIRST DIMENSION, AFTER PLS APPLICATION TO THE SENSORY ATTRIBUTES AND OBJECTIVE TESTS (PHYSICAL MEASUREMENTS) ON THREE CULTIVARS

Y matrix (dependent variables) Sensory attributes	% of the Y variances explained		X matrix (independent variables) Physical variables	% of the X variances explained	
	1st dimension	2nd dimension		1st dimension	2nd dimension
Cooked potato flavour	86.3	0.1	Load maximum shear force raw	96.6	2.1
Fracturability	86.2	2.7	Specific gravity	73.8	25.2
Cooked potato aroma	61.0	0.2	Percentage softening, warm	60.4	28.5
Blanched vegetable flavour	52.5	21.6	Load maximum cooked, warm	44.3	49.5
Adhesiveness/waxiness	47.9	4.5	Percentage softening, cooled	42.4	52.0
Mealiness	47.3	1.1	Load maximum cooked, cooled	31.7	64.8
Firmness	44.8	36.0			
Dryness upon swallowing	44.0	21.6			
Hardness in the mouth	41.2	37.3			
Earthy potato flavour	23.0	52.8			
Buttery aroma	21.7	62.3			
Buttery flavour	14.2	63.5			
Compression with the fork	13.8	53.5			
Graininess	12.6	77.2			
Earthy potato aroma	5.9	59.4			
Moistness	1.7	71.6			
Metallic after-taste	1.3	6.2			

Of the 17 sensory attributes (see Table 4.9), a cooked potato flavour (86.3%), fracturability (86.2%) and a cooked potato aroma (61.0%), as well as the objective measurements of load maximum shear force measurement, in a raw state (96.6%), specific gravity (73.8%) and percentage (%) softening cooked, still warm (60.4%) explained most of the variances in the first dimension (cf horizontal axis of Figure 4.7). In the second dimension (cf vertical axis of Figure 4.7), graininess (77.2%), moistness (71.6%), buttery flavour (63.5%), buttery aroma (62.3%) and load maximum cooled, once cooked (64.8%) explained most of the variances.

Figure 4.10 represents a dry-land production region in Region 2 (Eastern Free State region) where the BP1 (2) and Mondial (2) are more similar in nature compared to an irrigated production region in Region 1 (Limpopo region) where the Mondial (1) and the HDM (1) are more dissimilar.

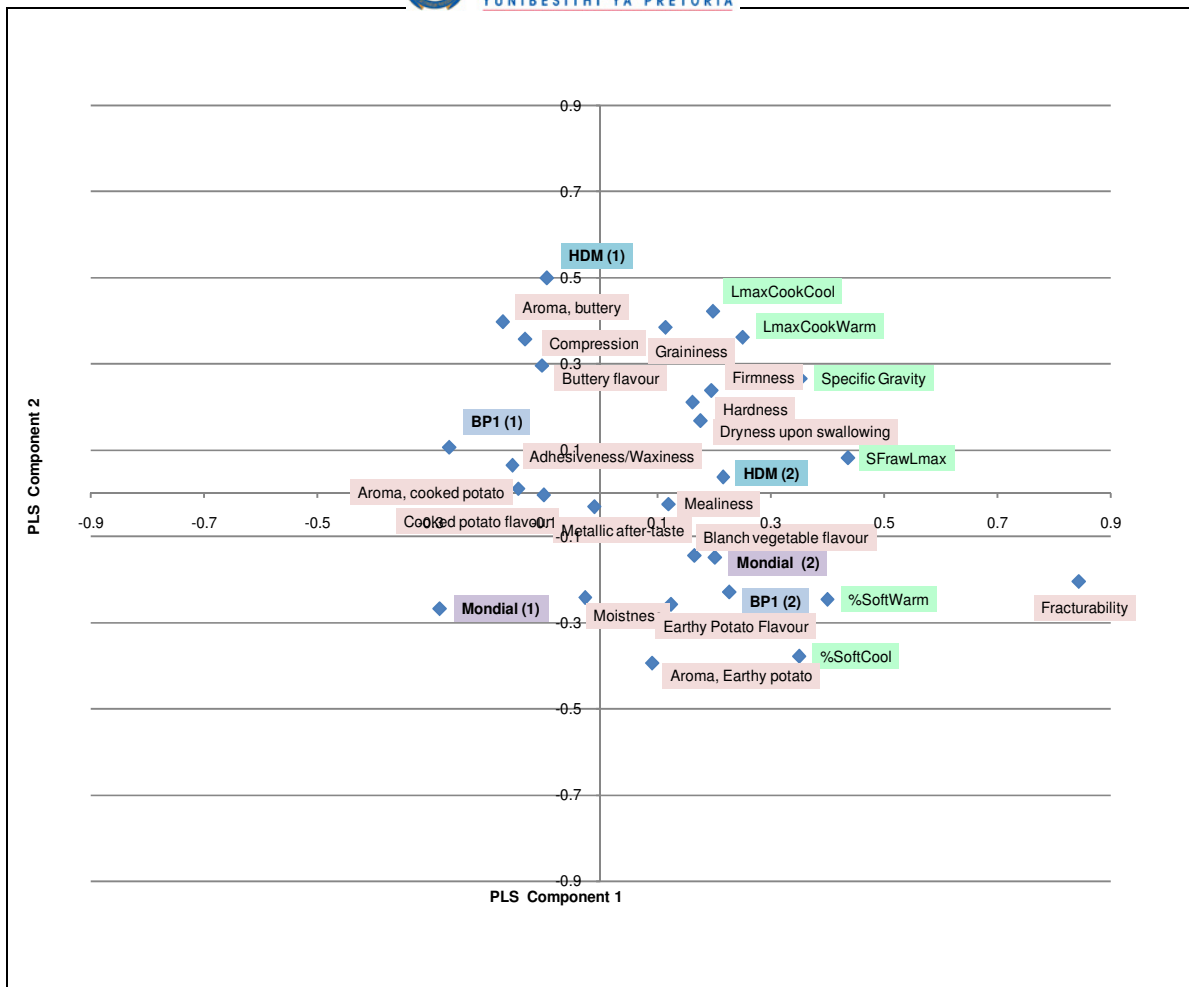


FIGURE 4.10: PARTIAL LEAST SQUARE (PLS) REGRESSION MODEL ON TWO PRODUCTION REGIONS

The three cultivars (BP1, Mondial and HDM) from Region 1 (Limpopo region) contrast with the three cultivars (BP1, Mondial & HDM) from Region 2 (Eastern Free State region) – (PLS component 1 – horizontal axis). The biplot indicates clearly that cultivar differences are less apparent (production points cultivars closer together) in Region 2 (Eastern Free State region) than in Region 1 (Limpopo region). Furthermore, the cultivars grown in Region 1 (Limpopo region) are associated with high values of the objective measurements of load maximum cooked, then cooled, load maximum cooked, still warm, specific gravity, load maximum (raw) shear force measurement, percentage softening cooked, still warm and percentage softening cooled, once cooked, and are thus more fracturable.

The sensory attribute of fracturability contrasts with all the other sensory attributes on PLS component 1 (far right) and, for example, a buttery aroma (Ab – top left quadrant) contrasts with an earthy aroma (Ae) – bottom right quadrant. This contrast is indicated in Figure 4.10.

As different growing and climatic conditions exist in the two potato production regions, one cannot assume that identical cultivars will have similar intensities for their sensory attributes. As depicted in Figure 4.10, similar cultivars (BP1, Mondial and the HDM) in each of the production regions were evaluated and tested, which produced dissimilar results for each of the cultivar types. Potatoes produced under dry-land growing conditions are more fracturable (see Figure 4.4, 4.5 and 4.10) compared to potatoes produced under irrigated growing conditions (see Figure 4.2, 4.3 and 4.10) that were less fracturable and more cultivar-specific with its associated characteristic elements.

Dry-land growing conditions produce a slightly drier potato crop compared to potatoes produced in an irrigated production region. It is assumed that, due to the exposure of water stress situations, potato cultivars are produced to be very similar and drier in nature, while an irrigated production region proves to produce different cultivars that are more distinctive and attribute-specific in nature (Figure 4.10). Thus, cultivar differences in a dry-land production region prove to be less evident as the dissimilarity of the cultivars produced in an irrigated production region.

From the above results it is apparent that the sensory attributes of the two production regions differ significantly within a region, and differ between the regions. Reason for the differences between the regions may be due to the biological variation between the identical replicates of the cultivars. See Addendum C for an exploratory research report on the three cultivars of the two production regions and an evaluation-comparison of the two regions.

This creates a challenge for Potato South Africa, as consumers have increased purchasing power that demands not only a food product of a high quality, but also a uniform product.

Objective three (3) of the study was to compare and determine the relationship between the sensory and the physical attributes of the three potato cultivars from two production regions in South Africa. The partial least square regression model was used to relate the sensory attributes to the physical measurements of the three cultivars from the two production regions. Figure 4.10 clearly illustrated the contrast between the cultivars of the two production regions.



4.11 CONCLUDING SUMMARY

Sensory and objective evaluation of the potato cultivars within each region together with an evaluation-comparison of the Limpopo and the Eastern Free State region, were performed. Significant differences among the eating quality of the three selected potato cultivars within each of the production regions were established with the statistical analysis of ANOVA and Principal component analysis. A Partial Least Square Regression modeling method was applied to the two production regions which showed a definite contrast in the eating quality of the potato cultivars among the two regions. In addition, Scanning electron microscopy was performed on raw and cooked potato samples from the BP1 and Mondial cultivars and the results thereof presented.

Based on these results, a proposed classification system for potato cultivars is presented in the next chapter.

CHAPTER 5

A PROPOSED POTATO CLASSIFICATION SYSTEM FOR THE SOUTH AFRICAN CONSUMER

5.1 INTRODUCTION

In order to propose a classification system, it is essential to give a theoretical background on how consumers process the information they acquire and store, and how it is activated in the decision-making process. This includes the theoretical background on script and schemata theories and the formation thereof. The decision-making process of consumers and the theoretical background will be presented first, followed by examples of classification models for potato cultivars. This chapter concludes with a proposed classification system for potato cultivars for the South African consumer, based on the results of this study.

5.2 CONSUMER DECISION-MAKING

According to Bray (2008), consumers are seen as practical decision-makers. Individuals are best viewed as "information processors," as they constantly seek and receive environmental and social stimuli as informational inputs. These informational inputs contribute to the internal decision-making process of a consumer. A typical consumer decision-making process involves five stages, namely problem recognition, information search, alternative evaluation, choice and outcome evaluation (Bray, 2008:3, 9).

From an economic perspective, according to Bray (2008:2), consumer decision-making is best viewed with the traditional model of utility theory. The utility theory suggests that consumers make choices based on the expected outcomes of their decisions. Therefore, consumer behaviour is defined as *"the behaviour that consumers display in searching for, purchasing, using, evaluating and disposing of products and services that they expect will satisfy their needs"* (Bray, 2008:3).

5.3 CONSUMER SCRIPTS AND/OR SCHEMATA

Consumer's expectations play a fundamental role in the evaluation of consumer satisfaction and product quality and it therefore makes sense to consider how expectations are formed and how they can be changed. Precursors of expectations are cognitive scripts (Curtis, Haugtvedt, Kardes, Herr, Herr & Kardes, 2008:133). A consumer script is classified as a function of contextual cues. The word "script", also referred to as schemata, are memory structures, derived from a chronological ordered schema. Knowledge is stored in long-term memory as schemata. It is viewed as cognitive structures that contain information about the nature of various events and activities (Bozinoff, 1982: 481). The theory on consumer scripts and schemata is briefly discussed.

A schema can be described as a data structure that represents generic concepts stored in memory. According to Erasmus, Boshoff and Rousseau (2002:2), schemata can be described as hypothetical mental constructs (abstract knowledge structures) that control attention and the reconstruction of memory that enables one to recognise and recall things that one has been exposed to. Schemata thus form knowledge structures that are the building blocks of cognition. It represents our knowledge about all concepts, those underlying objects, situations, events, sequences of events, actions and sequences of actions. This representation is regarded as "a network of interrelations" that is believed to normally hold among the constituents of the specific concept in question. A schema is a composite conceptualisation that assembles and incorporates the most important aspects or variations of a concept (Casson, 1983:429 – 431; Erasmus *et al.*, 2002:2).

Schemata are conceptual abstractions that mediate between stimuli received by the senses and behavioural responses. Unlike associations, schemata are organic wholes that are comprised of parts that are oriented towards both the whole and other parts. These abstractions serve as the basis for all human information processing, such as for example perception and comprehension, categorisation and planning, recognition and recall, including problem-solving and decision-making. The past operates as an organised mass rather than a group of elements, each of which retains its specific character. For example, in a restaurant consumers use a script that involves a pre-determined and defined sequence of actions for a well-known situation. For example, upon entering a restaurant, the consumer is greeted in a friendly manner and a waiter is assigned to serve his table. A menu is presented, from which drinks, starters, main course meals and desserts can be ordered and served. Subsequently the consumer receives an invoice for which payment is due.

A sequence of actions within a script is always grouped into elements within an analogous way. This is to ensure that any script contains numerous segments that represent the characteristic grouping of actions. Scripts could be used to reflect specific types of consumer/buyer behavior patterns. The potential application of script theory in consumer behaviour research lies in the potential that scripts could provide insights in consumers' expectations, pro-active planning and situational decision-making processes and behaviour (Erasmus *et al.*, 2002:1, 2, 6). According to Bozinoff (1982:481), specific situational cues trigger scripts and efforts to change scripts must therefore be aimed at critical situational cues. As consumer behaviour is generally unconscious and not easily recalled, consumers should move to a conscious mode of thought in order to alter the information-processing approach to guide routine consumer response behaviour into new and innovative ways. The schema theory explains how people store, retrieve and use information. It provides a framework for conceptualising the way in which people classify foods. Classification is an important aspect of conceptual representation (Blake, Bisogni, Sobai, Devine, & Jastran, 2007:501). Access to categorical knowledge is provided by classification, although knowledge may be used in a variety of ways (Ross & Murphy, 1999:496).

5.3.1 Consumer and categorical representation

Consumers unconsciously categorise foods, and thus provide an orderly system that gives structure and presents information on food. They place food in classes, make associations between a product and a group with which characteristics or benefits are shared (Costa, Dekker, Beumer, Rombouts and Jongen, 2001:231). Consumers thus use representations to assign a particular product or service to a consumer category, in order to understand it and draw inferences from it. Schemata as cognitive constructions are based on generalised collections of knowledge on past food usage and eating experiences. This provides organised and related categories that guide behaviour in different contexts, and shapes an individual's understanding of a food product and the eating thereof (Blake *et al.*, 2007:506; Furst *et al.*, 1996).

Consumers construct and use these categorical representations to classify, interpret and understand information. A consumer category is defined as a set of products, services, brands or marketing entities that are related to the consumer. Categorical representation as stated by Curtis *et al.*, (2008:133), is classified as information that becomes stored in the memory of a person, which is later retrieved and used for the processing thereof. Categorisation has implications for consumer decision-making. The structural aspects of a

product or consumer-relevant category need to be consistent and flexible in order to understand the information processing activity that underlies consumer behaviour, as the consumer environment is complex and ever-changing. Consistency requires consistent representations of products and brands in the memory that relates to the specific consumer's environment. Consistent representations thus provide a foundation upon which consumer information processing takes place. These are important for recognising, interpreting and evaluating both objects and events in a wide variety of consumer environments (Curtis *et al.*, 2008:136, 137).

According to research by Curtis *et al.* (2008), category representations are flexible and do not take the same form across different contexts or situations, as the perceived structure of a category depends on the goals that are salient at a particular time or in a particular context or situation. This flexibility allows consumers to adapt when they are exposed to an unlimited number of situations and changes. Therefore, a product should be positioned in such a way that consumers could identify it as belonging to a particular product category (Curtis *et al.*, 2008:134, 136). For example, a bagel is not just a type of bread; it may also be regarded as a sandwich food, a breakfast food, a Jewish food or even a snack food.

5.3.2 Application and role of the schemata in food selection

Schemata theory has been used to understand and explain food novelty as well as consumer food-choice behaviour (Blake *et al.*, 2007:502). According to Ross and Murphy (1999:537), people view foods as elements not only of taxonomic categories, but also as script categories. Taxonomic categories are structured around the intrinsic properties of the food itself while script categories are presented in memory (Ross & Murphy, 1999:540).

People employ taxonomic categories to capture the compositional similarities of foods, for example fruits and breads. Therefore, taxonomic categories appear to be more oriented towards the intrinsic properties of foods. The intrinsic properties of foods largely determine their taxonomic category membership, which can be based on their origin, composition and/or nutritional value. Script categories are based on the situations in which foods are used and eaten, for example breakfast foods or snacks. Script categories often strengthen these taxonomic divisions (Blake *et al.*, 2007:507; Ross & Murphy, 1999:495, 497, 499, 507, 535-539).

An individual's food schemata are further structured in terms of a hierarchy, where different hierarchy and non-hierarchy levels are used to categorise food schemata. Food is grouped and ranked into categories according to various factors. These factors are influenced by the cultural group to which the individual belongs and is guided by religious beliefs, cultural norms and values about certain food, current lifestyle decisions or situational circumstances. Food can furthermore be grouped and ranked according to an individual's preferences, for example, foods liked and disliked. A non-hierarchical structure refers to categories that are not mutually exclusive and items could be placed in more than one category. For example, "healthy snack foods" could represent different category meanings, therefore different categories could exist for the same foods in different contexts, resulting in category contents that are not mutually exclusive. For example, fruit can be enjoyed as part of a breakfast meal as fruit salad and yoghurt, a healthy snack enjoyed in-between meals, such as an apple or pear, or even be part of a healthy dessert as in the case of fruit salad or stewed fruit and custard. A non-hierarchical network of category relations is formed where items are connected to all the other categories they exemplify (Ross & Murphy, 1999:536). In the examples given, the shared category membership is fruit. This sort of network is less structured than a pure taxonomic category. Food can thus be cross-classified in non-hierarchical networks that are either taxonomic or script-oriented (Blake *et al.*, 2007:507; Ross & Murphy, 1999:495, 536). This implies that a food item can belong to a number of different non-hierarchical categories simultaneously. Therefore, cross-classification occurs for an item belonging to multiple categories that represent alternative conceptual organisations (Blake *et al.*, 2007:507; Ross & Murphy, 1999:497, 536).

Various examples of food classification systems exist. Two types of food classification systems are presented to illustrate how these classification systems can be compiled and used. The classification system used for South African meat and the classification system used for fruit and vegetables are given as examples.

5.4 FOOD CLASSIFICATION SYSTEMS

According to Ireland and Moller (2000:529), accurate food classification necessitates clearly defined, detailed descriptions of foods. It has different objectives, which lead to different manifestations of such systems. Foods with similar characteristics are grouped together, which serve as indicators to the consumer as end-user. Descriptive data is used in these systems. Food classification systems have been compiled for different uses and are even

included as part of legislation (Ireland & Moller, 2000:533). The South African Meat Industry, for example, has developed a classification system where the characteristics of meat are used to describe and classify various meats and meat cuts.

5.4.1 Classification system of South African meat

The classification of South African meat is promulgated in the Meat Classification Regulation No R 863, as published in the Government Gazette of the Republic of South Africa of 1 September 2006. This classification guides meat traders as it describes the specific characteristics of meat in an easy, understandable manner to ensure that the intended purchase meets the specifications set by retailers and consumers. Secondly, it guides their specified needs and requirements in simple terms when purchasing carcasses or meat cuts (Red Meat Classification Chart, 2007).

Physical characteristics of carcasses are used as criteria for the classification of meat. Five categories are used for the classification of beef, lamb, sheep, goat and pork meat. The five categories refer to the age, fatness, conformation, damage and the sex of the animal.

5.4.2 Classification of fruit and vegetables

Fruit and vegetables, on the other hand, are classified according to two kinds of classification systems (Pennington & Fisher, 2009:1). In the one system, the botanical components are used as the rationale for the classification, and in the other, the nutrient content is used. The botanical component includes aspects such as botanical families, colours and which part of the plant is edible (Pennington and Fisher 2009:5). Botanical classification is useful to establish plant origins and relationships and to identify plants among different cultural and language groups. In the second classification system the nutrient content of fruit and vegetables are used in a classification system, such as for example in the Food Guide Pyramid where food groups (i.e. the vegetables and fruit groups) are used to guide consumers to meet their nutrient and energy needs. Fruit is consumed in different contexts and can therefore be used in a variety of culinary applications, depending on the context or situation. It could be used as snacks, for dessert, or as a sweet dish in a meal, for example, fruit sosaties on a snack platter, as the main ingredients in a dessert such as a trifle, or in a sweet dish such as an apple tart. Culinary applications for vegetables could include salads, cooked side dishes and savoury dishes (Pennington & Fisher, 2009:1). For example, tomatoes can

be used raw in a salad, as a main ingredient in soup or as a cooked tomato sauce in a savoury dish like lasagne.

Current classification methods used for potatoes in other countries and South Africa are described in the following section.

5.5 EXISTING CLASSIFICATION METHODS FOR POTATOES

The existing systems that are available as consumer guides seem to be based on arbitrarily selected characteristics (i.e. starch content, colour, intended use or growing season). Each of the existing methods/models will be briefly discussed to indicate the shortcomings and limitations of each. The proposed classification system of potato cultivars for the South Africa consumer will be presented.

In some countries such as the United States of America, Denmark, Norway, Australia and Britain, classification models for potato cultivars are in place. However, it is not clear how some of these models were developed, as not all of them are based on scientific data. These classification models guide consumers towards informed decision-making. The allocation of the most appropriate culinary application(s) for a specific cultivar seems to serve as the rationale for the development of these classification models in order to assist the consumer.

Different types of potato classification systems are described in literature. Examples are presented to illustrate some of these classification systems. It appears that three different classification systems exist in the United States of America. These classification systems seem to make use of specific criteria, such as starch content, colour and type of potato (<http://www.potatoes.org>; <http://www.foodreference.com>). Each of these methods of classification is briefly discussed.

5.5.1 Classification based on the starch content of potatoes

In the United States of America, one classification system is based on the two main components of starch (Tongsook, 2001:17; Paul & Palmer, 1972:690), namely the amylose and amylopectin content. Potatoes are classified and categorised

(<http://www.foodreference.com>) into two groups, namely starchy (mealy) or waxy potatoes. Starchy (mealy) potatoes have a high starch and amylose content (Hassid & McCready, 1943b:1154). Conversely, waxy potatoes have a lower starch content with more amylopectin fragments (McWilliams, 2000:163). Thus **starchy potatoes** have a low moisture and sugar content, but a high starch content. This makes them the best choice for baked, mashed, fried or roasted potatoes. With their lower sugar content, their cell structure collapses more easily. In contrast, **waxy potatoes** have a high moisture and low starch content. These potatoes are a good choice for salads or casseroles, because they retain their shape when cooked (<http://www.foodreference.com>). This classification method is scientifically founded.

Another classification method for potatoes used in the United States of America is based on colour. This method appears to be subjective and not scientifically founded.

5.5.2 Classification according to the colour of potatoes

Colour is also used to classify potato cultivars and the proposed cooking method(s) are given accordingly.

Colour: White potatoes

Suitable cooking methods: General purpose – most cooking methods can be used

Colour: Yellow potatoes

Suitable cooking methods: Boiling and microwaving

Colour: Red potatoes

Suitable cooking methods: Boiling and microwaving

Another classification method is to classify a potato as “new,” “general purpose” or as “baking,” which implies that the intended use of potatoes is used as basis for this system (<http://www.foodreference.com>). This potato classification system seems to be subjective and no scientific justification for this method could be found.

5.5.3 Classification according to the intended use of the potato

New potatoes are frequently used to describe those freshly harvested potatoes during late winter or early spring. The name is also widely used in later crop production areas to designate freshly dug potatoes that aren't fully matured. They vary widely in size and shape, depending upon cultivar, but are likely to be affected by skinning (<http://www.foodreference.com>). New potatoes are suitable for boiling or mashing. **General-purpose potatoes** refer to the majority of potatoes offered for sale in the markets. These potatoes are categorised according to their shape and represent oval and round types of potatoes. With the aid of air-cooled storage, they are available all year round. These potatoes are considered suitable for boiling, frying and baking, even though many of these potatoes are not suitable for baking (<http://www.foodreference.com>). Both variety and area where the potatoes are grown are important factors that affect the baking quality of **baking potatoes** (<http://www.foodreference.com>). The Russet Burbank, a potato cultivar available in the United States of America, is a long shaped variety with fine, scaly netting on the skin, and is the most widely grown and best known variety (<http://www.foodreference.com>).

5.5.4 Potato South Africa's current classification system

Potato South Africa (PSA) currently has a classification system for the South African consumer. Table 5.1 illustrates the system Potato South Africa (PSA) uses for the classification of potato cultivars according to suggested suitable culinary applications. This classification system is presented below.

TABLE 5.1: POTATO SOUTH AFRICA'S CURRENT CLASSIFICATION SYSTEM

<u>Cultivar</u>	<u>Details</u>	BAKED	BOILED	CHIPS	CHRISPS	FRIES	MASHED	ROAST	SALAD	STEW	PROCESS
Astrid	Oval-shaped with medium deep eyes, white flesh and a slightly floury texture.	X					X				
Aviva	Round with shallow eyes, white flesh and a fairly firm texture.			X							
BP1	Oval with round eyes, white flesh and a firm texture.							X		X	
Mondial	Oval-shaped. Yellow flesh and a firm texture.		X					X	X		

Seed growers have determined and developed this classification method where potato cultivars are grouped according to colour, shape, texture and culinary applications in this classification method. The information presented seems unsystematic and therefore a need has been identified for a scientifically based classification model to guide the South African consumer in the decision-making process (see Chapter 1, paragraph 1.7).

At present, no scientifically based classification system exists for potato cultivars in South Africa. However, consumers need guidance towards making the correct potato cultivar choice for its intended use(s). To meet the culinary needs of consumers, a classification system for South African potato cultivars is proposed based on the results obtained from determining and describing the eating quality of seven potato cultivars from a production region.

5.6 DEVELOPMENT OF A PROPOSED CLASSIFICATION SYSTEM FOR POTATO CULTIVARS FOR THE SOUTH AFRICAN CONSUMER

This classification model strives to provide the most suitable culinary applications for each potato cultivar, to guide the South African consumer in selecting the most appropriate cultivar for its intended use. It is therefore developed to ensure optimum satisfaction in using a specific potato cultivar, based on the classification system as guide. A prerequisite for the success of such a system is that it has to be easy to use, understand, implement and interpret by all South African consumers, irrespective of their literacy level. Based on the studied literature (Ross & Murphy, 1999:540), a non-hierarchical categorisation is deemed the most appropriate model to be used. Each cultivar has its own most appropriate culinary application(s), which can include baking, roasting, boiling, making chips (fries) or crisps, mashing, microwaving and preparing salads or using it in stews (Jansky, 2010:209). In the proposed system, potato cultivars are grouped and categorised based on their eating quality.

Eating quality consists of both intrinsic and extrinsic properties, as derived from both sensory and objective evaluation. In turn, cultivars are categorised in taxonomic categories for the suggested culinary applications. Texture is recognised as a fundamental element that contributes to the consumers' perception of quality. The textural property produces the *mouthfeel* sensation of a product. *Mouthfeel* is defined as the composite of the structural elements of the food and the manner in which it is registered by the physiological senses, as it relates to density, viscosity, surface tension and other physical properties of the material

being sampled (Navarini, Cappuccio, Suggi-Liverani & Illy, 2004:526; Thybo *et al.*, 2004:315).

For the development of the classification model a sufficient number of potato cultivars, representative of an adequate sample of South African potato cultivars, had to be included, and sensory and objective evaluations needed to be performed on these cultivars. The sensory and objective evaluation results discussed in Chapter 4 were, however, from only three potato cultivars, namely BP1, Mondial and HDM from two different production regions. Furthermore, the production conditions of these two regions differed, as one region was an irrigated production region and the other a dry-land production region. Therefore, the data of these two production regions as presented in Chapter 4 was rather limited to use as an illustration of the proposed classification system. Hence, in order to justify the proposed classification system, seven potato cultivars from the Eastern Free State production region, were used. The cultivars included were BP1, Fabula, HDM, Mondial, Platina, Rodeo and Up-to-date.

For the development of the proposed classification system, descriptive sensory and objective evaluations were performed on these seven cultivars. The objective evaluation performed included six physical measurements. Similar standardised preparation methods and techniques were performed as described in Chapter 4. A trained sensory evaluation panel evaluated the samples according to the identified sensory attributes on the lexicons (see Addendum B, Table B3.3 - B3.4). The potato cultivars were characterised based on how each cultivar associated with the sensory attributes and objective measurements, and were consequently grouped according to their most suitable culinary application(s). The challenge was to capture the associated sensory attributes and objective measurements in a classification system in order to assign suitable culinary application(s) for a specific cultivar.

5.6.1 Description and explanation of the proposed classification system for South African potato cultivars

To facilitate the proposed potato classification model, the PLS regression modelling method was applied to seven cultivars from the Eastern Free State region. This method was used to understand the relationship between the sensory attributes and the physical measurements (Peppard *et al.*, 1999). The sensory attributes were related to the objective tests with the application of the PLS regression modeling method, which identified the most important attributes for differentiating between the potato cultivars to propose a classification model.

All the mean values obtained from the sensory attributes and physical measurements were used for each of the seven cultivars. Seventeen sensory attributes and six physical measurements were used in order to determine the most important physical measurements that influence the sensory profiles of the potatoes (Smith *et al.*, 2009:31, 33). The PLS regression modelling method was used to visualise the data.

Cultivar differences were determined in order to develop a proposed classification system for South African potato cultivars. The sensory attributes were the Y=dependent variables of 17 mean South African values per cultivar, and X=independent variables were six mean physical measurement values per cultivar for the interpretation of the data for the proposed classification model. The six physical measurements assisted in understanding the textural attributes of the cultivars, but moreover in the characterisation of the different potato cultivars (Smith *et al.*, 2009:32). The statistical results were obtained with GenStat® (Payne *et al.*, 2007).

Table 5.2 indicates the percentage of the variance explained by the PLS regression model. The dependent variables (sensory attributes) and independent variables (objective tests) are ranked according to significance in the first dimension. Most of the variation in the data is explained in the first dimension.

TABLE 5.2: PLS APPLICATION ON THE SENSORY ATTRIBUTES AND OBJECTIVE (PHYSICAL MEASUREMENTS) OF SEVEN CULTIVARS, PERCENTAGE VARIANCE EXPLAINED

Y matrix (Dependant variables)	% of the Y variances explained		X matrix (Independent variables)	% of the X variances explained	
Sensory attributes	1st dimension	2nd dimension	Physical variables	1st dimension	2nd dimension
Mealiness	63.6	11.4	% Softening, warm	88.6	2.2
Graininess	60.7	10.7	Specific gravity	78.0	18.1
Moistness	51.0	0.4	% Softening, cooled	77.4	14.7
Fracturability	50.2	0.4	Load maximum cooked, still warm	62.0	33.6
Metallic after-taste	49.0	5.4	Load maximum cooked, cooled	51.6	44.4
Adhesive-/waxiness	34.1	18.8	Load maximum - shear force raw	40.9	26.5
Hardness in the mouth	32.6	32.7			
Buttery aroma	31.9	0.0			
Cooked potato flavour	31.5	22.4			
Buttery flavour	29.7	5.3			
Dryness upon swallowing	28.8	27.0			
Cooked potato aroma	13.4	2.6			
Compression with the fork	6.3	66.6			
Firmness	1.8	54.7			
Blanched vegetable flavour	1.5	46.0			
Earthy potato aroma	0.6	38.2			
Earthy potato flavour	0.0	0.4			

Most of the variances in the first dimension (cf horizontal axis of Figure 5.4) were explained (Table 5.2) by the sensory attributes of mealiness (63.6%), graininess (60.7%), moistness (51.0%) and fracturability (50.2%). In addition, the physical measurements of (%) percentage softening cooked, warm (88.6%), specific gravity (78.0%), (%) percentage softening cooked, cooled (77.4%) and load maximum cooked, still warm (62.0%) explained most of the variances in the first dimension. In the second dimension (cf vertical axis of Figure 5.4), the sensory attributes of compression with the fork (66.6%) and firmness (54.7%) explained most of the variation.

A biplot (Figure 5.4) of the Y and X matrix loadings indicates points for the 17 sensory attributes, the six objective tests, and the seven cultivars in the one region. Again, points close together are more alike and those farthest apart are different in nature.

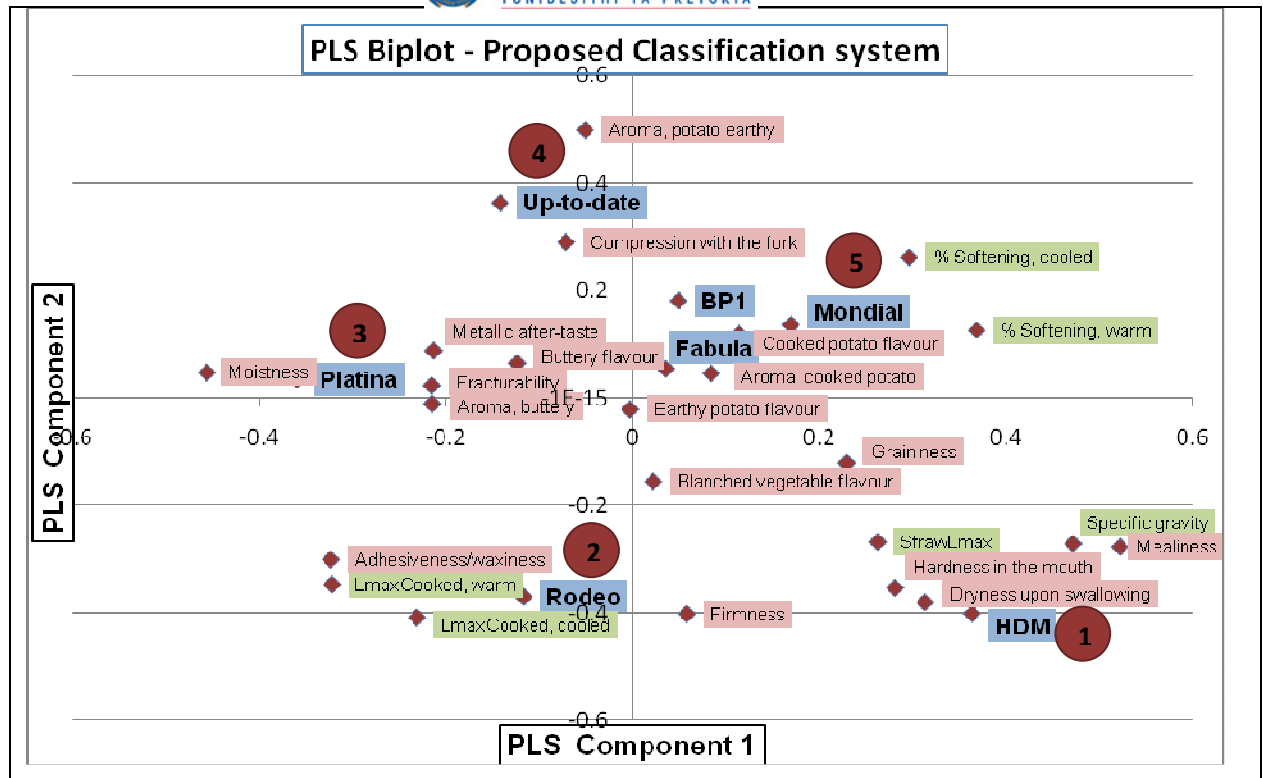


FIGURE 5.1: PARTIAL LEAST SQUARE (PLS) REGRESSION MODEL FOR THE PROPOSED CLASSIFICATION SYSTEM

The seven cultivars are positioned relevant to their associated sensory attributes, which characterises a cultivar. The intensity of the associated sensory attribute(s) of a specific cultivar (based on the positioning of a cultivar relevant to the associated sensory attribute(s)), explains the eating quality of a potato, which can ultimately assist in categorising and grouping a specific cultivar. Based on the sensory attributes and the physical measurements, the associated cultivar(s) are indicated in the cultivar groups. Five groups of cultivars are indicated with the PLS regression biplot (Figure 5.4).

Group 1 is represented with the HDM cultivar in lower right quadrant, Group 2 is represented with the Rodeo cultivar in lower left quadrant – PLS component 1 (left lower and upper right quadrants), Groups 3 is represented with the Platina cultivar (upper-left quadrant), Group 4 is represented with the Up-to-date cultivar (upper left quadrant) and Group 5 with the BP1, Fabula and Mondial cultivars (upper-right quadrant). Less cultivar dissimilarities among BP1, Fabula and Mondial are observed than between the other cultivar groups.

Three cultivar groups, namely Group 2 (Rodeo), Group 3 (Platina) and Group 4 (Up-to-date) contrast with the other two cultivar groups, namely Group 5 (BP1, Fabula, and Mondial) and

Group 1 (HDM) (PLS component 1, horizontal axis). An earthy potato aroma contrasts with firmness, while moistness present in the Platina cultivar (far left) contrasts with the dryness upon swallowing sensory attribute of the HDM cultivar in the PLS component 1 (far right). Six objective measurements were performed for each of the seven cultivars from the Eastern Free State region for the proposed classification model as presented in Table 5.3.

TABLE 5.3: OBJECTIVE MEASUREMENTS OF THE SEVEN POTATO CULTIVARS

Objective measurements	p-value	Cultivar varieties						
Specific gravity	<.001	HDM	Mondial	BP1	Up-to-Date	Fabula	Rodeo	Platina
		1.097 ^a	1.079 ^b	1.078 ^b	1.073 ^{bc}	1.073 ^{bc}	1.070 ^c	1.068 ^c
Shear force (raw) load maximum	<.001	HDM	BP1	Mondial	Platina	Rodeo	Up-to-Date	Fabula
		5.140 ^a	4.519 ^b	4.091 ^c	4.021 ^{cd}	3.882 ^{cd}	3.680 ^d	2.966 ^e
Load maximum cooked, still warm	0.009	Rodeo	Platina	HDM	Fabula	Up-to-Date	Mondial	BP1
		0.510 ^a	0.480 ^{ab}	0.365 ^{bc}	0.350 ^c	0.350 ^c	0.313 ^c	0.310 ^c
%Softening warm	<.001	BP1	HDM	Mondial	Up-to-Date	Fabula	Platina	Rodeo
		93.110 ^a	92.890 ^a	92.260 ^a	90.450 ^{ab}	88.020 ^{bc}	87.960 ^{bc}	86.810 ^c
Load maximum cooked, cooled	<.001	Rodeo	Platina	HDM	Fabula	Up-to-Date	Mondial	BP1
		0.759 ^a	0.552 ^b	0.433 ^{bc}	0.396 ^{bc}	0.393 ^{bc}	0.380 ^{bc}	0.322 ^c
%Softening cooled	<.001	BP1	HDM	Mondial	Up-to-Date	Fabula	Platina	Rodeo
		92.740 ^a	91.650 ^{ab}	90.680 ^{ab}	89.300 ^{ab}	86.530 ^{bc}	86.060 ^c	80.080 ^d

Group 1 -  Group 2 -  Group 3 -  Group 4 -  Group 5 - 

These measurements were performed in order to understand and interpret the textural attributes of the cultivars and characterisation thereof. Within Table 5.3, each cultivar group is indicated with a colour. Group 1 is indicated with pink, Group 2 with orange, Group 3 with brown, Group 4 with blue and Group 5 with purple.

Each group is discussed with regard to its associated sensory and physical attributes (Table 5.3), in order to explain the suitable culinary applications that could be assigned to the cultivars in each group.

Group 1 represents the HDM cultivar. This cultivar is associated with the sensory attributes of hardness in the mouth, mealiness and dryness upon swallowing and the physical measurements of a high specific gravity and raw shear force resistance measurement (Figure 5.4).

The HDM cultivar has a high specific gravity measurement (1.097) that indicates a high starch content (Table 5.3). This cultivar retains its shape when cooked, as stated by the high shear force resistance measurement value (5.140) of a raw potato, which is representative of mealy potatoes (McComber *et al.*, 1994; Thybo *et al.*, 2000 & Van Dijk *et al.*, 2000).

Suitable culinary applications: This cultivar is hard to cut, slightly sticky and compact. It is recommended for cooking applications such as chips and crisps, microwaving, with the emphasis on baking and roasting. This high dry matter potato is generally used for industrial processing.

Group 2 represents the Rodeo cultivar. The characteristics of this cultivar is associated with the sensory attributes of adhesiveness/waxiness and firmness in addition to the physical measurements of load maximum cooked, still warm and load maximum cooked, cooled. This cultivar is less mealy and grainy. A specific gravity of 1.070 was noted, which implies that a low starch content is present in the potato tubers and a lower resistance to shear through this cultivar is expected, as it was reported in Table 5.3.

Suitable culinary applications: The Rodeo cultivar is favoured for microwaving, making potato salad or boiling, as it retains its shape when cooked, due to the associated sensory attributes of adhesiveness/waxiness and firmness/compactness and the physical attributes of load maximum when cooked, still warm, as well as the load maximum, cooked then cooled.

Group 3 represents the Platina cultivar. The sensory attributes of a buttery aroma, fracturability, moistness and a metallic after-taste are associated with the Platina cultivar. This cultivar has a buttery aroma and flavour. A low specific gravity of 1.068 was reported, which is indicative of a low starch content (Table 5.3) and representative of waxy potatoes. A relatively high resistance (4.021) to shear through the potato tuber was reported for this cultivar.

Suitable culinary applications: Therefore, the Platina cultivar is recommended for baking, boiling, frying and microwaving.

Group 4 represents the Up-to-date cultivar. The Up-to-date cultivar is associated with an intense earthy potato aroma and a high resistance when compressed with the fork. An average specific gravity of 1.073 was reported for the Up-to-date cultivar, which signifies a moderate starch content and modest resistance to shear through the potato tuber as it was

reported in Table 5.3.

Suitable culinary applications: This cultivar will give a good, slightly dry and grainy but smooth mashed potato with an earthy potato aroma. Up-to-date does not retain its shape when cooked. It is suggested that the Up-to-date cultivar is suitable to be baked, fried (Smith et al., 2009:34) or microwaved.

Group 5 is represented by the cultivars BP1, Fabula and Mondial. The sensory attributes of a cooked potato aroma, a cooked potato flavour, an earthy potato flavour and the physical measurements of the percentage softening when cooked then cooled and the percentage softening cooked, while still warm, are associated with the cultivars BP1, Fabula and Mondial in Group 5. The BP1, Fabula and Mondial cultivars are pleasant and earthy tasting potatoes. An average specific gravity of 1.076 was reported for the cultivars, which in effect, implies an average starch content for the potato tubers.

Suitable culinary applications: These cultivars retain their shape when cooked and are relatively hard to cut, moist and compact with a cooked potato aroma. It is recommended for most cooking applications, such as making salads and chips, microwaving, as well as roasting and baking.

A large percentage of the South African population can be described as having a low literacy level. It is therefore imperative to consider the use of images in the proposed classification model. In the following section, attention is first given to the role and importance of visual imaging in the development of a classification system for the South African consumer as justification for including these in the proposed classification system. The proposed classification system then follows in the second section.

5.7 THE ROLE OF VISUAL IMAGES IN CATEGORICAL REPRESENTATION

Consumers are exposed to a range of textual material and therefore individual responses are given. The traditional definition of writing is “speech made visible” (Scott & Vargas, 2007:353). Writing is the communication of specific ideas in a traditional way, by means of words in a lasting and noticeable script. It is an activity that deals with language, however, it should be remembered that there are some people who cannot read and write. Writing is based on speech, and not the other way round. Another basic, but precise approach to

communicate information to consumers, is in the form of pictures or images (Scott & Vargas, 2007:353).

South African consumers have different literacy levels and script reading capabilities. The National Assessment of Adult Literacy (Ntiri, 2009) defined illiteracy as “using printed and written information to function in society, to achieve one's goals, and to develop one's knowledge and potential”. Literacy has various demands that do not only refer to decoding a message and creating text, but also to information processing and critical thinking skills, which guide adults in the marketplace. It is an instrument for reading the world and for self and societal empowerment and transformation (Ntiri, 2009). Literate people are able to read, listen, write, speak and spell words, in contrast to illiterate people who are not able to read, listen, write, spell or sometimes even speak the words. Very low-level skills, such as knowing the alphabet, signing one's name and reading the Bible, are essential to social functioning (Ntiri, 2009). Therefore, the proposed classification model for potato cultivars needs be developed in a way to meet the needs of the majority of consumers.

In using visuals or pictures, a different but creative technique is applied to present, communicate and explain a desired message to such consumers. Visuals are presumed to be meaningful communicative access points. The technique of using only images (pictures) to communicate or convey a desired message, is repositioning itself with an similar approach to become increasingly comparable to the traditional writing system. An image is an artifact, for example a two-dimensional picture, which has a similar appearance to a physical object or a person (Echtner & Ritchie, 2003:38). An image is formed with the development of a mental construct. This mental construct is based on a few impressions chosen from a flood of information, for example promotional literature, brochures, posters, opinions of others (family/friends) and the general media (newspapers, magazines, television, books, movies). As acknowledged by Harlick, Shanmugam and Dinstein (1973:610), three fundamental pattern elements, namely spectral, textual and contextual features, are used for human interpretation of colour photographs. With pictorial representation, information is often more effectively communicated than alphabetic writing and consumers from all literacy levels are accommodated. Consumers are thus most likely to become skilled at picture associations when “writing-with-pictures” is used for practical and simple representations (Scott & Vargas, 2007:341, 342).

By generating visual imagery, cognitive associations are facilitated. For example, visual images may serve as spatial representations that facilitate information processing. Visual imagery is thus effective when it is compatible with other aspects of the communication

process. For this reason, information presented tends to be more effective when pictures are accompanied by instructions. Pictorial information is processed both perceptually and conceptually, but the type of imaging influences the perceptual or cognitive processing in which consumers engage (Curtis *et al.*, 2008:140, 141).

Research conducted by Scott and Vargas (2007:341), revealed that consumers treat visuals as sensory data when they read product attributes from pictures, based on an emergent writing system. They recognised that consumers can read and comprehend simple information, such as lists or short declarative statements in the form of images. A visual image is thus regarded to be a clear reflection of reality. Complex symbolic meanings can be gathered when derived from pictures. Consumers read pictures as informational statements about products. The repetition of a simple stimulus initially causes a positive effect, but to sustain a positive consumer attitude, multiple repetitions that require the addition of elaborative thinking about the meaning of the content of the images, are required. According to Scott and Vargas (2007:343), consumers' response to the repeated exposure varies.

Often consumers limit their comprehension of pictorial communications when they insist on defining messages as concrete, sensory or even a depiction, rather than admitting the capability of pictures to be abstract, conceptual and even tools for thought. An all-picture-based writing system needs to be created to expand the extent of such a system. This system needs to be accepted in various cultures to be able to represent many qualities, actions, concepts and proper names by different methods and judgement. Individuals from different subcultures interpret pictorial messages differently, as there are differences in reading ability. Even so, through picture representation a picture can be taken beyond the point of merely referring to an object (Scott & Vargas, 2007:344). It is anticipated that consumers can learn to read pictures critically, adapt the pictures they read to new situations and use the images they read to comprehend new things or ideas. A fundamental thought is that images will operate in a way similar to writing, but with more detail (Scott & Vargas, 2007:342 – 344, 353). Presently people tend to think more visually, have shorter attention spans and are more susceptible to emotional appeals with the messages they receive. Thus, for improved readability and persuasiveness, the choice of words, the medium used and all the elements used in a visual environment need to be carefully planned for effective communication (Duffy, 1991:22).

Consumers utilise existing and easily obtained experiences in evaluation and decision-making, unless the relevance or information-value of these experiences is called into question (Curtis *et al.*, 2008:139). Recent developments in cognitive psychology have led to

increased empirical and theoretical interest in the interplay between cognitive systems (e.g. category representation) and the brain's modality-specific systems, such as vision, action and affect. It is therefore concluded that visuals or pictorial information could be used on the packaging of potatoes in the presentation of the proposed potato classification system for South African consumers.

From the interpretation and discussion of the PSL model, a proposed classification system for the South African consumer is now presented.



5.7.1 A proposed potato classification system for the South African consumer

This proposed classification system is built on pioneering, scientifically based data, which will guide the South African consumer into making informed decisions regarding the correct cultivar choice for its intended culinary application(s).

South African consumers have different literacy levels. For this reason, in order to reach and communicate the various culinary applications of the potato cultivars in an easy and understandable manner to all consumers, images representative of the different culinary applications were developed. These images are referred as icons. Five (5) icons that represent the various culinary applications of the potato cultivars were developed.

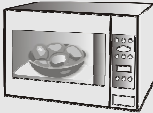
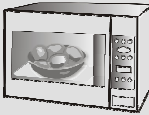
Table 5.4 briefly describes each image according to the culinary application it represents.

TABLE 5.4: CULINARY APPLICATION IMAGE DESCRIPTION

<u>Images representative of the various culinary applications</u>	<u>Description and explanation of the images</u>
	The image is representative of the culinary application of boiling.
	The image is representative of the culinary applications of making chips and crisps.
	The image is representative of the culinary applications of baking and roasting.
	The image is representative of the culinary application of microwaving.
	The image is representative of the culinary application of preparing a potato salad.

For the presentation of the proposed classification system, each cultivar group is discussed according to cultivars it consists of, followed by the associated characteristics of the cultivar and the suggested culinary applications. The characteristics and culinary applications is presented in Table 5.5. Group 1 is presented first, followed by the other four groups. Each group will be discussed in brief.

TABLE 5.5: CULINARY APPLICATIONS OF GROUPS 1-5

Presentation of the proposed potato classification system of groups 1-5				
Group	Cultivar	Characteristics	Suggested culinary applications	
1	HDM cultivar	<u>Sensory attributes</u> - Hardness in the mouth - Mealiness - Dryness upon swallowing		 Mash
		<u>Physical attributes</u> - High specific gravity and - Raw shear force resistance measurement		
	<u>Suggested culinary applications</u> Because the HDM cultivar retains its shape when cooked, most cooking methods can be used. These include making chips and crisps, boiling and, microwaving. It is also suitable for baking and roasting			
2	Rodeo cultivar	<u>Sensory attributes</u> - Adhesiveness/waxiness - Firmness		
		<u>Physical attributes</u> - Load maximum cooked, still warm - Load maximum cooked, cooled		
	<u>Suggested culinary applications</u> The low starch content and firmness of this cultivar makes it suitable for boiling, microwaving and making salads			
3	Platina cultivar	<u>Sensory attributes</u> - Buttery aroma - Fracturability - Moistness - Buttery flavor - Metallic after-taste		
		<u>Physical attributes</u> - Low specific gravity and - Raw shear force resistance measurement		
	<u>Suggested culinary applications</u> Fracturability and a low starch content indicates that the cultivar is suitable for baking boiling, microwaving and frying.			
4	Up-to-date cultivar	<u>Sensory attributes</u> - Earthy potato aroma		
		<u>Physical attributes</u> - High resistance when compressed with the fork - Moderate starch content		
	<u>Suggested culinary applications</u> Moderate starch content and resistance to compression indicates cultivar is suitable to fry, bake and microwave			
5	BP1, Fabula and Mondial cultivars	<u>Sensory attributes</u> - Cooked potato aroma - Cooked potato flavour - Earthy potato flavour		
		<u>Physical attributes:</u> - Percentage softening when cooked then cooled and - Percentage softening cooked, while still warm		
	<u>Suggested culinary applications</u> The average starch content of the cultivars contributes to suitability for most culinary applications, such as making salads and chips, microwaving, as well as roasting and baking			

5.8 VALUE OF THE PROPOSED CLASSIFICATION SYSTEM

This proposed classification system has been developed to assist the South African consumer in making the optimum cultivar choice for a specific culinary application. The proposed classification system will give the consumer access to information that could be useful in a wide variety of situations. The taxonomic categories could provide the type of information required to ensure consumer satisfaction (Ross & Murphy, 1999: 542).

For the proposed classification system to be beneficial and helpful to all, Potato South Africa and the potato industry should firstly accept this system. Their acceptance of this proposed classification system would reinforce and encourage its use. With their acceptance of this system, retailers will be able to inform and advise consumers on the various culinary applications of the different potato cultivars available. Consumers' intended cultivar choice will be assisted by supplementing scientifically based facts in order to make an informed decision. When consumers make use of the classification system, they will become acquainted with the differences between the various cultivars. The proposed classification system, however, needs to be tested at all levels from the farmer to the industry, as well as with retailers and the consumer for the successful implementation thereof. More cultivars from different regions also needs to be analysed to be fully representative as this was only a pilot study.

5.9 CONCLUDING SUMMARY

In this chapter, the fourth and last objective of this study, namely to propose a classification system for South African potato cultivars was achieved. A proposed classification system based on the eating quality of seven potato cultivars from one production regions in South Africa was developed and presented. Suitable culinary applications for these cultivars were assigned based on the eating quality of the potato cultivars. Images representative of the various culinary applications, were developed and are presented as examples of the applicable culinary applications within each of the five groups of potato cultivars in the classification system proposed. It is envisaged that this classification system could benefit South African consumers and marketers. As consumers find it more difficult to use traditional food categories to identify and classify food, largely due to the noted decline in culinary skills (Costa *et al.*, 2001:232) such a classification system could enhance consumer satisfaction.

Consumer satisfaction or dissatisfaction with a product has significant marketing implications. Food marketers should therefore also take note of the advantages that the proposed classification systems holds for marketing potatoes to enhance consumer satisfaction.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

In this final chapter the main findings, conclusions and limitations of the study are presented. Recommendations for future research are given.

6.2 MAIN FINDINGS

Various sensory and physical attributes influence the eating quality of potatoes. Eating quality constitutes many interrelated factors, which should be viewed together in order to provide a complete description thereof. It was therefore important to gain an understanding of all the contributing factors that determine the eating quality of potato cultivars produced under different production conditions.

Every food product has its own, unique composition that determines its eating quality. In the case of potatoes, the texture is influenced by production conditions (Van Dijk *et al.*, 2002b:2082). Production conditions such as soil potential, climate, topography and water supply thus contribute to the structure of potatoes which in turn determines the eating quality. The structural components comprise the physical attributes, which include the dry matter content and specific gravity, as well as chemical attributes relating to the starch composition. The sensory-perceived texture of potatoes is mainly determined by starch (Van Dijk *et al.*, 2002b:9056). The unique combination of not only the physical but also the chemical attributes is determinant of the overall eating quality and subsequent acceptance of the sensory attributes, such as aroma, texture, flavour and after-taste of different potato cultivars. It was thus important to measure the sensory and physical attributes of the different potato cultivars in order to explain and understand the factors that influence the eating quality.

Due to different growing and climatic conditions that existed in the two production regions, identical cultivars had dissimilar intensities for the sensory attributes evaluated. More drier,

thus more fracturable potatoes that were more similar in nature were produced in the dry-land production region in contrast to the potatoes produced in the irrigated production that were less fracturable and more cultivar-specific with the associated characteristics.

The four objectives of the study as spelled out in Chapter 3 (see 3.4) were accomplished and the main findings of each are presented.

6.2.1 Conclusions with regard to the sensory attributes of the three selected potato cultivars from the two production regions: Objective one - Sensory attributes

The first objective aimed to determine, describe and compare the sensory attributes namely aroma, texture, flavour and after-taste of the three cultivars within in each region, in order to compare the eating quality of the potato cultivars from the two production regions. Three potato cultivars, BP1, Mondial and HDM, from two potato production regions were evaluated with regard to these sensory attributes.

Differences were present in the eating quality of the three potato cultivars within each region as well as between the two potato production regions. Location, soil types and cultivation practices determine the potato cultivar to be produced in a production region. The Limpopo production region produced potatoes that were more cultivar-specific with associated sensory attributes of each cultivar. The ANOVA analysis detected significant differences for 16 of the 17 sensory attributes that were measured in this region. The Eastern Free State production region produced potatoes that were more similar in nature. Significant differences were established for only four of the 17 sensory attributes that were measured for this region with the ANOVA analysis.

However, comparing the cultivars from the two regions, the intensity of the sensory attributes of BP1 and Mondial cultivars varied between the two regions. In order to explain the variation in the intensity of the sensory attributes of similar cultivars between the regions, it is assumed that the differences are mainly due to the different growing and climatic conditions and the amount of water applied to the cultivars in the two production regions. Addendum C presents an exploratory view on the results of the three cultivars evaluated from the two production regions.

Objective one was achieved through the descriptive sensory evaluation and the analysis of variance (ANOVA) and principal component analysis performed (See Figure 4.1 and 4.2).

6.2.2 Conclusions with regard to the physical attributes of the three selected potato cultivars from the two production regions: Objective two - Physical attributes

The second objective aimed to determine, describe and compare the physical attributes of the three cultivars within in each region, in order to further interpret and compare the eating quality of potato cultivars from the two production regions. The physical measurements performed included specific gravity, shear force resistance measurement. Shear force measurements were performed cooked, still warm, and then when cooled. Percentage softening, still warm and then when cooled were also performed.

The potatoes from the Limpopo region had lower specific gravity measurements than those from the Eastern Free State region. Water applied to potato tubers decreases the specific gravity of potato tubers (Yuan *et al.*, 2003:153). The results of the physical measurements of the potato cultivars from the Limpopo region is therefore supported by this explanation, as they obtained lower specific gravity measurements compared to the potato cultivars from the Eastern Free State region. The lower specific gravity measurements resulted from the irrigation practices used in the Limpopo region.

With lower specific gravity measurements, a lower resistance to shear, a lower starch content and dry matter content could also be expected in the cultivars from the Limpopo region. They are expected to be more waxy and thus less fracturable in nature, compared to the potato cultivars from the Eastern Free State.

In the Eastern Free State region, the potato cultivars in comparison had high specific gravity measurements. It is therefore most likely that a higher dry matter content with a greater resistance to shear through the potato sample together with a high starch content and thus a more mealy, but fracturable, potato is expected for potato cultivars produced in this region. This assumption is supported by the fact that a dryer potato is produced in the Eastern Free State region compared to the Limpopo region (see Addendum C).

Objective two was achieved through the objective evaluations performed. In using the standardised formula to determine the specific gravity, Instron measurements to determine the shear force resistance and an electron microscopy for scanning electron microscopy images of the potatoes from the two production regions, triangulation of objective measurements were enhanced.

6.2.3 Conclusions with regard to the relationship of the three selected potato cultivars from the two production regions: Objective three - Comparison of the relationship between the sensory and physical attributes of the selected potato cultivars

In order to give a complete description of the eating quality of the potato cultivars both the sensory and objective data was used. Therefore, the third objective of the study was to compare and determine the relationship between the sensory and the physical attributes of the three potato cultivars from two production regions in South Africa. Partial least square regression modelling was used to relate the sensory attributes to the physical measurements of the three cultivars from the two production regions. The differences between the cultivars of the two production regions are clearly illustrated in Chapter 4 (see Figure 4.10).

A partial least regression (PLS) modelling method was applied to the three potato cultivars from two production regions. This modelling regression method was applied to relate the sensory attributes to the objective measurements (Peppard, *et al.*, 1989; Toscas *et al.*, 1999) and to identify the most important attributes differentiating between the potato cultivars as well as between the two regions. The objective measurements assisted in assigning suitable culinary applications for the different potato cultivars. Most of the variance in eating quality is explained by the sensory attributes of a cooked potato flavour, fracturability, a cooked potato aroma, adhesiveness/waxiness, mealiness, firmness and dryness upon swallowing. The physical attributes included shear force resistance in a raw state, specific gravity and percentage softening cooked, while still warm.

Different growing conditions exist in the two production regions. From the results presented, it is evident that one cannot assume that identical cultivars will have similar sensory attributes. Potato cultivars from an irrigated potato production region could be expected to be waxy and less fracturable, and more cultivar-specific, with its associated characteristic elements, as opposed to a dry-land potato production region. Potato cultivars from a dry-land production could be expected to be more similar in nature, i.e. mealy and more fracturable (see Chapter 4, Figure 4.5).

It is apparent that the sensory attributes of the potato cultivars from the two production regions differ significantly within a region, as well as between regions. The differences between the regions may possibly be due to the biological variation between the replicates of identical cultivars.

Objective three was achieved with the PLS regression modelling method as applied to the sensory attributes and the objective measurements from both production regions in order to identify the most important attributes that differ between the potato cultivars as well as between the two regions.

Based on the results obtained from the above objectives, a classification system for potato cultivars could be developed.

6.2.4 Conclusions with regard to the proposed classification system for the South African consumer: Objective four - A proposed classification system of potato cultivars for the South African consumer

The fourth and last objective of this study was to propose a classification system based on the culinary applications of the various potato cultivars for the South African consumer. Suitable culinary applications, based on the eating quality of the potato cultivars, were assigned to the cultivars and presented in a classification system in Chapter 5 (see 5.7.1).

As only three similar potato cultivars from both production regions were used to compare the eating quality, a larger sample of cultivars for the proposed classification system was needed. Therefore seven different potato cultivars from the Eastern Free State region were used to compile the classification system. The eating quality of the potato cultivars was described and quantified. The partial least square (PLS) regression modelling method was used to understand the relationship between the sensory attributes and the objective measurements between the cultivars (Peppard *et al.*, 1989; Toscas *et al.*, 1999). The sensory attributes were related to the objective measurements and the most important attributes that differed between the potato cultivars were identified.

The sensory attributes of mealiness, graininess, moistness and fracturability, as well as the physical measurements of the percentage softening (cooked, warm), specific gravity, load maximum (cooked, cooled) and load maximum (cooked, warm) explained most of the variances in the first dimension (see Chapter 5). The sensory attributes of compression with the fork and firmness, explained most of the variation in the second dimension for the proposed classification system.

The fourth objective of the study was achieved with the PLS regression biplot that indicated five cultivar groups. Potato cultivars were categorised and grouped according to their eating

quality. Culinary applications were assigned to the various cultivar groups based on the cultivars' associated sensory attributes and physical measurements. The proposed classification system therefore suggests the most suitable culinary applications for a potato cultivar.

In the proposed classification system for the South African consumer, images were carefully selected and used to illustrate the suggested culinary applications for the various potato cultivars (see Chapter 5). These images were used to communicate the suggested culinary application(s) of the potato cultivars to all South African consumers irrespective of their literacy level. The literacy level of South African consumers is diverse and the use of images is a means to reach consumers on all literacy levels in the South African society.

6.3 CONCLUSION OF THE STUDY

The results from the sensory and objective evaluation showed that eating quality is important and determines the consumer's acceptance of a potato cultivar. Texture is therefore important for a consumer's perception of potato quality as it is the single most important physical attribute that determines consumers' perception of the eating quality of potatoes. The texture of cooked potatoes is influenced by the biological variation between potato tubers (Thybo *et al.*, 2004:92). Although the texture of cooked potatoes is mainly determined by biological variation that exists between potato tubers, the sensory attributes of aroma, flavour, texture and after-taste are also regarded as important and discriminatory for eating quality. Texture and flavour were found to be the two sensory attributes of importance in the evaluation of the selected potato cultivars in this study.

From the results presented, it is evident that the sensory attributes of the different cultivars BP1, Mondial and HDM differ among the two regions. Therefore, it cannot be assumed that the sensory and physical characteristics of a specific potato cultivar will be similar in different potato production regions in South Africa. Dissimilar growing conditions such as rainfall, day temperatures and growing periods are present within the two regions. Different growing conditions, and more specifically the water supply during cultivation, seems to be an important factor responsible for the differences noted in the sensory and physical attributes of similar cultivars from the two production regions. Significant differences in the sensory and physical attributes of the potato cultivars occurred within the two regions (refer to Chapter 4) and differences were observed between the regions (see Addendum C).

Therefore, variations in a cultivar's characteristics should be measured, considering the various factors involved with the production conditions within regions, which in turn determine the eating quality of a specific potato cultivar.

The eating quality of potatoes plays an important role in the decision-making process of consumers for its intended use. This study contributed to determine, describe and understand the eating quality of a limited number of potato cultivars in South Africa. Scientific information was acquired from the sensory and objective evaluation performed in the two regions from which the eating quality of the potato cultivars was determined and described. A classification system of potato cultivars was proposed, based on the scientific information obtained. Potato cultivars were grouped into meaningful groups according to their eating quality and other characteristics. Based on this classification, suggested culinary applications for the groups of cultivars were recommended by means of a proposed classification system for the South African consumer. The proposed classification system will play an important role to ensure that consumers are satisfied with their cultivar selection and choice of culinary application.

6.4 LIMITATIONS OF THE STUDY

In conducting this study, certain limitations were present during the study. These related to the growth and harvest season of the potatoes and the physical measurements performed during the objective evaluation.

6.4.1 Growth and harvest season of potatoes

As a continuous supply of potatoes is required for the South African market throughout the year, potatoes are planted and harvested during different stages within a production season in various production regions. This study was performed during harvest periods in December 2006 and February 2007 which represented two different harvest periods. Different growing conditions (climate, soil type and moisture content, i.e. rainfall and the water supply) existed during the two growing and harvesting periods. The results obtained from the sensory and objective evaluation of the potatoes from the two regions were not from the same harvesting period and some of the differences recorded could be attributed to this fact.

6.4.2 Physical measurements used with Objective Evaluation

Specific gravity and shear force resistance measurements in a raw and cooked stage, at cold and warm temperatures were measured with the objective evaluation. Dry matter content and moisture content form part of the physical measurements for the objective evaluation of the potato samples, but they were not performed in this study. These measurements, in addition to the physical measurements performed, could have provided an enhanced and a more accurate representation of the physical properties of these potato cultivars. This contributes to the overall representation of the potato cultivars' eating quality.

6.5 RECOMMENDATIONS FOR FUTURE RESEARCH

Only three cultivars from the two production regions were evaluated. Different production and growing conditions existed in these two regions. In addition to the physical measurements performed during the objective evaluation of the cultivars, it is recommended that additional physical measurements need to be performed. These physical measurements include determining the dry matter content and moisture content, which will give a more complete representation of the physical and chemical attributes that influence the eating quality of a specific cultivar. Thus, for the purpose of a more refined classification system, adequate data collection should take place with more repetitions of the sensory and objective evaluations, including the physical and chemical measurements, with more cultivars and more production regions. This will not only ensure accuracy and consistency of the data, but also enhance the credibility and reliability of the results. More data from different cultivars and regions will ultimately lead to a more robust model on which the classification system could be based.

In order to commence the development of a complete classification system for the South African consumer, the eating quality of all potato cultivars available in South Africa needs to be determined based on their sensory and physical attributes. It is thus recommended that all the potato cultivars available on the South African market be subjected to sensory and objective evaluation in order to describe both their sensory and physical characteristics. Based on these characteristics, a cultivar profile could be created for each of the cultivars. This will contribute to the creation of a comprehensive potato classification system for the South African consumer. However, this proposed classification system serves only as a theoretical system and would need to be thoroughly tested in practice. The aim of a potato

classification system is to create and develop sensory profiles for all South African potato cultivars under various production conditions and environments. Understanding by customers need to be tested.

This study is one of the first in a series to determine the eating quality of the cultivars. Opportunities for further research to determine and categorise the eating quality of the various potato cultivars available in the different production regions into a classification system should continue.

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ADDENDUM A

PROOF OF APPROVAL FOR THE STUDY FROM THE ETHICS COMMITTEE

100
1908 - 2008



UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Ref: EC090209-009

05 March 2009

Mrs AT Viljoen
Department of Consumer Sciences
University of Pretoria
Pretoria
0002

ETHICS COMMITTEE

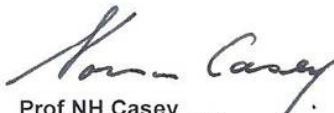
Faculty of Natural and Agricultural Sciences
University of Pretoria
Pretoria
0002
Tel: 012-4204107
Fax: 012-4203290

Dear Mrs Viljoen

Re: EC090209-009 A comparison of the eating quality of selected potato cultivars from two potato production regions and a proposed classification system for the South African consumer

The project conforms to the requirements of the Ethics Committee.

Kind regards


Prof NH Casey
Chairman: Ethics Committee

ADDENDUM B

LEXICONS USED IN THE STUDY

TABLE B1: THE LEXICON USED FOR SENSORY EVALUATION OF THE POTATO CULTIVARS FROM THE LIMPOPO PRODUCTION REGION DURING NOVEMBER/DECEMBER 2006

AROMA	
Cooked potato	The aroma and flavour that refers to the internal portion of a baked or cooked potato as opposed to a raw potato
Potato / earthy	Aromatic notes associated with damp soil, wet foliage or slightly undercooked potatoes
Buttery	Aromatic notes associated with potato to which a small amount of butter has been added – a potato with more flavour, less bland
TEXTURE (Initial impression of appearance: visual or break with fork and evaluate the appearance of the texture.)	
Reflection from the surface	Evaluate the surface that divides the potato in the width. Reflection from surface: expressed by the percentage of the surface covered by loose white reflecting starch grains (not reflective = 0% of the surface: very reflective = 100% of the surface)
Compression with the fork	Ease with which the potato is compressed with a small fork
Feel of potato	Rub potato flesh between fingers and evaluate the graininess
First bite (Use half sample, in mouth, tongue on palate)	
First bite: hardness in mouth	Force required to divide the potato in two parts by the front teeth
First chew: Firmness/compactness	Degree of compression between molar teeth before item falls apart. Expresses the work (amount of mastication) before the potato is ready to be swallowed
Mastication/chewing	
Graininess	Expresses the content of grainy particles in the mouth after chewing
Adhesiveness	Force required to remove potato sticking to teeth and palate after chewing
Mealiness	Expresses how mealy/crumbly the potato is felt in the mouth after chewing
Moistness	Expresses how moist the potato is felt in the mouth and how much moisture that item releases in the mouth after chewing
Dryness when swallowing	Evaluate the ease with which the sample is swallowed. Dryness in the throat
FLAVOUR	
Cooked potato	The flavour that refers to the internal portion of a baked or cooked potato as opposed to a raw potato
Buttery	A taste associated with potato to which a small amount of butter has been added – a potato with more flavour, less bland
Earthy/potato skin	Taste associated with earthy potato skin notes
Blanched water/earthy	A flavour of recycled water used to cooked potatoes, water is not fresh, slightly dirty, stale and earthy aroma
AFTER-TASTE	
Metallic	A metallic-like taste that causes drying in the mouth

Table B2 presents the sensory evaluation form used for the sensory evaluation of the cultivars from the Limpopo region.



TABLE B2: THE SENSORY EVALUATION FORM USED FOR THE ASSESSMENT OF THE POTATO CULTIVARS FROM THE LIMPOPO PRODUCTION REGION, DECEMBER 2006

Sensory evaluation of potatoes: 28 Nov – 1 Dec 2006								
Name:	Date: 1/12				Code: 822			
	None	Hint	Slight	Weak	Mode-rate	High	Very high	Extremely
AROMA								
Cooked potato	1	2	3	4	5	6	7	8
Potato/earthy	1	2	3	4	5	6	7	8
Buttery	1	2	3	4	5	6	7	8
TEXTURE (Initial impression of appearance: visual or break with fork and evaluate the appearance of the texture)								
Reflection from the surface	1	2	3	4	5	6	7	8
Compression with the fork	1	2	3	4	5	6	7	8
Graininess between fingers	1	2	3	4	5	6	7	8
First bite (use half sample, in mouth, tongue on palate)								
Hardness in mouth (first bite)	1	2	3	4	5	6	7	8
Firmness/compactness (mouth)	1	2	3	4	5	6	7	8
Mastication/chewing								
Graininess	1	2	3	4	5	6	7	8
Adhesiveness	1	2	3	4	5	6	7	8
Mealiness	1	2	3	4	5	6	7	8
Moistness	1	2	3	4	5	6	7	8
Dryness upon swallowing	1	2	3	4	5	6	7	8
FLAVOUR								
Cooked potato	1	2	3	4	5	6	7	8
Earthy/potato skin	1	2	3	4	5	6	7	8
Buttery	1	2	3	4	5	6	7	8
Blanched vegetable water	1	2	3	4	5	6	7	8
AFTER-TASTE								
Metallic	1	2	3	4	5	6	7	8

Table B3 presents the lexicon used for the sensory evaluation of the Eastern Free State region during February 2007.

TABLE B3: THE LEXICON USED FOR SENSORY EVALUATION OF THE POTATO CULTIVARS FROM THE EASTERN FREE STATE PRODUCTION REGION, DURING FEBRUARY 2007

ATTRIBUTE	DESCRIPTION
AROMA	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.
Hardness - knife	Force required to shear/slice through potato with knife.
Hardness - fingers	Force required to compress $\frac{1}{4}$ of the potato with one finger, when pressing longitudinally.
Fracturability with fingers	Degree of compression between fingers before the potato fractures. If the potato fractures at low compression degree, the potato has high fracturability, and oppositely. (Madeira cake = 8; biscuit = 5, hard candy = 1)
First bite (use half sample, in mouth, tongue on palate)	
First bite: Hardness in mouth	Force required to divide the potato in two parts by the front teeth. <i>Break off piece with knife, bite into potato.</i>
Fracturability – in the mouth	Degree of compression before the potato is separated into parts. If it separates immediately, the potato has high fracturability. If the potato fractures at low compression degree, the potato has high fracturability and oppositely (<i>press potato lightly against palate with tongue</i>). <i>Breaks easily, soft and smooth = high fracturability;</i> <i>Hard to break, breaks in pieces = low fracturability.</i>
Compactness	Degree of compression between molar teeth before item falls apart. Expresses the work (amount of mastication) before the potato is ready to be swallowed.
Mastication/chewing	
Mealiness	Expresses how mealy/crumblly the potato feels in the mouth after chewing. A potato that is hard, drier and more particulate.
Adhesiveness/waxiness	A waxy potato has been described as moist, mushy and smooth, and is associated to some degree with stickiness. Force required to remove potato sticking to teeth and palate after chewing. (Vegetable oil = 1; cream cheese (Philadelphia) = 5; processed cheese = 8).
Graininess	Expresses the content of grainy particles in the mouth after chewing. (jelly = 0; solution of potato flour = 8)
Moistness	Expresses how moist the potato feels in the mouth and how much moisture that item releases in the mouth after chewing.
FLAVOUR	
Buttery	A taste associated with potato to which a small amount of butter has been added – a potato with more flavour, less bland.
Earthy/potato skin	Taste associated with earthy potato skin notes.
Blanched water/earthy	A flavour of recycled water used to cooked potatoes, water is not fresh, slightly dirty, stale and earthy aroma.
AFTER-TASTE	
Metallic	A metallic-like taste that causes drying in the mouth.

The sensory evaluation form used for the sensory evaluation of the cultivars from the Eastern Free State region is presented in Table B4.



TABLE B4: THE SENSORY EVALUATION FORM USED FOR THE ASSESSMENT OF THE POTATO CULTIVARS FROM THE EASTERN FREE STATE PRODUCTION REGION, FEBRUARY 2007

Sensory evaluation:		February 2007							
Sensory evaluation of potatoes:		Date:							
Name:		Code:							
		None	Hint	Slight	Weak	Moderate	High	Very high	Extremely
AROMA									
Cooked potato		1	2	3	4	5	6	7	8
Potato/earthy		1	2	3	4	5	6	7	8
Buttery		1	2	3	4	5	6	7	8
Blanched vegetable water		1	2	3	4	5	6	7	8
TEXTURE: NON-ORAL									
Hardness – with the fingers		1	2	3	4	5	6	7	8
Hardness – with the knife		1	2	3	4	5	6	7	8
Fracturability - with the fingers		1	2	3	4	5	6	7	8
First bite (use half sample, in mouth, tongue on palate)									
Hardness – in the mouth		1	2	3	4	5	6	7	8
Fracturability - in the mouth		1	2	3	4	5	6	7	8
Firmness/compactness		1	2	3	4	5	6	7	8
TEXTURE: ORAL									
Mastication / chewing									
Mealiness		1	2	3	4	5	6	7	8
Adhesiveness/waxiness		1	2	3	4	5	6	7	8
Graininess - in the mouth		1	2	3	4	5	6	7	8
Moistness		1	2	3	4	5	6	7	8
Dryness upon swallowing		1	2	3	4	5	6	7	8
FLAVOUR									
Cooked potato		1	2	3	4	5	6	7	8
Earthy/potato skin		1	2	3	4	5	6	7	8
Buttery		1	2	3	4	5	6	7	8
Blanched vegetable water		1	2	3	4	5	6	7	8
AFTER-TASTE									
Metallic		1	2	3	4	5	6	7	8

ADDENDUM C

EXPLORATORY RESEARCH ON THE COMPARISON OF THE TWO PRODUCTION REGIONS

C1. DESCRIPTIVE SENSORY ANALYSIS OF THE TWO PRODUCTION REGIONS

The sensory data of the two regions could not be analysed statistically, given the unbalanced design of the sensory data of the Limpopo region (Chapter 4) and the balanced design of the sensory data of the Eastern Free State region. Thus, the results of the two regions were graphically compared and explored.

Figure 4.6 presents a detailed, visual comparison of the differences in the sensory attributes of the cultivars from the two production regions. The blue line represents the ratings of the sensory attributes of the potatoes from the Limpopo region, whereas the red line is illustrative of sensory attributes of the potatoes from the Eastern Free State region. All three cultivars of a region is analysed as one variable. Therefore, mean values of the cultivars' sensory attributes were used.

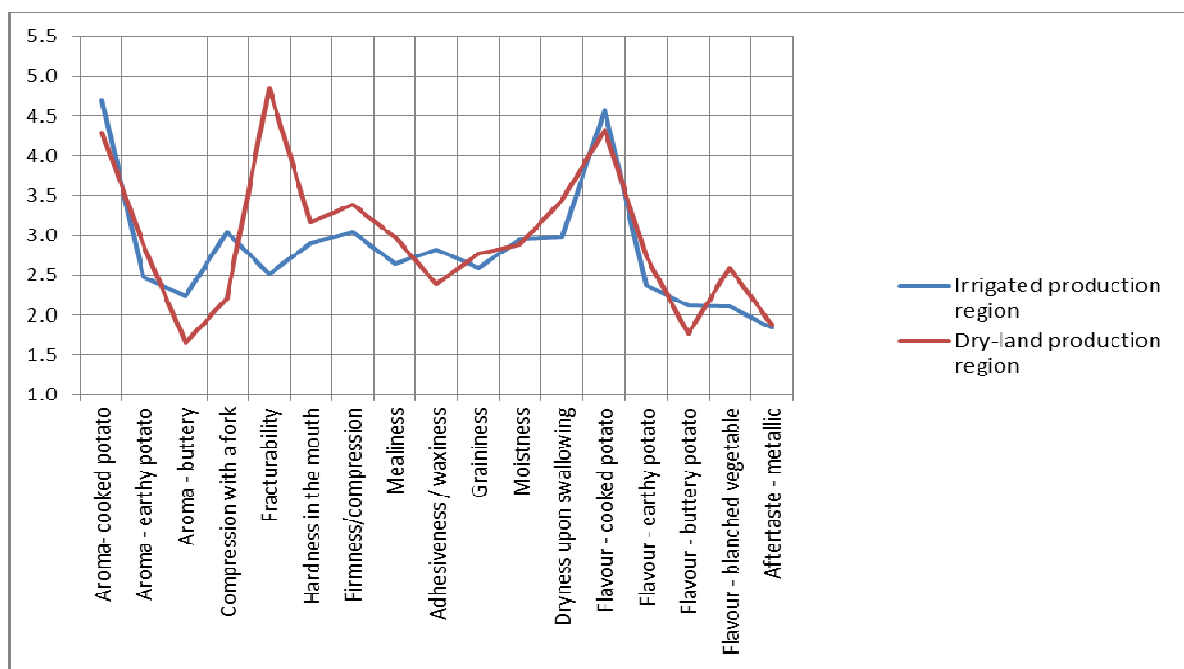


FIGURE C1: COMPARISON OF THE SENSORY ATTRIBUTES OF THE CULTIVARS FROM THE TWO PRODUCTION REGIONS

The sensory attributes of a cooked potato aroma, a buttery aroma, compression with the fork, adhesiveness/waxiness and a buttery flavour achieved higher ratings for the three cultivars tested from the Limpopo region. On the other hand, the sensory attributes of fracturability, hardness in the mouth, firmness/compactness, mealiness, moistness, dryness upon swallowing and an earthy potato flavour were most dominant in the Eastern Free State region. Similar results from the two regions will most probably occur for an earthy potato aroma, compression with the fork, moistness, a cooked potato flavour and a metallic after-taste.

It is thus apparent that the sensory attributes of one production region contrast with the other production region.

To further explore the differences in the sensory attributes of the cultivars from both production regions, a combined dataset was compiled and is presented.

C2.1 COMBINED DATASET OF THE SENSORY ATTRIBUTES OF THE CULTIVARS FROM BOTH PRODUCTION REGIONS

The mean sensory data from both regions was combined in order to determine whether differences existed between the eating quality of the cultivars from the two production regions with a region-to-region evaluation-comparison as presented in Table C1.



TABLE C1: COMPARISON OF THE MEAN VALUES OF THE SENSORY ATTRIBUTES OF THE TWO PRODUCTION REGIONS

SENSORY ATTRIBUTE	LIMPOPO BP1	EASTERN FREE STATE BP1	LIMPOPO MONDIAL	EASTERN FREE STATE MONDIAL	LIMPOPO HDM	EASTERN FREE STATE HDM
AROMA						
Cooked potato	4.79	4.79	4.14	4.72	4.28	4.38
Potato/earthy	2.18	2.18	3.5	2.88	2.88	2.2
Buttery	2.53	2.53	1.34	1.8	1.73	2.65
TEXTURE						
Compression with the fork	3.06	2.77	2.75	2.6	3.8	2.41
Fracturability	2.62	4.83	2.14	4.95	3.28	4.77
First bite						
Hardness in mouth (first bite)	2.92	3.22	2.66	2.83	3.53	3.42
Firmness/compactness (mouth)	3.06	3.47	2.75	3.05	3.8	3.61
Mastication / chewing						
Graininess	2.71	2.61	2.18	2.78	2.53	2.91
Adhesiveness	2.55	2.58	3.05	2.33	2.93	2.3
Mealiness	2.46	2.78	2.82	2.95	2.68	3.16
Moistness	3.04	3.06	3.07	2.68	2.35	2.93
Dryness upon swallowing	2.73	3.39	2.97	3.53	3.7	3.41
FLAVOUR						
Cooked potato	4.64	4.28	4.59	4.4	4.4	4.32
Earthy/potato	2.12	2.97	2.72	2.55	2.1	2.75
Buttery	2.38	1.61	1.73	1.85	2.53	1.8
Blanched vegetable water	1.9	2.56	2.34	2.53	2.03	2.68
AFTER-TASTE						
Metallic	1.68	1.86	1.99	2	1.84	1.77

No scientific information on the eating quality of South African potato cultivars is currently available. Assumptions are made to explain the differences in the eating quality of the potato cultivars in the two production regions. The Limpopo production region produces a potato crop that is harvested during the winter months, compared to the Eastern Free State production region that produces a crop that is harvested during the summer months.

No water-stress situations will be experienced in the Limpopo region potatoes with the natural rainfall of this region and the irrigation systems in place to enhance the water supply to the potatoes. Therefore, a continuous supply of water to the potatoes in this region is ensured. This condition will probably have an effect on the following sensory attributes of the potato cultivars (see Table 4.7): for a BP1 cultivar, increased sensory ratings are expected with a cooked potato aroma, a buttery aroma, increased compression with the fork, graininess, an earthy potato aroma, a cooked potato flavour and a buttery potato flavour. For

the Mondial cultivar, the sensory attributes of a cooked potato aroma, compression with the fork, adhesiveness/waxiness, moistness, a cooked potato flavour and an earthy potato flavour attained higher ratings by the sensory panel.

The potatoes growing in the Eastern Free State region will most probably experience the occurrence of water-stress situations. From the sensory evaluation's results obtained, it is most likely that increased sensory ratings will be expected in some of the other sensory attributes. The BP1 cultivar, for example, will have an earthy potato aroma, fracturability, hardness in the mouth with the first bite, firmness and compactness in the mouth, adhesiveness/waxiness, mealiness, moistness, dryness upon swallowing, an earthy potato flavour, a blanched vegetable water flavour and a metallic after-taste.

With the Mondial cultivar, a cooked potato aroma, a buttery aroma, fracturability, hardness in the mouth, firmness and compactness in the mouth, graininess, mealiness, dryness upon swallowing, a buttery flavour and a blanched vegetable water flavour will have higher ratings. According to Nourian *et al.* (2003:257), excessive quality loss due to the breakdown of the cellular material such as pectin may be caused by the cooking conditions.

However, with the comparison of the sensory evaluation's results of the two production regions, no difference will be expected in the sensory attributes of hardness in the mouth and graininess for the BP1 and Mondial cultivars, and similar results will most probably be obtained for the sensory attributes of an earthy potato aroma and a metallic after-taste.

The eating quality of the BP1, Mondial and HDM cultivars will be compared and explored based on a region-to-region evaluation, with a "per cultivar" comparison in order to determine if differences (if any) exist in the eating quality of similar potato cultivars between the regions.

C2.2 GRAPHIC COMPARISON OF THE SENSORY AND OBJECTIVE EVALUATIONS' RESULTS, PER CULTIVAR, FOR THE TWO PRODUCTION REGIONS

The results of the sensory and objective evaluation for each cultivar from both production regions were compared in order to determine the differences in the eating quality of the potato cultivars between the regions. Only sensory evaluation was performed for the HDM cultivar, as the HDM cultivar was used as the control.

The comparison of the sensory attributes and objective evaluation, followed by the results of the scanning electron microscopy performed for the two potato cultivars BP1 and Mondial is presented, followed by the results for the comparison of the HDM cultivar. The Limpopo region is referred to as (R1) and the Eastern Free State region as (R2).

C3.1 COMPARISON OF THE SENSORY ATTRIBUTES OF THE BP1 CULTIVAR FROM THE TWO PRODUCTION REGIONS

In Figure C2 the BP1 cultivar from the Limpopo region (R1) is represented by the blue bar, while the BP1 cultivar from the Eastern Free State region (R2) is represented by the red bar.

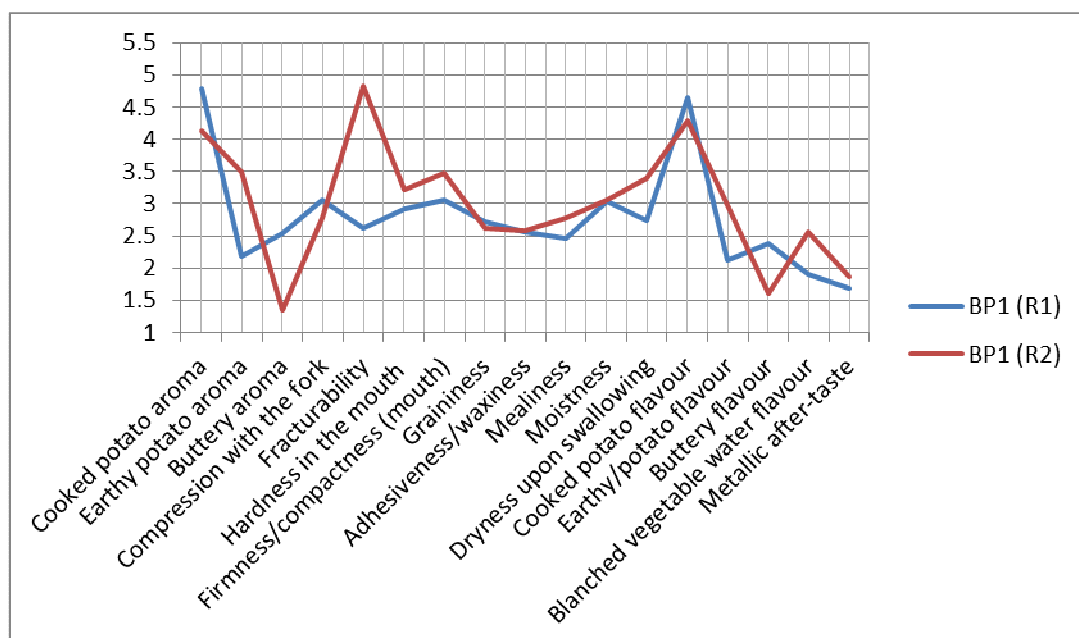


FIGURE C2: COMPARISON OF THE SENSORY ATTRIBUTES OF THE BP1 CULTIVAR FROM BOTH PRODUCTION REGIONS

The sensory attributes of the BP1 cultivar from the Eastern Free State region differed from the sensory attributes of the BP1 cultivar from the Limpopo region.

The BP1 cultivar from the Limpopo region had higher intensities for the sensory attributes of a cooked potato aroma, a buttery aroma, compression with the fork, graininess, a cooked potato flavour and a buttery flavour compared to the BP1 of the Eastern Free State region.

Noticeably, the BP1 cultivar from the Eastern Free State region had a higher intensity for the sensory attribute of fracturability.

C3.2 COMPARISON OF THE OBJECTIVE MEASUREMENTS OF THE BP1 CULTIVAR FROM THE TWO PRODUCTION REGIONS

The objective measurements of the BP1 cultivar between the two regions are illustrated in Figure C4. Higher percentage softening values and higher intensities of load maximum cooked, still warm and load maximum cooked, then cooled, were obtained for the BP1 cultivar from the Eastern Free State region, compared to the BP1 cultivar from the Limpopo region. According to Chiavaro *et al.* (2005), the cooking of potatoes causes a decrease in the force needed to shear the product. An increased resistance to shear through the potatoes of the BP1 cultivar from the Eastern Free State region was noted in Figure C4 compared to the BP1 cultivar from the Limpopo region.

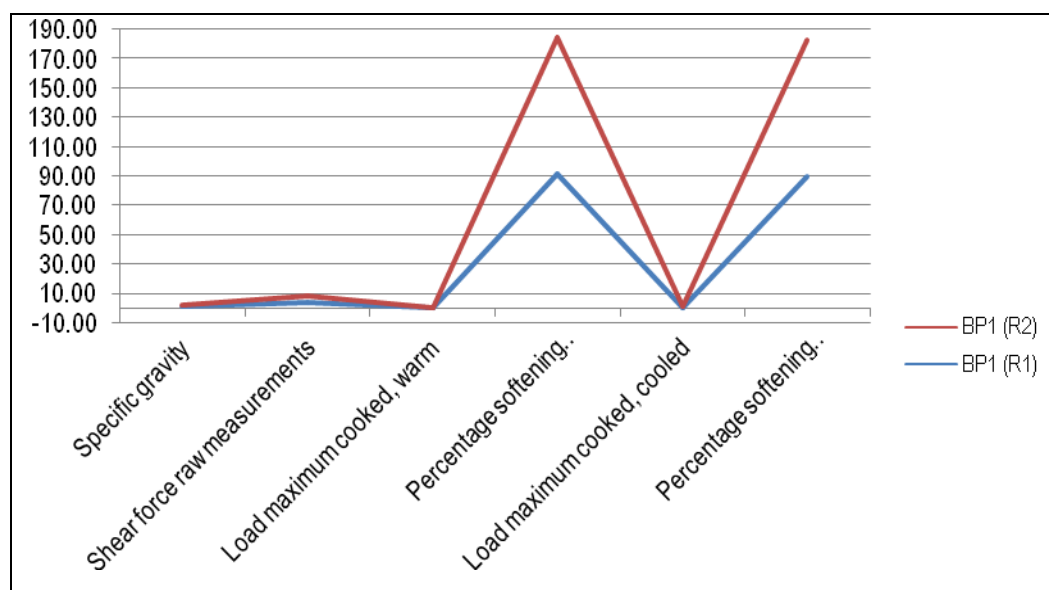


FIGURE C3: COMPARISON OF THE OBJECTIVE MEASUREMENTS OF THE BP1 CULTIVAR FROM BOTH PRODUCTION REGIONS

C4.1 COMPARISON OF THE SENSORY ATTRIBUTES OF THE MONDIAL CULTIVAR FROM BOTH PRODUCTION REGIONS

Differences were found for the sensory attributes of the Mondial cultivar between the Limpopo and the Eastern Free State regions. Figure C5 illustrates the differences of the sensory attributes between two potato production regions.

Figure C5 represents the Mondial cultivar from the two regions with the blue bar representing the Mondial cultivar from the Limpopo region (R1) and the red bar representing the BP1 cultivar from the Eastern Free State region (R2).

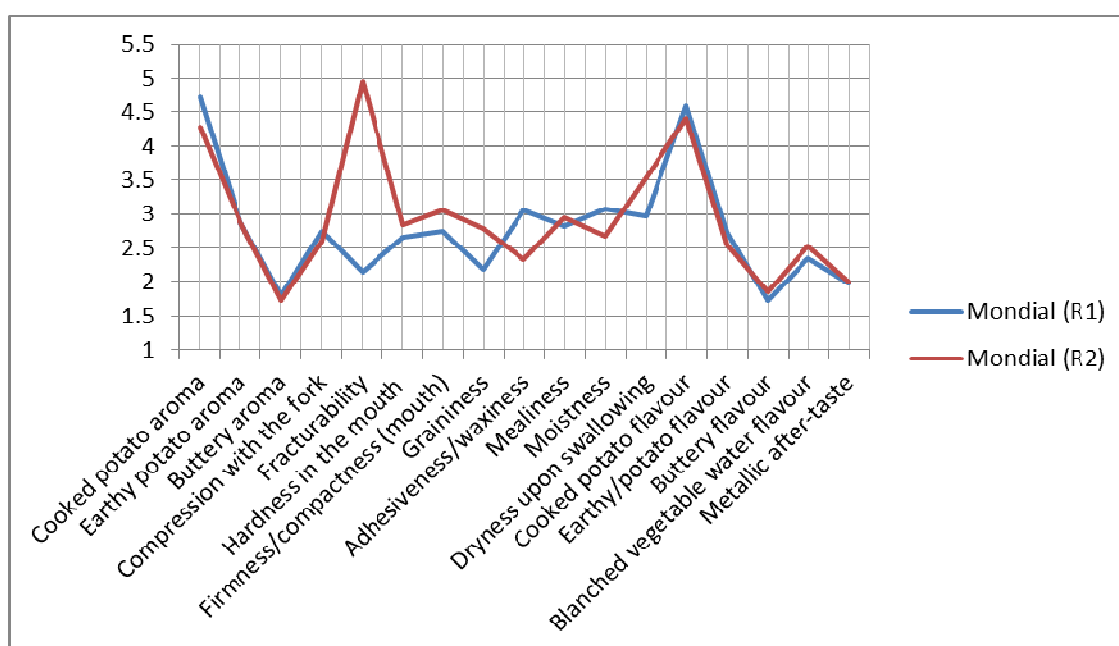


FIGURE C4: COMPARISON OF THE SENSORY ATTRIBUTES OF THE MONDIAL CULTIVAR FROM BOTH PRODUCTION REGIONS

From the results of the sensory evaluation, the Mondial cultivar from the Limpopo region had higher intensities of the sensory attributes of a cooked potato aroma, a buttery aroma, compression with the fork, adhesiveness/waxiness, moistness, a cooked potato flavour and an earthy potato flavour compared to the Mondial cultivar from the Eastern Free State region.

Yet again, for the sensory attribute of fracturability, similar to the BP1 cultivar of the Eastern Free State (Figure C3), the Mondial cultivar from the Eastern Free State (Figure C5) had higher intensities of the sensory attribute of fracturability.



C4.2 COMPARISON OF THE OBJECTIVE MEASUREMENTS OF THE MONDIAL CULTIVAR FROM THE TWO PRODUCTION REGIONS

Figure C6 illustrates the objective measurements of the Mondial cultivar between the two regions.

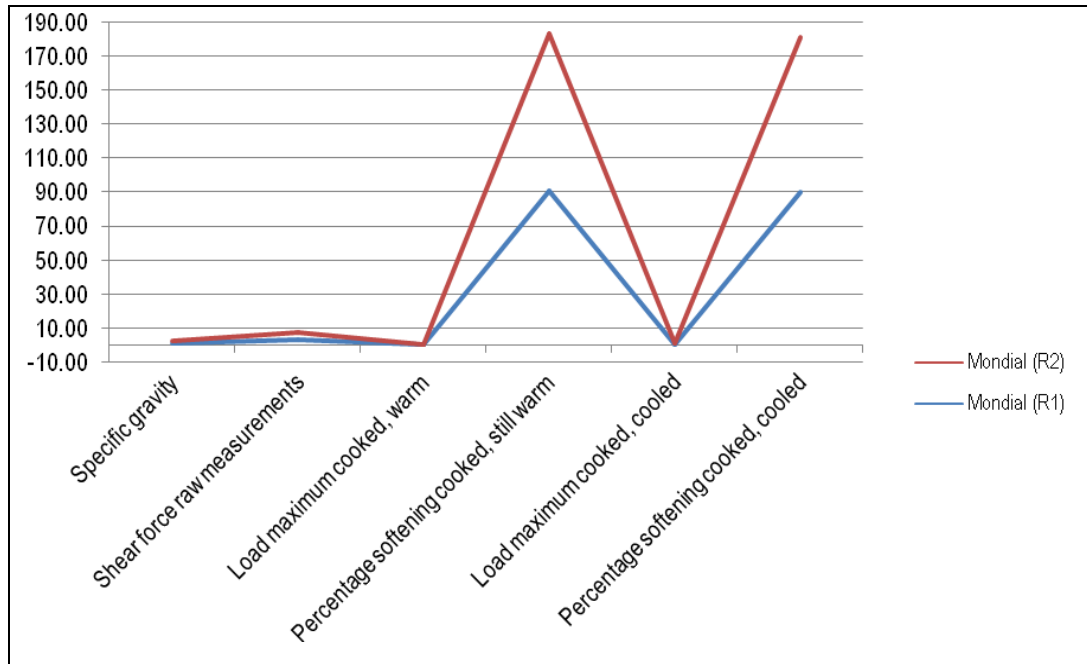


FIGURE C5: COMPARISON OF OBJECTIVE MEASUREMENTS OF THE MONDIAL CULTIVAR FROM BOTH PRODUCTION REGIONS

Higher percentage softening values and higher intensities of load maximum cooked, still warm and load maximum cooked, cooled, were obtained for the Mondial cultivar from the Eastern Free State region, compared to the BP1 cultivar from the Limpopo region. As seen in Figure C6, the Mondial cultivar from the Eastern Free State region presented an increased resistance to shear through the potato sample compared to Mondial cultivar from the Limpopo region.

Within a region, the objective measurements of the cultivars were compared.

C5.1 COMPARISON OF THE OBJECTIVE RESULTS OF THE TWO PRODUCTION REGIONS

In Table C2 the objective measurements of the two regions are compared with a region-to-region evaluation comparison.

TABLE C2: COMPARISON OF THE OBJECTIVE MEASUREMENTS OF THE TWO PRODUCTION REGIONS

ATTRIBUTE	LIMPOPO BP1	EASTERN FREE STATE BP1	LIMPOPO MONDIAL	EASTERN FREE STATE MONDIAL	LIMPOPO HDM	EASTERN FREE STATE HDM
Specific gravity	1.07	1.08	1.06	1.08	1.09	1.10
Load maximum shear force, raw	3.30	4.52	3.07	4.09	4.13	5.14
Load maximum cooked, warm	0.27	0.31	0.27	0.31	0.38	0.37
Percentage softening cooked, still warm	91.9	93.1	90.9	92.3	90.8	92.9
Load maximum cooked, cooled	0.33	0.32	0.30	0.38	0.44	0.43
Percentage softening cooked, cooled	90.1	92.7	90.3	90.7	89.2	91.7

The different growing conditions have an influence on the objective measurements of the three cultivars from the two production regions.

C5.1.1 DISCUSSION OF THE OBJECTIVE MEASUREMENTS OF THE BP1 AND MONDIAL CULTIVARS FROM THE TWO PRODUCTION REGIONS

The objective measurements performed included specific gravity, load maximum shear force (raw), load maximum cooked (warm), percentage softening cooked, still warm; load maximum cooked, cooled, and percentage softening cooked, then cooled. These aspects are discussed below.

Influence of specific gravity measurements of potato cultivars from the two production regions

Specific gravity of potato tubers is widely used as an indicator of quality (Young, 1961:14). The specific gravity of the potato tubers tend to decrease as the water applied increases (Yuan, Nishiyama & Kang, 2003:153). A lower specific gravity of the potato cultivars from the Limpopo region is noted compared to the cultivars from the Eastern Free State region (Table C2). Potato cultivars in the Limpopo region grow during the late summer season, early autumn. With the irrigation systems in place and the amount of water applied to the cultivars in this region, and with reduced sunlight during the days throughout this time of year for evaporation of any excess water, it may possibly have a decreasing effect on the specific gravity of the potato cultivars.

Specific gravity of the BP1 and HDM cultivars had similar results in both regions, while the results of the Mondial cultivar had dissimilar results between the regions. Higher specific gravity measurements were obtained for the BP1 and Mondial cultivar from the Eastern Free State region. As explained by Barrios, Newsom and Miller (1960:182), a high specific gravity is usually associated with a high dry matter content, a high starch content and thus a quality potato. As stated by Young (1961:14) and Lujan and Smith (1964:244), a high correlation between dry matter content, specific gravity and the mealiness of the cooked product was indicated as one of the major factors of potato quality. According to Singh *et al.* (2005:1275), higher specific gravities, starch and amylose content as well as a higher percentage of large starch granules are associated with mealy potatoes. Factors related to mealiness were grouped into those of physical and chemical nature, which determines the degree of mealiness (Barrios *et al.*, 1960:182). Mealy potatoes have a mealy or relatively dry, flaky texture after cooking, it crumbles readily when mashed and gives a dry floury mash (Lujan & Smith, 1964:244).

BP1 cultivar from the Eastern Free State region, with a specific gravity of 1.08, was more mealy compared to the BP1 cultivar from the Limpopo region (see Figure C3.1) with a specific gravity of 1.07, which is contrary to what was expected, as the sensory attribute of mealiness is normally associated with the Mondial cultivar. The Mondial cultivar from the Eastern Free State region, with a specific gravity of 1.08, was also more mealy than the Mondial cultivar from the Limpopo region, with a specific gravity of 1.06 (Figure C4.1). However, according to Greenwood, McKendrick and Hawkins (1952:192), potato tubers with similar specific gravities may not always exhibit the same degree of mealiness.

Specific gravity is positively associated with the starch content of potato tubers. Waxy-textured tubers display a moist and smooth appearance and less integration after cooking as the tuber's structure is left intact. Waxy potatoes have a lower starch content than mealy potatoes (Feltran, Lemos & Vietes, 2004:600, 602; McComber *et al.*, 1994:2434). With lower specific gravity measurements of (1.06 – 1.09) for the cultivars from the Limpopo region, these cultivars are expected to be more waxy in nature compared to the cultivars from the Eastern Free State region having higher specific gravity measurements of (1.08 – 1.10), as presented in Table 4.8.

Influence on the shear force measurements of the cultivars from the two production regions

Shear force is an indicator of firmness (Abu-Ghannam & Crowley, 2006:335). When force is applied to a structure, consisting of a network of interconnected cells, a rupture occurs at the point of minimum resistance. In this structure, the cells can either separate through the middle lamella or the cells can burst, depending upon the strength of the middle lamella (Singh *et al.*, 2005:1275). Cell rupture usually occurs in raw potatoes, as explained by Singh *et al.* (2005:1275), and according to Nourian *et al.* (2003:257, 261), the intercellular adhesion in raw potato tubers is important in relation to the texture of the cooked potatoes. The shear force resistance measurements in raw potato samples was more prominent in the Eastern Free State region (5.14 - 4.52) compared to the Limpopo region (4.13 - 3.30).

As stated by Lujan & Smith (1964:244), there is a positive correlation between shear force values and specific gravity. According to the results presented in Table 4.8, the cultivars from the Eastern Free State region obtained higher specific gravity measurements. The shear force measurements from raw potato samples were also higher, as it was reported in the table, thus confirming the statement made by Lujan & Smith (1964:244).

According to Singh *et al.* (2005:1275), cooked potato samples present cell separation as a result of thermal destabilisation. The textural changes that occur during the cooking of potatoes are mainly associated with the gelatinisation and retrogradation behaviour of starch, which represents the predominant substance in the tuber cell wall and middle lamellae structural components. Higher softening values and higher intensities of load maximum cooked, still warm and load maximum cooked, then cooled, were obtained for the two potato cultivars BP1 and Mondial from the Eastern Free State region, compared to the potatoes from the Limpopo region. Moreover, higher ratings were achieved for the percentage softening cooked, still warm (93.1–92.3) and for percentage softening cooked, then cooled,

(92.7–90.7) measurements, for the three potato cultivars from the Eastern Free State region as presented in Table 4.8.

C6.1 COMPARISON OF THE HDM CULTIVAR FROM THE TWO PRODUCTION REGIONS

The HDM cultivar illustrated differences in the intensity ratings of the sensory attributes between the two regions. The HDM from the Limpopo region is represented by the blue bar, whereas the red bar represents the HDM from the Eastern Free State region. The observable differences of the sensory attributes are presented in Figure 4.12. The HDM cultivar was only used as the control measure, therefore no objective measurements or scanning electron microscopy was performed for this cultivar.

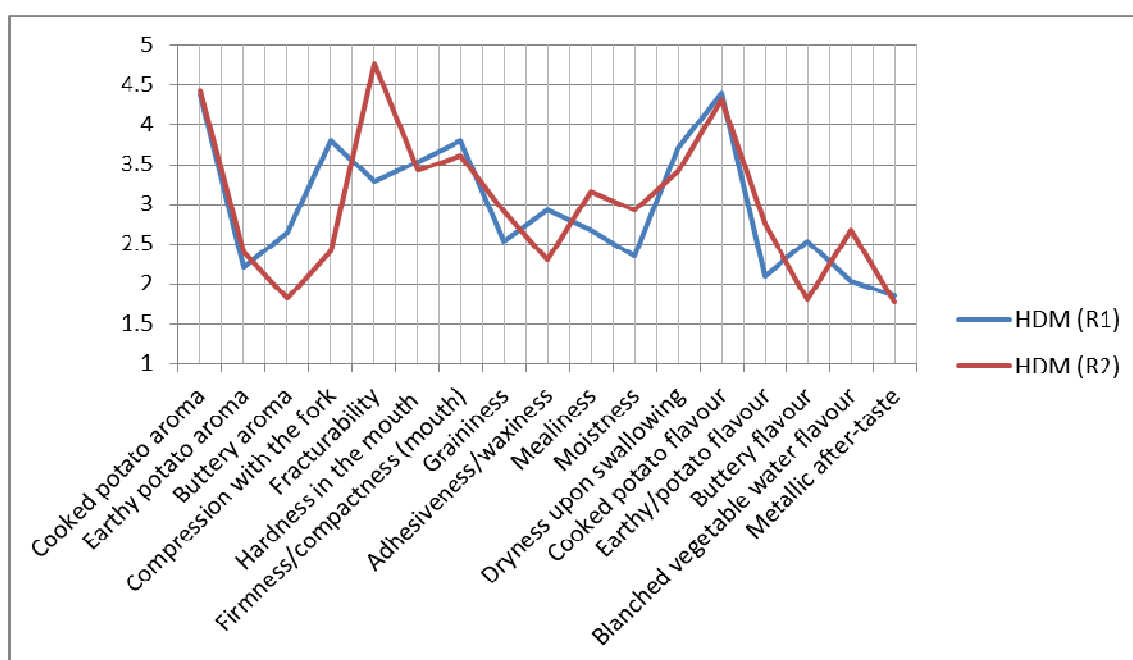


FIGURE C6: COMPARISON OF THE SENSORY ATTRIBUTES OF THE HDM CULTIVAR FROM BOTH PRODUCTION REGIONS

The HDM cultivar of the Limpopo region appears to have a more intense buttery aroma, a higher compression with the fork, adhesiveness/waxiness as well as a buttery flavour. On the other hand, the sensory attributes of fracturability, graininess, mealiness, moistness and a blended vegetable water flavour are associated with the HDM cultivar from the Eastern Free State.

The sensory attribute of fracturability of the HDM cultivar from the Eastern Free State region has again had higher intensity ratings compared to the HDM cultivar from the Limpopo region. Van Marle *et al.* (1997b:1686), explained that, upon processing of potatoes, pectic material is degraded and partly solubilised into the cooking media. This degradation greatly influences intercellular adhesion and the structure of the remaining cell walls which are both important texture parameters.

C7. SENSORY EVALUATION'S RESULTS OF THE THREE CULTIVARS FROM THE TWO PRODUCTION REGIONS

Figure C8 gives a detailed representation of the sensory evaluation of the potato cultivars from both production regions.

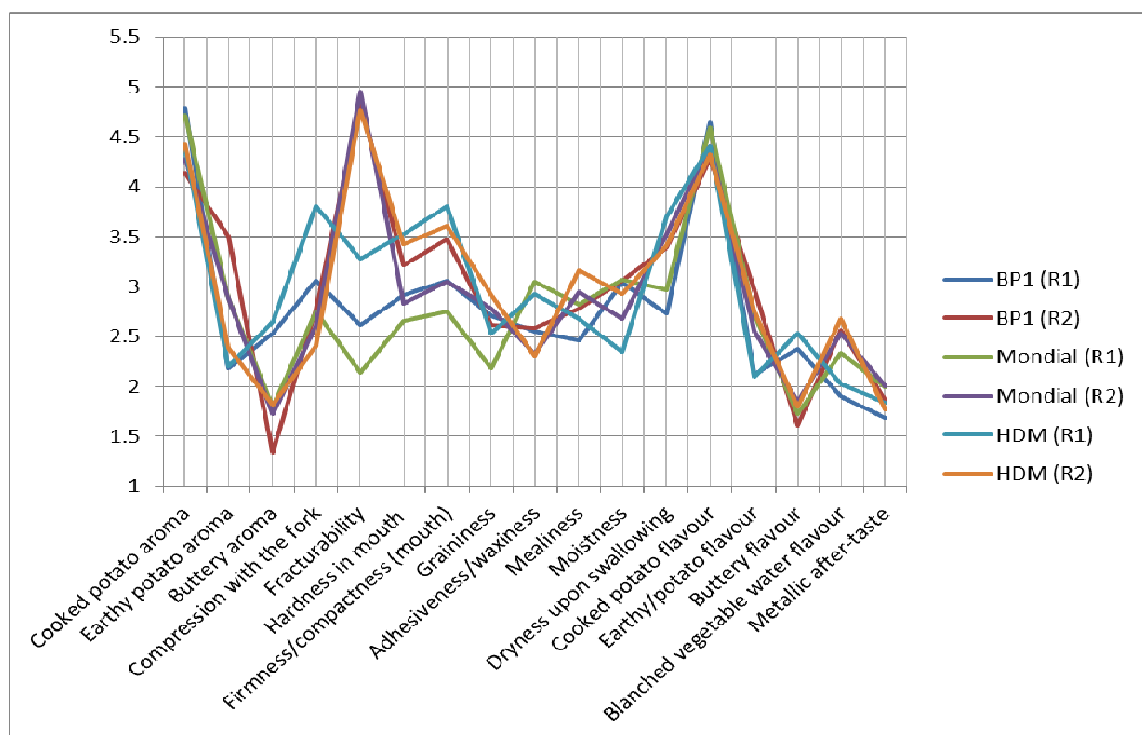


FIGURE C7: COMPARISON OF SENSORY ATTRIBUTES OF THE THREE CULTIVARS FROM BOTH PRODUCTION REGIONS

The sensory attributes of the BP1 and the Mondial cultivars differed between the two regions. The intensity of the sensory attributes of a specific cultivar varied between the two production regions as seen in Figure C3.1 and Figure C4.1. A number of factors namely tissue total

solids, starch content, starch granule size, parenchyma cell size, pectic substance nature and content, influence cooked potato texture. In potatoes, the abundance of starch in the cells, the shape and size of the starch granules and the structure of the cell wall polymers are reported as being important for the final texture (Singh, Kaur, Ezekiel & Guraya, 2005:1275). Due to the variation in the sensory attributes of either the BP1 or Mondial cultivar between the regions, the assumption is that the constituents of the cell wall material of any of the three cultivars are dissimilar between the regions. Therefore, according to Singh *et al.* (2005:1275), the structure and properties of the cell wall polymers influence the way in which the plant tissues undergo mechanical deformation and failure during mastication. According to Van Marle *et al.* (1997b:1688), the amount of arabinose, rhamnose, mannose and xylose in the cell wall material between cultivars are slightly different.

As different growing and climatic conditions exist in the two potato production regions, one cannot assume that identical cultivars will have similar intensities for their sensory attributes. As depicted in Figure 4.14, similar cultivars (BP1, Mondial and the HDM) in each of the production regions were evaluated and tested, which produced dissimilar results for each of the cultivar types. Potatoes produced under dry-land growing conditions are more fracturable (see Figure C3, C5 and C7) compared to potatoes produced under irrigated growing conditions were less fracturable and more cultivar-specific with its associated characteristic elements.

From the above results, it is apparent that the sensory attributes of the two production regions differ significantly within a region, and differ between the regions. Reason for the differences between the regions may be due to the biological variation between the identical replicates of the cultivars.

This creates a challenge for Potato South Africa, as consumers have increased purchasing power that demands not only a food product of a high quality, but also a uniform product.

Cooking gains and losses, cooking temperatures and cooking times for the two regions were captured and are presented below.

C8. Cooking gains and losses, temperature and cooking times recorded

As part of the cooking process, potatoes' weight was measured before and after the cooking process in order to determine whether cooking gains or losses occurred during the cooking process. Table C3 presents the cooking results of the three cultivars from both production regions.

TABLE C3: RECORDED MEASUREMENTS OF COOKING GAINS AND LOSSES FOR THE THREE CULTIVARS FROM BOTH PRODUCTION REGIONS

		Weight (g) before cooking	Weight (g) after cooking	Weight gain/loss (g)	
Limpopo	BP1	838.4	838.0	-0.4	Weight loss
	Mondial	659.0	657.8	-1.2	Weight loss
	HDM	1086.8	1090.2	3.4	Weight gain
Eastern Free State	BP1	674.0	766.4	92.4	Weight gain
	Mondial	975.8	975.8	0.0	No difference
	HDM	1040.4	1040.4	0.0	No difference

The BP1 and Mondial cultivar from the Limpopo region showed 0.4 g and 1.2 g of moisture loss during the cooking process compared to the HDM cultivar from the Limpopo region and the BP1 cultivar from the Eastern Free State region that gained irrespectively 3.4 g and 32.4 g of moisture during the cooking process. No change in the cooking mass was recorded for the Mondial cultivar from the Limpopo region and the Mondial and HDM cultivar from the Eastern Free State region.

Starting and internal temperatures were recorded for the BP1, Mondial and HDM cultivars from both production regions.

TABLE C4: RECORDED TEMPERATURE MEASUREMENTS OF THE THREE CULTIVARS FROM BOTH PRODUCTION REGIONS

		Starting temperature (room temperature)	Internal temperature
Limpopo	BP1	25 °C	92 °C
	Mondial	25 °C	92.5 °C
	HDM	25 °C	93 °C
Eastern Free State	BP1	25 °C	92.5 °C
	Mondial	25 °C	92 °C
	HDM	25 °C	93 °C

Cooking times were recorded for the BP1, Mondial and HDM cultivars from both production regions.

TABLE C5: RECORDED COOKING TIMES OF THE THREE CULTIVARS FROM BOTH PRODUCTION REGIONS

		Time started	Time finished	Total cooking time
Limpopo	BP1	09:10	10:00	50 minutes
	Mondial	09:10	10:05	55 minutes
	HDM	09:10	10:15	65 minutes
Eastern Free State	BP1	09:10	10:05	55 minutes
	Mondial	09:10	10:15	65 minutes
	HDM	09:10	10:25	75 minutes

ADDENDUM D

PHOTOGRAPHS

A descriptive sensory evaluation was performed on three potato cultivars from two potato production regions (Limpopo and Eastern Free State regions) in South Africa to determine, describe and compare the eating quality of the two production regions.



FIGURE D1: SAMPLES USED WITH THE SENSORY EVALUATION

Samples were sourced within the region from various farms, from both production regions.



FIGURE D2: TRAINING OF THE SENSORY PANEL AT THE AGRICULTURAL RESEARCH COUNCIL (ARC), IRENE

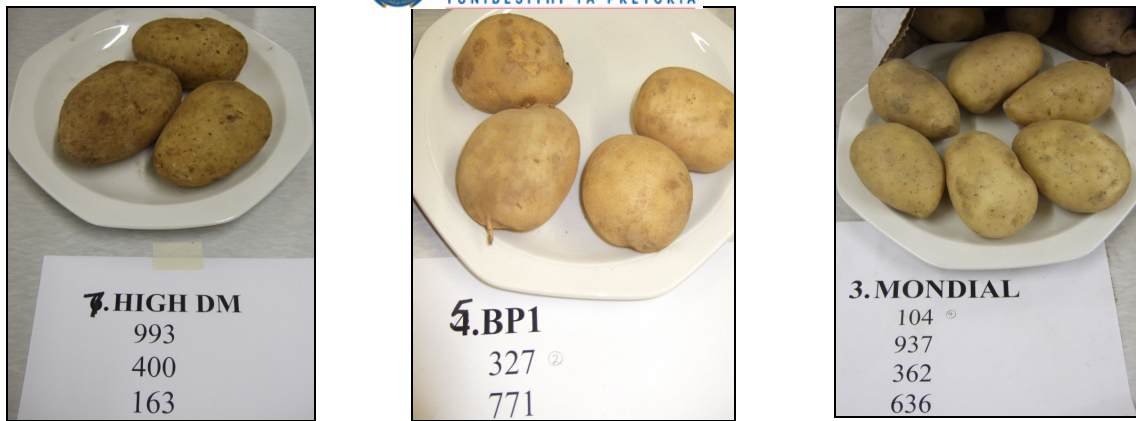


FIGURE D3: SAMPLE SELECTION FOR THE SENSORY EVALUATION

3-Digit numbers were assigned to the cultivars evaluated with the sensory evaluation in order to assist with the statistical analysis of the sensory data.



FIGURE D4: WEIGHING OF POTATOES

Potatoes were weighed before and after the cooking process to determine moisture gains or loss.



FIGURE D5: COOKING PROCESS OF POTATOES

Potatoes were cooked until soft and reached an internal temperature of 92-93 °C, tested with a hand-model Kane-Mane probe.



FIGURE D6: SAMPLE PREPARATION FOR SENSORY EVALUATION

All materials needed for sample preparation for the sensory evaluation is presented in above Figure.



FIGURE D7: PREPARATION OF THE POTATO SAMPLES FOR SENSORY EVALUATION

Potatoes were cut vertically (from top to bottom) into halves for the sensory evaluation.

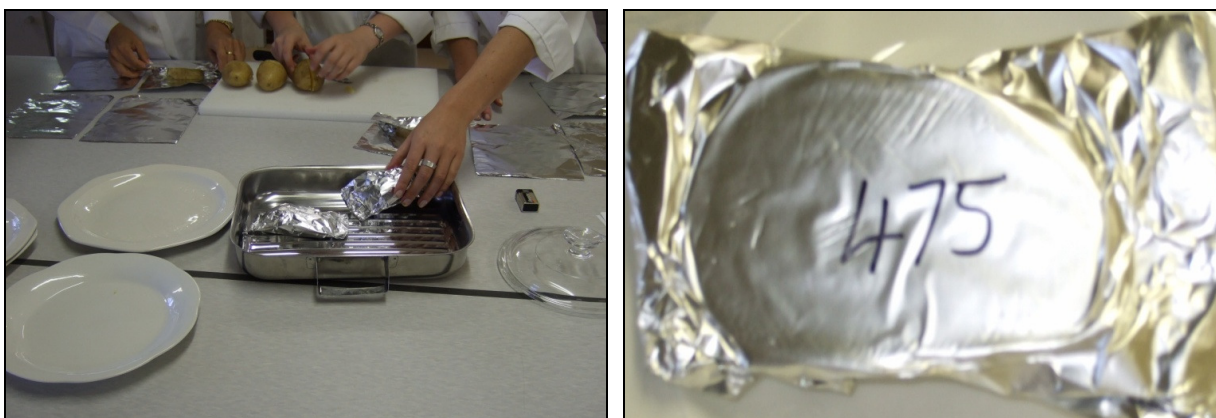


FIGURE D8: PREPARATION AND CODING OF THE SAMPLES FOR SERVING THE POTATO SAMPLES FOR THE SENSORY EVALUATION

Each of the samples were foil wrapped, shiny side inside, and coded with a 3-digit code to hide the identity of the specific cultivar to avoid bias or pre-conceived perceptions about a certain cultivar.

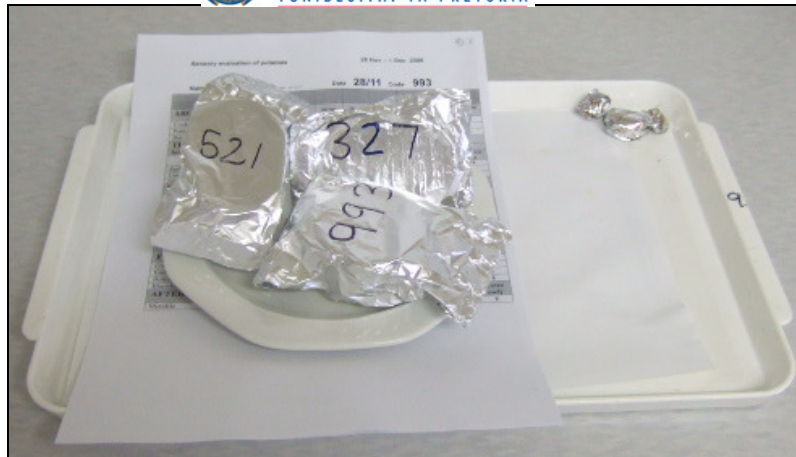


FIGURE D9: THE TRAY FOR THE SENSORY EVALUATION

Each trained panelist was presented with a tray of three 3-digit coded potato samples for the sensory evaluation.

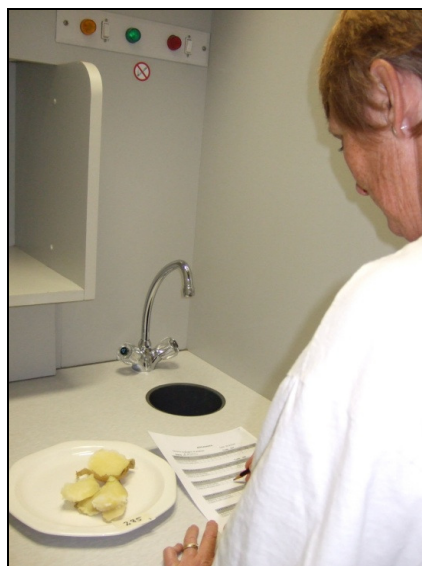


FIGURE D10: A TRAINED SENSORY PANELIST EXECUTING SENSORY EVALUATION

Trained sensory panelists performed the sensory evaluation in the sensory booth at the Agricultural Research Council, Irene



OBJECTIVE EVALUATION PERFORMED WITH THE SELECTED POTATO CULTIVARS

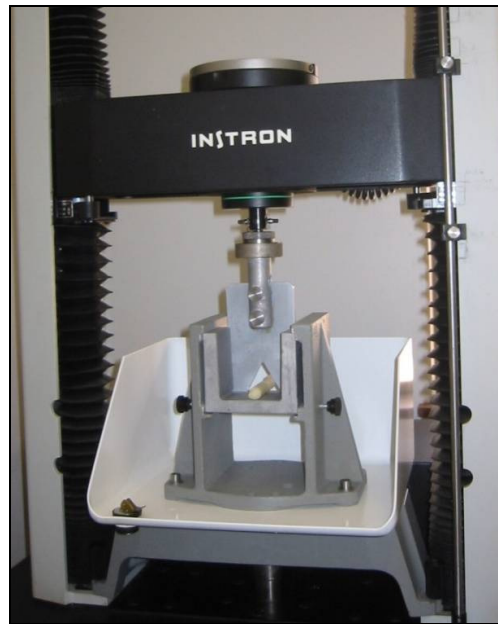


FIGURE D11: SHEAR FORCE MEASUREMENTS WITH THE INSTRON MACHINE

Shear force resistance measurements were performed with the Instron machine

Potatoes were cored for the samples used in the objective evaluation.

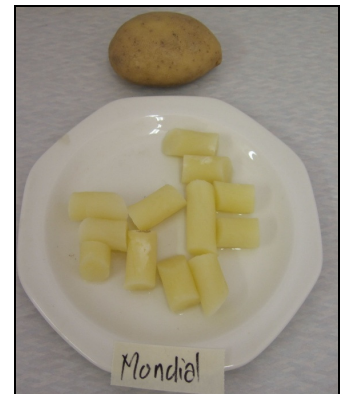
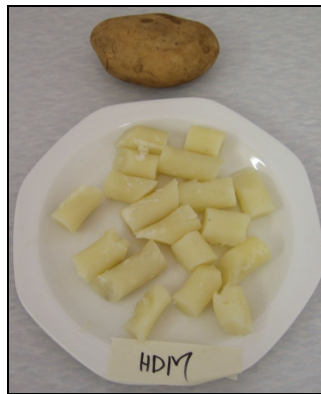
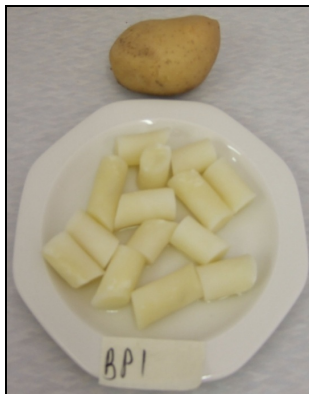


FIGURE D12: SAMPLE PREPARATION FOR THE OBJECTIVE EVALUATION OF THE BP1, MONDIAL AND HDM CULTIVARS



FIGURE D13: MRS J V NIEKERK & MRS E VISSER FROM THE AGRICULTURAL RESEARCH COUNCIL (ARC), IRENE