FRUIT QUALITY OF SOUTH AFRICAN CACTUS PEAR CULTIVARS

By

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MASTER SCIENTIAE

I hereby declare that this study, for the qualification M.Sc. Food Science, at the University of the Free State, my own dependant work is and that it was not previously done for any other university or department.

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Ek verklaar dat die verhandeling wat hierby vir die kwalifikasie, M.Sc Voedselwetenskap, aan die Universiteit van die Vrystaat deur my ingedien word, my selfstandige werk is en nie voorheen deur my vir 'n graad aan 'n ander universiteit/fakulteit ingedien is nie.

Ek verklaar ook dat daar afstand gedoen word van outeursreg in die verhandeling ten gunste van die Universiteit van die Vrystaat.

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GLOSSARY OF ABBREVIATIONS

SED IFT	-	Committee of the IFT Sensory Evaluation Division
QDA	-	Quantitative Descriptive Analysis
GDA	-	Generic Descriptive Analysis
QFP	-	Quantitative Flavour Profiling
QDA	-	Quantitative Descriptive Analysis
FCP	-	Free Choice Profiling
h	-	hours
mg	-	milligram
g	-	gram
kg	-	kilogram
ppm	-	parts per million
m.a.s.l	-	meter above sea level
µm	-	Micrometer
mm	-	Millimeter
mm^2	-	Millimeter squared/squared millimeter
cm	-	Centimeter
°C	-	degrees Celsius
mℓ	-	Milliliter
r.p.m	-	rates per minute
s	-	Seconds
min	-	Minutes
ANOVA	-	Analysis of Variance
LSD	-	Least Significant Difference
CV	-	Coefficient of variance
D.F	-	Degree of Freedom
F - value	-	Measurement of distance between individual distributions. As F goes up, P goes down (i.e., more

		confidence in there being a difference between two means). To calculate: (Mean Square of X / Mean Square of Error) (http://www.isixsigma.com/dictionary, 2007)
FAC	-	Fat Absorption Capacity
WBC	-	Water Binding Capacity
WAI	-	Water Absorption Index
WSI	-	Water Soluble Index
PC1	-	First principal component
PC2	-	Second principal component
HTST	-	High-temperature, short-time
ER	-	Expansion Ratio
BD	-	Bulk Density
BS	-	Breaking-Strength
PME	-	Pectin Methyl Esterase
TA	-	Titratable Acidity
T	-	Titre
MSNF	-	Milk Solids Non-Fat
PV	-	Peroxide Value
GPA	-	Generalised Procustes Analysis
P – value	-	The *p*-value is defined as the probability, calculated under the null hypothesis, of obtaining a value of the statistic that is as extreme as the one observed from the data (in a given direction) (http://www.xlstat.com, 2007)
SEM	-	Standard Error
m.a.s.l.	-	metre above sea level
B	-	Blank
St	-	Standard
A	-	Absorption value at the absorption maximum

		corrected by the absorption at 600 nm,
DF	-	Dilution Factor
L	-	path length (1cm) of the cuvette.
L	-	Lowveld
M	-	Middle veld
H	-	Highveld
MW	-	Molecular Weight
t	-	metric tons
ha	-	Hectare
LDL	-	Low-density Lipoproteins
MF	-	Microfiltration
UF	-	Ultrafiltration
PCA	-	Principal Components Analysis
CAM	-	Crassulacean Acid Metabolism
INIFAP	-	Instituto Nacional de Investigaciones Forestales Agrícolas y Pecuarías
TEAC	-	Trolox Equivalent Antioxidant Capacity
LMP	-	Low Metoxyl Pectin
MF	_	Microfiltration
UF	-	Ultrafiltration
NIDDM	-	Non-insulin Diabetes Mellitus
NS	-	Not significant

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IMAGE

GLOSSARY OF ABBREVIATIONS

ANOVA	-	Analysis of Variance
°Bx		Degree Brix
°C		Degree Celsius
CAM	-	Crassulacean Acid Metabolism
CV	-	Coefficient of Variance
D.F	-	degree of freedom
DF	-	dilution factor
F-value	-	Measurement of distance between individual distributions. As F goes up, P goes down (i.e., more confidence in there being a difference between two means). To calculate: (Mean Square of X / Mean Square of Error) (http://www.isixsigma.com/dictionary, 2007)
FAC	-	fat absorption capacity
FCP	-	Free Choice Profiling
g	-	gram
GPA	-	Generalised Procustes Analysis
H	-	highveld
ha	-	hectare
HTST	-	high-temperature, short-time
INIFAP	-	Instituto Nacíonal de Investígaciones Forestales Agrícolas y Pecuarías
kg	-	kilogram
kg ha^{-1}		kilogram per hectare
µl		microliter
L	-	path length (1cm) of the cuvette.
L	-	lowveld
LDL	-	low-density lipoproteins
LMP	-	low metoxyl pectin
LSD	-	least Significant Difference

M	-	middle veld
µm	-	micrometre
m.a.s.l	-	metre above sea level
ml	-	milliliter
MF	-	microfiltration
mg	-	milligram
min	-	minutes
mm	-	millimetre
mm²	-	millimetre squared/squared millimetre
NI	-	not indicated
NIDDM	-	non-insulin diabetes mellitus
NS	-	non significant
p-value	-	The p-value is defined as the probability, calculated under the null hypothesis, of obtaining a value of the statistic that is as extreme as the one observed from the data (in a given direction)
Pr	-	Measurement of distance between individual distributions. As F goes up, P goes down (i.e., more confidence in there being a difference between two means). To calculate: (Mean Square of X / Mean Square of Error) (http://www.isixsigma.com/dictionary, 2007)
PANOVA	-	Procrustes Analysis of Variance
PC - 1	-	first principal component
PC - 2	-	second principal component
PCA	-	principal Components Analysis
PME	-	pectin methyl esterase
ppm	-	parts per million
r.p.m	-	rates per minute
s	-	seconds
SED IFT	-	Committee of the IFT Sensory Evaluation Division
SEM	-	standard error

St	-	standard
T	-	titre
t	-	metric tons
TA	-	titratable acidity
TSS		total soluble solids
TEAC	-	Trolox Equivalent Antioxidant Capacity
UF	-	ultrafiltration
WBC	-	water binding capacity

CHAPTER 1

INTRODUCTION

The cactus pear (*Opuntia ficus-indica*) is a plant that has the distinction of being a vegetable, fruit and flower all in one (Ntsane, 2008). The driving force behind its popularity is that each part of this plant functions as both food and medicine. If developed further, cactus pears can contribute to sustainable food production in countries with large areas of semi-arid and arid land (Felker & Inglese, 2003).

An anecdote says that people from some countries of North Africa call cactus pear "the bridge of life", because of the feeding and watering resource for animals during drought seasons (Piga, 2004). The cultivation of cactus pears requires low input and has been grown widely in drier areas of South-Africa as fodder crop, particularly for times of serious drought and is conducive to a sustainable system that will increase the efficiency and economic viability of low income farmers (Brutsch, 1993; Oelofse, 2006). The specialised photosynthetic system in cacti, known as Crassulacean Acid Metabolism (CAM), provides greater water to dry matter conversion than C3 and C4 photosynthetic pathways (Felker, 2005); such efficient conservation of water in times of drought caused this plant to be widely used as an emergency livestock feed (Parish & Felker, 1997). Cactus pears have been planted on steep slopes to control erosion (Snyman, 2006).

Cactus pears serve as a source of inexpensive nutritious food for lower income groups. The tender young pads (vegetative portions) of *Opuntia* are known as *nopalitos* and are used as a fresh green vegetable in Mexico (Russell, 1987). Hippocrates recommended, as far as 2500 years ago that food must be our medicine. Nutraceuticals and functional food make this old tenet a new reality. The cactus pear can support the genuine "antioxidant machinery" of the human body (Livrea, 2006). There are numerous medicinal uses of the cactus pear plant. The medicinal components of the plant are found in the flowers, leaves and fruit. American Indians used prickly pear juice to treat burns. A cone of plant material would be burned on the skin to treat irritation or infection, a process known as "moxabustion" in Chinese medicine. The Lakota tribe used prickly pears in a tea to assist mothers during childbirth. The cactus pear is traditionally used in Mexico to treat diabetes and the cactus pear pads have been used as a poultice for rheumatism. The fruit can be used for treating diarrhea, asthma and gonorrhea. High cholesterol, blood pressure, gastric acidity, ulcers, fatigue, dyspnea, glaucoma, liver conditions and wounds can be treated by the fleshy stems. A flower decoction of cactus pear has been used as a diuretic and the cladodes are valued for their anti-inflammatory activity in treating edema, arthritis and whooping cough (Gurrieri *et al.*, 2000; DeFelice, 2004).

The chemical components are mainly found in the flowers, leaves (or pads) and fruit. The flowers of the cactus pear contain of isorhamnetin-glucoside, kaempferol, luteolin, penduletin, piscidic acids, quercetrin, rutin and ß-sitosterol (D'Amelio, 1999).

The leaves or pads are rich in mucilage and contain primarily of polysaccharides that contain galactose, arabinose, xylose and rhamnose (D'Amelio, 1999; Matsuhiro, 2006). The pads contain a full range of amino acids (257.24 mg/100 g), the building blocks of proteins, including the eight essential amino acids, leucine, isoleusine, lysine, methionine, phenylalanine, threonine, tryptophan and valine (Knishinsky, 1971; Feugang *et al.*, 2006).

Cactus pear fruit is high in nutritional value (El Kossori *et al.*, 1998). Ethanol soluble carbohydrates are the most abundant components of cactus pear fruit pulp and skin (50% in the pulp and 30% in the skin). The betalain compounds are responsible for the various colours of the fruit (Butera, 2002). The sweet taste of the fruit is due to sugar constituents' glucose and fructose. The ratio between sugars and acids, which contributes to flavour in cactus pear fruit, is often used as harvest and quality indices in different fruits (Cantwell, 1986).

The skin contains calcium, iron, potassium, magnesium, manganese, sodium and selenium (El Kossori, *et al.*, 1998; Galati *et al.,* 2003). The skin oils are not susceptible to oxidation due to the presence of the fat soluble vitamins: alpha-, beta-, delta- and gamma-tocopherols, vitamin K1 and beta-carotene (Feugang *et al.*, 2006; Moßhammer, 2006). The edible pulp contains biothiols, taurine, flavonols, tocopherols and cartenoids (Dok-Go, 2003; Tesoriere, 2005).

The seeds are rich in phosphorus and zinc. The oils from the seeds and peel are a good source of polyunsaturated fatty acids (Ramadan, 2003; Ennouri, 2005). The seeds in the cactus pear have been proven to contain a significant amount of neutral lipids (87% of total lipids), while the pulp lipid oil contains a higher amount of polar lipids (nearly 53% of total lipid). Both oils are rich sources of essential fatty acids and sterols (Feugang *et al.*, 2006; Moßhammer, 2006). The oil of the seed has high linoleic acid content (57.7 - 73.4 %) and makes it similar to other edible vegetable oils like corn and grape seeds oils (Saenz-Hernandez, 1985).

The chemical composition of cactus pear fruit plays an important role during processing, because of the high soluble solids content. The high pH value classifies this fruit within the low-acid group with a pH higher than 4.5 and requiring a thermal treatment of at least 115°C to obtain good control of the micro-organisms (Gurrieri, 2000; El-Samahy *et al.*, 2008). The total soluble solid content of a cactus pear is higher than 16 percent – it is a higher total soluble content than peaches, apples and cherries. (Saenz, 2000; Piga, 2004 and Feugang *et al.*, 2006). Large differences occur among cultivars in total soluble solids (TSS) (12-17°Brix), Titrable acidity (TA) (0.03-0.12 %), pH (6-6.6) and vit. C (20-40 mg/100g fresh) (Mashope, 2009; De Wit, 2010).

The volatile components are important constituents for the flavour of the cactus pear. A total of 61 aroma volatiles have been found in a white-flesh cultivar *Opuntia ficus-Indica* (L.) Mill. Alcohol in the form of ethanol forms the major proportion (76.33%) (Piga, 2004).

Cactus pears are packed with co-factors that boost immunity in the form of vitamin B1, vitamin B6, niacin, riboflavin and panthothenic acid. A large proportion of anti-oxidant compounds, in the form of vitamin C and flavenoids help protect the body against the oxidation of cholesterol. The fruit contains significant portions of the minerals calcium, magnesium, and potassium (Knishinsky, 1971)

Cactus pear pulp has become well known in the industry today. Many methods are used in processing of the cactus pear pulp to develop various products (Saenz, 2007). Cactus pear is widely cultivated and used in juices, jellies, candies, teas and alcoholic drinks. The flowers and fruit of the plant are used as natural food colourants and essential oils from the flowers are used to make perfumes and the seeds are a source of oil. Cactus gum is used to stiffen cloth. Cactus pear has also been used as a source of animal feed and dye (DeFelice, 2004; Saleem *et al.*, 2006).

South Africa has one of the greatest genetic pools (germplasms) of opuntias and is the only country where original spineless Burbank cultivars are still available (Potgieter and Mashope, 2009). There is an increasing interest in the major markets for the fruits of the spineless cactus pears where it competes with some of the better known traditional fruits. Cactus fruit has a mild pleasant taste with subtle differences in the flavour of fruit from different species. The acid content is very low and the juice of cactus fruit with higher acid content is favoured in sensory tests. Sensory evaluation has been included in few studies on cactus pears and the need to conduct such studies is emphasised to determine consumer preference of different cultivars (Cantwell, 1986).

Sensory analysis is used in the food industry to establish differences, and to characterise and measure sensory attributes of products. Various applications include: monitoring competition; product matching; product optimization; process change; cost reduction and/or selection of a new source of supply; quality control; quality assurance; determining storage stability; product grading or rating; product sensory specification; raw materials specifications; advertising claims; correlation of sensory with chemical and physical measurements; process / ingredient / analytical / sensory relationships;

consumer acceptance and/or consumer preference; and new product development, reformulation and/or cost reduction (SED IFT, 1981; Stone & Sidel, 2004).

Free Choice Profiling (FCP) is a descriptive technique that may decrease the time and money expenditures to formally train and maintain traditional descriptive panels (Williams & Langron, 1984). This technique was adapted in recent years for the profiling of a large amount of different products (Lachnit, 2003), including: Chilean goat cheese (González Viñas *et al.,* 2007); commercial black filter coffees (Narian *et al.*, 2004); Spanish unifloral honeys (González Viñas *et al.,* 2007); different fruit products like sweet orange gels (Costell *et al.,* 2007) and chocolate (McEwan, 2007).

Training of FCP panels use descriptor generation to express findings (Kittel, 2008). The technique differs from conventional descriptive testing in that the members of a taste panel describe perceived qualities of a product analyses in an individual manner, use their own list of terms to describe the sensory characteristics of that product (Oreskovich *et al.,* 1991). The panelists require less training and hence, the total process takes less time. The method takes into account minor individual variation while accentuating those panelists who respond differently from the rest (Rubico, 1992). The resulting data is then transformed using General Procrustes Analysis (GPA) to a consensus configuration to reveal the relationships between samples (Kittel, 2008).

Sensory preference testing, that has been done on cactus pear fruit, is mainly in countries such as Italy (Gurrieri *et al.*, 2000), Egypt (El-Samahy *et al.*, 2007), Spain (Retamal *et al.*, 2006), Argentina (Mestrallet *et al.*, 2008), Mexico (Ruiz Pérez-Cacho *et al.*, 2006), Chile (Sáenz *et al.*, 2001) and also recently in South Africa (Potgieter, 2000; Snyman, 2006).

Recent sensory analysis done on cactus pear fruit was used to develop various products such as: the possibility of long-term storage of cactus pears for their juice (Gurrieri, 2000); edible films and coatings to increase food quality and decrease disposable packaging (Del-Valle *et al.*, 2005); determination of sensory analysis of edible young cladodes, named nopalitos (Ruiz Pérez-cacho, 2006); the possibility of producing a new value-added snack-type extrudate based on cactus pear pulp concentrates (El-Samahay, 2007); canned cactus pear nectar to determine the heat resistance parameters of pectin methyl esterase (El-Samahy, 2008); powders obtained from spiny and spineless cladodes showing a great technological potential in water binding capacity (WBC) and fat absorption capacity (FAC) (Ayadi, 2009) and ice-cream with cactus pear pulp (El-Samahy *et al.*, 2009).

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The cactus pear has been traditionally used as a "panacea" of different ailments. The first conquistador, H. Cortes had been welcomed in Spain with fruit of cactus pears (named, *nochtli*) and began to eat the fruit. Oviedo y Valdes (the first author to describe the tunas), described the morphology of the plant in 1535 as "its seeds and skin are like those of the fig and are tasty too". The first opuntias were probably grown in the vicinity of Seville or Cadiz, the terminus for traffic with the Indies; from there they spread to the rich gardens of aristocratic mansions and to botanic gardens (Donkin, 1977). European immigrants introduced the first species of thorny prickly pears in South Africa in the Karoo and the Eastern Cape in 1772. These first species were seen as foreign plant specie. Biological management began in 1932 through a prickly pear moth (*Cactoblastis cactorum*), cochineal insect (*Dactylopius opuntiae*) and weevil (*Metamasius spinolae*) (Brutch *et al*., 1993).

The Research Institute at Grootfontein imported twenty-two species of Burbank (spineless) cactus pears in 1914 for cattle in the Karoo. The first specialised plantations were in Transvaal and Ciskei (Wessels, 1988; Barbera, 1995). Only thornless species can be cultivated. The thorn species are classified as weeds. (Potgieter, 2000). These cultivated spineless prickly pears have traditionally been cultivated mainly as drought resistant fodder crop and is today recognised as a fruit in its own right (Brutsch, 1992).

Early European Botanists called cactus pears *Ficus Indica*, because of its resemblance to the then already known Indian fig (possibly Ficus bengalensis L.) (Anderson, 2001). Linnaeus published it under a new name, *Cactus ficus-indica*, in the group Cactus *opuntia* in Species Plantarum. Above mentioned names were combined in 1978 by

Miller into *Opuntia ficus-indica* (Griffith, 2004). The classification of cactus pear is briefly summarised below:

Order: Caryophyllales

Suborder: Portulacineae

Family: Cactaceae

Subfamily: Opuntioideae

Genus: Opuntia

Subgenus: Opuntia

Species: ficus-indica (L.) Mill. Gard. Dict. Abr. Ed. 8. No. 2. 1768 (Scheinvar, 1995).

The cactus pear (*Opuntia spp.*) is a plant that has the distinction of being a vegetable, fruit and flower all in one (Ntsane, 2008). The driving force behind its popularity is that each part of this plant functions as both food and medicine. It has been a staple in the diets of the people in the south portion of the United States, the Middle East, parts of Europe and Central and South America for hundreds of years. If developed further, cactus pears can contribute to sustainable food production in countries with large areas of semi-arid and arid land (Felker & Inglese, 2003).

2.2 Cactus pears in various countries today

2.2.1 Mexico

Mexico hosts the greatest genetic diversity of edible Opuntias and is the main source of cactus germplasm in the world. Instituto Nacíonal de Investígaciones Forestales Agrícolas y Pecuarías (INIFAP) in Mexico holds the largest number of entries and other germplasm collections are maintained at several locations around the world (Chapman *et al.*, 2002). Cactus pear research in germplasm collection and characterisation has been done by Mexican institutions and is very costly. Collection of accessions is largely based on morphological traits and often leads to duplication (Chapman *et al.*, 2002). Cactus pears serve as economic purposes for animal husbandry and are the main source of water in the dry season for livestock in Mexico (Barbera, 1995). An average of eight metric tons of top quality fruit can be harvested within four years of plantation establishment, at a plant density of 2000 per hectare (ha). The tender young pads (vegetative portions) of *Opuntia* are known as *nopalitos* and are used as a fresh green vegetable in Mexico (Russell, 1987). Two of the main processed products in Mexico are 'nopalitos' in brine and pickled 'nopalitos' (Saenz, 2000).

The pads are prepared during the Lenten season during Holy Week as a cooked green vegetable and are prepared as a marinated vegetable throughout the year (Russell, 1987). Dairy products produced from cattle fed with cactus pads get a premium price in the local market (Russell, 1987).

2.2.2 South Africa

South Africa has one of the greatest genetic pools (germplasms) of seventy-eight cactus pears cultivars and is the only country where original Burbank cultivars are still available. Cactus pears are primarily cultivated at Mara, which hosts more than 80 accessions. Duplicates are planted in secondary orchards such as Waterkloof, Oudtshoorn and Cradock. The well known South African species are *Opuntia ficus-indica for* human consumption and *Opuntia robusta* used for animal fodder (Potgieter, 2000 & Mashope, 2009). A production of about 15 000 tons can be harvested on 1500 hectares in South-Africa (Basile, 2001). All the varieties currently grown in South Africa were developed from original material. The main production areas in South Africa are in the summer rainfall areas. Prices obtained for cactus pear fruit on the national fresh produce markets of South Africa compare favourably with common fruit such as apples, peaches and oranges (Oelofse, 2006). The ten most commonly grown cactus pear cultivars in South Africa under rain fed, subtropical conditions are Skinners Court (favoured vegetative growth with the thickest peel), Gymno Carpo, Roedtan (high cladode yield, producing fruit of good quality and a high total soluble solids content), Turpin, Meyers, Zastron (small fruit- and pulp mass is expected from Zastron), Nudosa (significantly higher fruit- and pulp mass than the rest of the cultivars), Algerian (one of the cultivars with the highest total soluble solids) and Malta and Morado (Oelofse, 2006).

2.2.3 Israel

Commercial interest of cactus pear fruit in Israel has grown and the fruit is referred to as "sabrah". According to the folklore, like the prickly pear fruit, the people of Israel have a rough exterior but are tremendously sweet and soft inside. From that the word "sabrah", used to identify a person born in Israel. The skin is rich in minerals and vitamins. The flowers, which grow from the fruit, are used as herbs (Knishinsky, 1971).

2.2.4 Egypt

Cactus pears grow especially in sandy areas in various parts of Egypt, because it is extremely drought tolerant. The trees are grown for their fruit, fences, windbreaks and erosion control in deforested areas (El-Samahy, 2008). Interesting new products have been developed in Egypt in recent years. Both yellow and red cactus pear pulp were concentrated to 40 °Brix and then added to rice grits to develop a product of rice based extrudates. The expansion ratio (ER), water absorption index (WAI) and water soluble index (WSI) decrease by increasing the added concentrated pulp ratio. Breaking strength (BS) decrease up to 10% of the added ratio then increased. The bulk density, ash content and colour attributes increased with the increasing added concentrated pulp. Sensory characteristics can be extremely enhanced by adding both concentrated cactus pear pulps to rice flour to produce a new value added snack type (El-Samahy, 2007).

El-Samahy (2009) found that red cactus pear pulp (concentrated up to 30°Brix) can be added to basic ice-cream mix and that cactus pear pulp can be used as a good fruit substitute in the production of new products.

Cladode and fruit rots of cactus pears were observed in some commercial orchards located at the major producing areas in Egypt. The study revealed that Topsin M70, Bellis and Tecto were the best treatments against the effect of different fungicides (Ammar, 2004).

2.2.4 United States

The fruit of domesticated *Opuntia* cultivars are known as prickly pears in the southwestern United States or *tunas* in Latin America. These cultivars can be very sweet and are highly regarded in the markets of California (Russell, 1987). Ninety percent of the total world production of carmine dye comes from Peru. Carmine dye is produced by the pigments found in the cactus pear (Barbera, 1995).

2.3 Physical attributes

Cactus pears grow as small ground hugging plants to quite massive trees and are generally branched with distinctive jointed, fleshy, flattened, often rounded stem-segments known as cladodes or phylloclades ("pads"). The stems have varying numbers of areoles (a specialised axillary) that produce spines, new flowers, fruit, stems and white, gray or tan to brown hair as well as fixed or minute spines (glochids). Flowers of cactus pears are radially symmetrical and vary in colour. The fruit can be club shaped or cylindrical to void or nearly spherical, spineless to spiny, fleshy or dry and range in colour from green, yellow, red, orange or purple in the fleshy types or tawny to gray in the dry ones. (Anderson, 2001; Benson, 1982; Pinkava, 2003; Stuppy, 2002).

The cactus pear plant is divided into two functional parts:

- The root which is responsible for the absorption of water. The root system is tight, fleshy and shallow. Every light rainfall can be used effectively. The root system reacts on drying of the ground through a main root (Snyman, 2006).
- The vegetative multifunctional cladodes which can act as the stem to transport water and nutrients to various parts of the plant and perform the role of the leaves for photosynthesis. The cladode is divided into the outer chlorenchyma for photosynthesis and the inner parenchyma with a great amount of mucilage for water retaining (Feugang *et al.*, 2006).

The cactus pear fruit is an oval shaped berry fruit with an average weight of 100-200 g. The fruit has a thick, fleshy skin that contributes 30-40% of the total fruit weight. The juicy pulp contributes 60-70% of total fruit weight and contains many seeds that contribute 5-10% of the fruit weight. The main components of the fruit pulp are water (85%), carbohydrates (10-15%) and vitamin C (25-30 mg/100 g) (Cantwell, 1995).

2.4 Chemical composition

The chemical composition of cactus pears plays an important role during processing, because of the high soluble solids content. The high pH value classifies this fruit within the low acid group with a pH higher than 4.5 and requiring a thermal treatment of at least 115°C to obtain good control of the micro-organisms (Gurrieri, 2000; El-Samahy *et al.*, 2008). The total soluble content of a cactus pear is higher than 16 percent – it is a higher total soluble content than peaches, apples and cherries. (Saenz, 2000; Piga, 2004 & Feugang *et al.*, 2006). Large differences occur among cultivars in total soluble solids (TSS) (12-17°Brix), Titrable acidity (TA) (0.03-0.12 %), pH (6-6.6) and vit. C (20-40 mg/100g fresh) (Mashope, 2009).

2.4.1 Pigments

The most important fruit pigments in cacti are the betacyanins and betaxanthins (Gibson and Nobel, 1986 in Slawomir, 2001). Pigments chlorophyll and betalain of cactus pears are rich in antioxidants. Betalains, the red-violet betacyanins and the yellow betaxanthins are in a class of water-soluble nitrogenous pigments. Red beetroot and prickly pear are the only food products containing this class of pigments (Slawomir, 2002). The presence of these different pigments influence the stability of the products obtained from cactus pears. Betalains are more stable than chlorophylls under thermal treatment and pH variation. This finding indicated that products from purple cactus pears would be more stable than those from green cactus pears (Saenz, 2000). Piga (2004) stated that, although the purified betanin (red colour) has more than tenfold higher Trolox Equivalent Antioxidant Capacity (TEAC) value than the yellow indicaxanthin pigment, the methanolic extracts from yellow fruit had a significantly higher TEAC value, compared to the red pigment.

2.4.2 Volatile components

The volatile components are important constituents for the flavour of the cactus pear. A total of 61 aroma volatiles have been found in a white-flesh cultivar *Opuntia ficus-Indica* (L.) Mill (Piga, 2004). Alcohol in the form of ethanol forms the major proportion (76.33%). The presence of 1-nonanol, several nonon-1-ols, nonadien-1-ol and 2-nonenal, along with the light melon-like flavour that is characteristic of the fruit are in comparison with cucumber- and melon-volatiles studies. Long thermal treatments can cause a hay-like taste and cause an unattractive aroma in the products (Saenz, 2000). The strongest flavour intensity was found for yellow, followed by red and finally, white cactus pear fruit (Moßhammer, 2006).

2.4.3 Micronutrients

Cactus pears are packed with co-factors that boost immunity in the form of vitamin B1, vitamin B6, niacin, riboflavin and panthothenic acid. A large proportion of antioxidant compounds, in the form of vitamin C and flavonoids help protect the body against the oxidation of cholesterol. The fruit contains significant portions of the minerals calcium, magnesium, and potassium (Knishinsky, 1971). The long term storage of the cactus pear was investigated by Sergio (2000) and he found that among the transition of metals, a high content of manganese (1.7-2.9 ppm) and good amounts of iron (0.6-1.2 ppm) and zinc (0.3-0.4) were found. Such ions appear to be present mainly in the thick skin of the fruit (Knishinsky, 1971). During the storage of minimally processed cactus fruit at 4 °C, it was found that the content of vitamin C did not change, while polyphenolics decrease after six days (Livrea, 2006). The chemical- and mineral composition as well as the technological characteristics of the cactus pear pulp are indicated in Tables 2.1, 2.2 and 2.3. The tables summarise the chemical- and mineral composition of cactus pears from Argentina, Spain, Algeria, and Italy. From Table 2.1 it is clear that cactus pears have a high moisture content of almost 85 percent. The pulp consists of a significant amount of vitamin C of 0.02 %. This value is higher than the vitamin C value of apples, pears, grapes and bananas. Table 2.2 indicates that cactus pears consist of high amounts of potassium (156 mg/100 g), calcium (20 mg/100 g) and sodium (0.83 mg/100 g). The peel contributes more than half of the total mass of the cactus pear (51% of the total mass of the fruit) and the total soluble content is 14 g /100 g, shown by Table 2.3. The high pH value and low acidity level (Table 2.3) influence the processing operations of cactus pears. Sugar range from 10 °Brix to 17 °Brix and is mainly the reducing type. Glucose is the predominant sugar with fructose as the second sugar, thus the fruit pulp is very sweet. (Saenz-Hernandez, 1985; Brutch, 2007; Salim, 2009; Piga, 2004).

Table 2.1

Chemical composition of cactus pear pulp (g/100 g) (Saenz-Hernandez, 1985; Brutch, 2007; Salim, 2009; Piga, 2004).

Parameters	**g/100g** (Saenz-Hernandes-Argentina)	**g/100g** (Brutch - Spain)	**g/100g** (Salim-Algeria)	**g/100g** (Piga - Italy)
Moisture	84.8	82.01	94.4	84-90
Protein	0.82	0.87	1.45	0.2-1.6
Fat	0.4	0.48	0.7	0.09-0.7
Fibre	1.17	5.65	NI	0.02-3.1
Ash	0.57	0.409	1	0.3-1
Total sugar	12.71	NI	Glucose: 29 Fructose: 24	10-17
Vitamin C (mg%)	2.19	17.1	NI	1-41
ß-carotene	0.53	NI	NI	NI

*NI – Not Indicated

Table 2.2

Mineral composition of cactus pear pulp (mg/100g) (Saenz-Hernandez, 1985; Brutch, 2007; Piga, 2004; Salim, 2009).

Mineral	**Mg/100 g** (Saenz-Hernandez-Argentina)	**Mg/100 g** (Brutch – Spain)	**Mg/100 g** (Salim – Algeria)	**Mg/100 g** (Piga - Italy)

Ca	20.7	24.4	12.4	12.8-59
Mg	47.4	2.67	18.8	16.1-98.4
Fe	0.77	0.2	NI	0.4-1.5
Na	0.83	5.24	1.09	0.6-1.1
K	156	159.5	199	90-217
P	24.23	NI	NI	15-32.8

*NI – Not Indicated

Table 2.3

Technological characteristics of cactus pear pulp (g/100g) (Saenz-Hernandez, 1985; Brutch, 2007; Piga, 2004).

Parameter	**g/100 g** (Saenz-Hernandez)	**g/100 g** (Brutch – Spain)	**g/100 g** (Piga)
Pulp and seeds	48.8	NI	Pulp: 43-57 Seeds: 2-10
Peel	51.2	NI	33-55
pH	4.78	6.39	5.3-7.1
Acidity (% citric acid)	0.1	0.072	0.05-0.18
°Brix	14.11	14.98	12-17
Total solids	14.5	NI	10-16.2
Pectin	0.18	NI	NI

*NI – Not Indicated

2.4.4 Macronutrients

2.4.4.1 Amino acids

The pads contain a full range of amino acids (257.24 mg/100 g), the building blocks of proteins, including the eight essential amino acids, leucine, isoleusine, lysine, methionine, phenylalanine, threonine, tryptophan and valine. Vegetarians who rely on legumes such as soybeans and peas for their protein requirements will find in the nopel pads a high quality of protein (Knishinsky, 1971; Feugang *et al.*, 2006). The percentage protein in the pulp is 0.21-1.6. The total of free amino acids is the same as citrus and grape and is above average than other fruit like apples and bananas. Compared to other fruit, cactus pears have a high content of serine; γ-amino butyric acid, glutamine, proline, arginine, histidine and methionine (Saenz, 2000; De Wit, 2010).

2.4.4.2 Lipids

The seeds in the cactus pear have been proven to contain a significant amount of neutral lipids (87% of total lipids), while the pulp lipid oil contains a higher amount of polar lipids (nearly 53% of total lipid). Both oils are rich sources of essential fatty acids and sterols. The peel contains nearly 37 g lipids per kilogram. The peel oils are not susceptible to oxidation due to the presence of fat soluble vitamins, alpha-, beta-, delta- and gamma-tocopherols, vitamin K1 and beta-carotene (Feugang *et al.*, 2006; Moßhammer, 2006). Edible oil can be obtained from its seeds. The oil shows a high grade of unsaturation and has high linoleic acid content (57.7 - 73.4 %) and make it similar to other edible vegetable oils like corn and grape seeds oils (Saenz-Hernandez, 1985).

2.4.4.3 Carbohydrates

Carbohydrates are one of the major components of cactus pears (10-15 percent of fruit content) (Cantwell, 1986). The sweet taste of the fruit is due to sugar constituents glucose and fructose. The predominant sugars in the pulp of ripe cactus fruit are glucose and fructose. Sucrose can also be found in the peel. The low sucrose content of ripe fruit is consistent with the presence of active invertases. During the latter stages of development, the fruit pulp rapidly accumulates sugars. Harvesting the fruit too early in the ripening process, reduces fruit sweetness and should be avoided (Cantwell, 1986). The high sugar content of the pulp results in sugar : acid ratios within the range of 90:1 up to 490:1, which is responsible for the bland taste and a low sensory acceptance (Moßhammer, 2006). The polysaccharide fraction of cactus pear pulp was recently reported to be composed of a complex mixture of polysaccharides of which less than 50% corresponded to a pectin-like polymer (Moßhammer, 2006).

2.4.4.4 Dietary fiber

Pulp fibers are rich in pectin (both skin- and seed pectin content are less than the pulp fibers' pectin content). Seed fibers have the greatest cellulose content of the fruit (Feugang, 2006). Mucilage forms part of dietary fiber and imides large amounts of water forming gelatinous colloids (Nobel, 2002). Mucilage is composed of various proportions of L-arabinose, D-galactose, L-rhamnose, D-xylose and galacturonic acid (Sáenz, 2000). The pectin is partially responsible for the viscosity of the pulp and is a positive element for the production of juices, marmalades and jams. The content of pectin in cactus pear pulp is 0.17 to 0.21 percent and is not sufficient for the production of gels (Saenz, 2000).

2.5 Quality attributes

Quality is a major concern for consumers and forms an integral part of research (Wuzhong, 2002). Fruit quality is complex, but can be simplified as 'whatever the consumer desires' (Baritt, 2001). The consumer evaluates the appearance of the fruit first at the point of sale, followed by its taste (Kader, 2002). Appearance is determined by fruit size and colour (Callahan, 1986). According to Felker *et al.* (2005), the major variation in fruit quality is related to genetic factors, rather than environment or edaphic factors.

Felker (2005) stated that the ideal cactus cultivar has the following attributes: spineless cladodes, the glochids can be easily removed by mechanical brushing techniques, a tolerance to minus nine degrees Celsius, a pulp percentage of higher than 55%, °Brix higher than 13%, pulp firmness higher than 1 kg, mature yield higher than 20 000 ha, post harvest shelf life at two degrees Celsius for longer than four weeks, seediness less than 3.5 seeds per 100 g pulp and has a variety of colours.

2.5.1 *Quality standards for class 1 cactus pears (Directorate Plant Health and Quality, 2001).*

- General appearance: Intact, sound, attractive, fresh with the thorns removed where possible, long white thorns must not appear.
- Shape: Well formed and typical for the cultivar concerned
- Length (measured by bisecting the fruit on the longitudinal axis): Not more than a third of the total length of the fruit – provided that a portion of an attached leaf on the pedicel shall not be more than 30 mm in length and not more than 10mm in width.
- Skin thickness: Summer fruit – not more than 7 mm thick

  Winter fruit – not more than 10 mm thick
- Prevention of desiccation: May be treated with a suitable wax
- Healed or callused wounds or punctures: As set out for blemishes, provided the depth shall not exceed 2 mm
- Sunburn: Visibly free of external signs of sunburn
- Bruises: May not exceed a total surface area of 100mm^2
- Cochenille stains: Stains of which the total surface area does not exceed 100 mm^2 is allowable – provided that the stains do not detrimentally affect the appearance of the fruit
- Cochenille damage: May not exceed a surface larger than 30 mm^2
- Cochenille residue: May not occur
- Hail marks: Depth – may not exceed 2 mm

  Surface area – may not exceed150 mm^2 in surface area
- Blemishes: May not exceed a total surface area of 150mm^2, provided that it does not detrimentally affect the fruit

- Foreign matter: Practically free from any visible foreign matter
- Uniformity in the same container: colour – reasonably uniform

(Directorate Plant Health and Quality, 2001).

2.5.1.1 Fruit mass and size

Fruit mass or size is a very important factor determining fruit quality to give the best value for money. The export fruit mass in South Africa must exceed 120g (Inglese *et al.*, 1995; Brutsch, 1992), but Potgieter & Mkhari (2002) explained that the mass of cactus pears should be greater than 140g for export potential. The cactus pear fruit size is also determined by seed number. The higher the number of seeds inside a fruit, the larger the fruit will be. Fruit with viable seeds are best for export (Barbera, et al., 1995).

Cladode load refers to the number of cactus pear fruit per cladode and also influences fruit mass. Fruit thinning is a technique used to remove some fruit from the cladodes for good quality (Brutsch, 1992; Inglese *et al.*, 1995). It is recommended that the number of fruit per cladode must be six to eight (Inglese *et al.*, 1995), while Wessels (1988) and Brutsch (1992) suggested nine to twelve fruit per cladode in South Africa. Previous findings indicated that irrigation and thinning to six fruit per cladode significantly increase fruit size (Mashope, 2009).

"Scozzolatura" is the removal of early flower buds from September to October in South-Africa (Potgieter, 2000). This technique is used to enhance a new blooming flush to delay ripening of fruit and harvesting.

Water accessibility is an important factor during fruit formation (Barbera *et al.*, 1984) and fertilisation plays a major role in fruit production to increase fruit size and yield (Inglese *et al.*, 1995).

2.5.1.2 *Edible pulp percentage*

Potgieter and Mkhari (2002) suggested that pulp percentage for cactus pear fruit should be more than fifty percent. Felker & Inglese (2003) found that seeds contribute in pulp percentage; seedless cultivars can produce a small percentage pulp.

2.5.1.3 *Total soluble solids*

Total soluble solids (TSS) are an indication of total sugar content, measured in °Brix. Consumers like the taste of sweet fruit and sugar amount plays a decisive role in defining the quality of fruit. Glucose and fructose increase quickly in the last weeks of flesh development and optimum values at harvest time range from 13% to 15% (Nobel, 2002). Cactus pears lose over 60% of water by transpiration, causing a great build-up of solutes (De la Barrera, 2004 & Nobel, 2002). Potgieter and Mkhari (2002) suggested that TSS should not be below 13 °Brix to meet the minimum criteria in South Africa for exportation.

2.5.1.4 *Peel thickness*

The peel is the outer part (receptacle) covering of the pulp (locule) and must be removed before eating (Mashope, 2009). Trials conducted at Middelburg in the Karoo region proved that, when thinning is done early in October, the fruit will usually have thinner peels (Wessels, 1988). Potgieter and Mkhari (2002) suggested that cactus pear fruit should have less than six millimeter peel thickness.

2.5.1.5 *Seed content*

The seed content is influenced by the environment and the growing factors of the fruit (Inglese *et al.*, 1995; Barbera, 1995). More seeds per fruit mass enlarge the size of the fruit, but more seeds per fruit are less acceptable by consumers (Wessels, 1989).

2.5.1.6 Seed size

Seed size refers to range between small and large, which may be determined by any of the three means: weight, volume or dimension (length, width and thickness) (Kays, 1999). Weight of the seed varies from two to seven grams per fruit (Nobel, 2002).

2.5.1.7 Pulp firmness

Corales-Garcia *et al.* (1997) found that pulp firmness of cactus pears decrease during storage at 20° and decreasing of temperature reduces fruit quality. Felker & Inglese (2003), rated pulp firmness greater than 2 kg as excellent, 1.5 kg – 2 kg as good, 1 kg – 1.5 kg as fair and less than 1 kg as unacceptable. Felker (2005) also found that firmness could be an inherited trait and that pulp with low firmness value lacks structural integrity and breaks apart when the peel is separated from the pulp. The acid induction of low molecular weight expansions that are responsible for an increase in cell wall plasticity might influence the correlation of decreasing pulp firmness with decreasing fruit pH (Felker, 2005).

2.6 Uses of various cultivars of cactus pears

2.6.1 Industrial

Cactus pear pulp has become well known in the industry today. Many methods are used in processing of the cactus pear pulp to develop various products (Saenz, 2007).

Two of the most common uses for cactus pears are juices and pulps. Pectin (part of the fibre of cactus pears) is partially responsible for the viscosity of the pulp and can be used in the production of juices and jams (Saenz, 2007). The first cactus pear juice was made by Paredes and Rojo in 1973 by using citric acid to reduce the pH value to 4.3, sodium benzoate and a thermal treatment for five minutes at 90 °C. The juice was then vacuum and canned in an enamelled tin. The product had a pleasant taste and flavour, without microbiological problems (Saenz, 2000). Extracted pectin from *O.ficus-indica* (L.) Mill fruit and their characterisation showed that the galacturonic acid content is sufficient for the use as a cosmetic additive (Piga, 2004). Piga (2004) also suggested a possible use of low methoxyl pectin (LMP) in cactus pears as a gelling agent for low caloric foods.

The effect of microfiltration (MF) and ultra filtration (UF) processes on the physic-chemical composition of cactus pear juice produced from Italian fruit were studied by Cassano (2010). The original juice is characterised by a high pH value (5.5-5.7) and a very low acidity (0.03% in citric acid). TSS, pH and acidity remained unchanged in the clarified juice of both processes. A remarkable reduction of the protein content was observed for both processes. Betacyanins were not detectable, while significant removals were observed for betaxanthins for both processes. The permeate for both processes is a clear solution with a low proteic content enriched of antioxidant compounds in the form of polyphenols, vitamin C, as well as sugars, amino acids and minerals. The permeate can be marketed as part of fruit beverages. The retentate is a fraction enriched in fibres, sugars and betalains. The retentate can be pasteurised and added to the concentrate juice in order to obtain a pulped juice. It can also be used for mousses, ice-creams and jellies, as well as an ingredient for baby foods. Finally, retentate can also be used as a raw material directly in functional food or to extract betalains (Cassano, 2010).

Cactus pear jam and marmalade are manufactured and sensory evaluation on jam and marmalade products indicate that the consumer prefers jams with flavours like clove, grapefruit extract, orange extract and almond (Saenz, 2000)

There is evidence to suggest that communities in the developing countries have used plant based materials as one strategy for purifying drinking water. Miller (2008), evaluated the use of *Opuntia spp.* for turbidity removal from synthetic water samples and steps were made toward elucidating the underlying coagulation mechanism. *Opuntia spp.* reduced turbidity by 98% for a range of initial turbidities. This result is similar to the observed coagulation activities described for *Moringa oleifera,* a widely studied natural coagulant. *Opuntia spp.* operates predominantly through a bridging coagulation mechanism. Application of these readily available plants as part of point-of-use water treatment technology may offer a practical, inexpensive and appropriate solution for producing potable water in some developing communities (Miller, 2008).

Increased consumer demand for higher quality food in combination with the environmental need to reduce disposable packaging waste has led to increased interest in research into edible films and coatings. The mucilage of cactus pear can be used as an edible coating to extend the shelf-life of strawberries (Del-Valle, 2005).

Extracted pectins from *O.ficus-indica* (L.) Mill fruit and their characterisation showed that the galacturonic acid content is sufficient for the use as a cosmetic additive (Piga, 2004).

The pulp of *Hylocereus polyrhizus* cacti is already used in Israel for the production of red-violet ice-cream. It also has the potential to be used in low temperature dairy drinks and in light drinks with or without fruit juice (Slawomir, 2002). Enzymes from unripe fruit of *O.ficus-indica* (L.) Mill fruit could be a good source of milk clot enzymes for the dairy industry for their pleasant smell and structural properties and the enzymes do not delay clotting times, unlike other plant rennets (Piga, 2004).

Older preservation procedures are widely applied today to wild cactus pear species. They include tuna "cheese", prepared by using cottage cheese industry procedures by boiling the pulp and juice of the cactus pear until a certain viscosity is obtained. The juice, which is highly concentrated and beaten, is placed in rectangular recipients, which is sold once it has dried (Russel & Felker, 1987). Dried cactus pear can be a edible product (Russel & Felker, 1987).

The fructose content of cactus pear is shown by studies to be the same as the fructose content of grape sugar syrups. Studies show that cactus pear can be used to obtain natural liquid sweetener (Saenz, 2007).

The cottage industry prepares alcoholic beverages such as 'Colonche' through the fermentation of the juice and pulp of cactus pears in wooden barrels. 'Colonche' is a low-alcoholic drink and is best when freshly fermented, because it can quickly turn acidic (Saenz, 2000). Wines of *O. robusta* have a delicate fruit like taste (Russel & Felker, 1987).

Betalain, the pigment obtained from the red cactus pear *O. robusta*, is being used as a natural additive as pharmaceutical, cosmetic and food colourant (Saenz, 2000).

2.6.2 Medicinal

Hippocrates recommended as far as 2 500 years ago that food must be our medicine. Nutraceuticals and functional food make this old tenet a new reality. The cactus pear can support the genuine antioxidant machinery of the human body (Livrea, 2006).

2.6.2.1 Benefits from fruit ingestion *in vivo*

Radical scavenging molecules like antioxidant vitamin A, C and E, polyphenol compounds and dietary constituents can be found in cactus pear fruit. These molecules minimise the effects of pro-oxidant factors and maintain appropriate endocellular redox milieu (Livrea, 2006). Supplementing healthy humans with cactus pear fruit decrease low-density lipoproteins (LDL). Studies show that LDL can be purified from the plasma of healthy volunteers three hours after ingestion of 500 g Sicilian *Opuntia ficus-indica* (Livrea, 2006). Livrea (2006) also found that cactus pear fruit has anti-ulcer and hepatoprotective effects in rats.

The fruit of the cactus pear has been under intense medical focus in the recent years. The most important component in the cactus pear is its dietary soluble fiber, which comes especially in the mucilage pectin. Mucilage is the sticky juice that oozes from the pads when sliced. In medical circles, this sticky substance is referred to as mucilaginous polysaccharide which is the primary active ingredient of other popular immune-stimulating herbs such as Aloe Vera, Echinacea, Astragalus, and Oriental mushrooms (Knishinsky, 1971).

Scientists have noted that there is a positive link between the consumption of the cactus fruit and its anti-hypoglycemic effects. Daily intake of this fruit yielded positive results in laboratory animals. Results showed decrease in plasma cholesterol, which is mainly content in low density lipoprotein. Nopal cladodes have high fibre content and a high water absorption capacity of mucilage. These characteristics explain the current use of certain products to control obesity (Knishinsky, 1971).

Recent medicinal studies on cactus pear pads verified their use as an "anti-diabetic" remedy. Results of the studies have shown noticeable hypoglycemic effects in patients with non-insulin diabetes mellitus (NIDDM). It increases the releasing of insulin from the pancreas and delays the absorption of glucose (Saenz-Hernandez, 1985; Knishinsky, 1971).

Wolfram (2003) found that cactus pears may induce beneficial actions in the cardiovascular system via decreasing platelet activity and thereby improving haemostatic balance.

The juice of cactus pears can also be used as protection against nickel chloride toxity in water (Hfaiedh, 2008).

2.6.2.2 Protective effects of fruit extracts.

Livrea (2006) found that fruit extracts from *Opuntia ficus-indica*, injected intraperitoneal in humans, one day prior to tumor cells injection and then during the following six weeks, tumor growth was significantly suppressed and tumor related genes were modulated expressed, with effects comparable to those caused by 4-HPR. Methanol extracts protect the body against global ischemic injury surgically induced (Livrea, 2006).

2.6.2.3 Bioactive components

Cactus pear fruit contains peculiar phytochemicals, such as betalain pigments and small amounts of polyphenol compounds that are present in the peel. A cell-protective β-amino acid with anti-oxidative effects, taurine, also forms part of the bioactive components.

2.6.2.4 Adverse Reactions

Dermatitis is the most common adverse reaction from cactus pear consumption. A case report of cactus dermatitis in a 2-year-old child was described and the development of severe keratoconjunctivitis in the right eye was also reported. Cactus granuloma formation was found in a 24-year old man from contact with cactus pear thorns (Vakilzadeh *et al.*, 1981; Spoerke *et al.*, 1991; Yoon *et al.*, 2004).

2.6.3 Agricultural

Growers have been giving more attention to cultivated spineless cactus pears. These plants are important for soil conservation, preventing soil erosion, preventing encroachment of deserts and protecting biodiversity (Tibe, 2008). The spines of the cactus pear are been used as an advantage in subsistence agriculture as "fences", because the plants are less attractive to most livestock. Large spines can be used as needles, toothpicks and pins (Tibe, 2008).

Cladodes can be chopped and left overnight for the spines to soften in the plant sap before being served as animal fodder (Brutsch, 1993). Research has found that the skin of prickly pear is processed to be used as one third of cattle's' ration in South Africa. The cultivar, Algerian, of the specie *Opuntia ficus-indica* is a popular cultivar which can be used for fodder. Urea is added to make up for the low protein contents (Snyman, 2006). The cladodes of the cactus pear can also serve as strong fibers and can be pounded and dried to make baskets, fans, mats and fabrics (Tibe, 2008).

Mass rearing of cochineal insects for the commercial production of carminic dye is increasing in South Africa, especially in the Northwest Cape. A practical method in processing of Carmen dye (red Carmen colourant) involves the rearing of *D. coccus* on harvested cladodes under roof cover (Brutsch, 1993).

Cactus pears serve as a source of inexpensive nutritious food for lower income groups and have been grown widely in drier areas of South Africa as fodder crop, particularly for times of serious drought (Brutsch, 1993).

2.7 Harvest management of cactus pears

2.7.1 Harvest physiology

The cactus pear has a crassulacean acid metabolism (CAM) which characterises the plant as a high potential of biomass production with very low water consumption (Gurrieri, 2000). The cultivation of cactus pear requires low input and is conducive to a sustainable system that will increase the efficiency and economic viability of low-income farmers (Oelofse, 2006)

The ideal climate for harvest is moderate and dry winter climate with a summer rainfall between 300-700 mm yearly. Cactus pears withstand high summer temperatures (higher than 40 °C) and can be successfully cultivated on any ground. The ground must be highly drained. Most cactus pear species are sensitive to low acidity (pH greater than 5.5) and brackish ground. Mokoboki (2005) found that the decrease of fruit mass over two seasons might be due to low rainfall and temperature. The mean fruit mass decreased from 143.4 g in 2005 to 127.3 g in 2006. Felker (2002), compared the fruit parameters of 12 *Opuntia* clones grown in Argentina and the United States. He found that the rainfall in the last two months prior to fruit maturation was 110 and 290 mm in Argentina versus 86 and 13 mm in the U.S.A. The absolute fruit sugar concentrations and the ranking of the varieties for fruit sugar was virtually the same in both climates, indicating the stability for fruit sugar. In contrast, the fruit fresh weight and percentage pulp was significantly greater in Argentina with the higher rainfall at the end of the fruit maturation period.

Cactus pears grow in large quantities and must be harvest regularly (Potgieter, 2000). For harvesting, choose a terrain where the cactus species face to the North to get maximum sunlight. Chocenille and cactoblastis are the main insects causing plagues for the cactus species. Chemicals are used to destroy it. Cactus pears are non-climacteric fruit with low respiration rates in comparison to those of other common fruit. As the cactus fruit develops and ripens, the peel decreases in thickness and becomes easier to remove. Thinning and softening of the peel both contribute to the fruits' increased susceptibility to physical damage during handling (Cantwell, 1986). Irrigation increase fruit size and percentage pulp content. Application of nitrogen increases biomass production, fruit mass and TSS content and phosphorous increase fruit production (Mashope, 2009).

Table 4 indicates the best climate area for cultivation of cactus pears as well as the colour of the peel (Cantwell, 1986).

2.7.2 Fruit development and maturity indices

Typical changes in the physical characteristics and chemical composition of cactus pear are illustrated by data obtained from *"Tuna Blanca"* fruit harvested at different stages of development. This fruit type has a pale greenish white pulp within a yellow coloured peel when ripe. Sugar and vitamin C contents increase substantially during the ripening process, while firmness and acid content decline (Cantwell, 1986).

Table 2.4 Cultivation areas of the cactus pear (Cantwell, 1986).

Cultivar	**1. Climate area**	**Yielding potential**	**2. Internal fruit colour**	**Average ripening time**
Algerian	L, M	Very high	Red	Before December
Gymno Carpo	L, M	Very high	Orange	Before December
Malta	L, M	Very high	Orange	Before December
Meyers	L, M	High	Red	January/February
Morado	L, M	High	White	January/February
Nudosa	M, H	High	Orange/red	March/April
Skinners Court	M, H	Low	Green/white	January/February
Roedtan	L, M	High	Orange	December
Turpin	L, M	High	Orange	December/January/February
Zastron	L, M, H	High	White	Before December

3 Best area for cultivation. L=Low Veld, M= Middle Veld, H= High Veld

4 Determine colour of the peel

2.7.3 Stages of development and ripening for cactus pear fruit:

Cactus pear cultivars first stage of development have a characteristic of mature green fruit: almost fully developed, with a light green peel. The ripening stage follows where the peel begins to show colour change. Colour development may vary from incipient up to 75 percent of the fruit surface. Fruit at this stage is considered optimal for commercial harvest. Glochids also begin to abscise during this stage. The cactus pear fruit begins to ripen in the third stage of development when the peel colour is 75 - 100 % yellow. The peel is noticeably softer than stage 2 fruit and can easily be damaged during harvest. The fourth stage may show an increasing intensity of yellow peel colour with small, rusty brown discoloured areas (Cantwell, 1986).

2.7.4 Compositional changes of quality attributes during maturation

According to Cantwell (1986), maturity indices for fruit quality for commercial handling include: Fruit size and fullness, changes in peel colour, abscission of the glochids, fruit firmness, flattening of the floral cavity, the percentage of pulp, the thickness of the peel and its ease of removal and the resistance of the peel to physical handling.

In comparison to other fruit, the organic acid content is low and acid levels decrease during fruit ripening. The major organic acids are oxalic and citric acids, with minor amounts of malic and succinic acids (Cantwell, 1986).

The pulp and the peel of cactus fruit exhibit important compositional changes during ripening. The titrable acid content of the peel is much higher than that of the pulp. The fruit pulp contains very little acid at any stage of development. The pH values of the peel and pulp tissues increased in ripening, while the acid content decreased (Cantwell, 1986).

Changes in fruit firmness are often correlated with changes in cell wall constituents and enzymes, especially pectin and pectinases. There are no changes in the pectin content of the pulp during ripening. The total pectin content of the peel is notably higher and decrease with ripening. The percentage of soluble pectin remains relatively constant during ripening (Cantwell, 1986).

2.8. Conclusion

Cactus pear fruit is known in various countries of the world and can be successfully cultivated in large quantities on any ground. These nutritious fruit is packed with co-factors that boost immunity in the form of vitamins and minerals. Significant portions of vitamin C in the fruit help protect the body against oxidation (Knishinsky, 1971). Macronutrients which can be found in cactus pears are: eight essential amino acids, essential fatty acids and sterols, carbohydrates in the form of sugars and dietary fibre (Feugang *et al.*, 2006). Quality is essential for determining consumer acceptance and parameters include: fruit mass and size, total soluble solids, edible pulp percentage, peel thickness, seed content, seed size and pulp firmness (Potgieter and Mkhari, 2002). Cactus pears form an integral part of the agricultural, industrial and medicinal field. The fruit have been under intense medicinal focus in recent years, especially the link between cactus pear fruit and its anti-hypoglycemic effects (Knishinsky, 1971). The chemical composition of the cactus pear plays an important role during processing. The volatile components give the cactus pear and its products their flavour (Saenz-Hernandes, 1985). Sugars and acids are the principle contributors to flavour in fruit. The ratio is often used as harvest and quality indices in different fruit. Cactus fruit has a mild pleasant taste with subtle differences in the flavour of fruit of different species. The acid content is very low and the juice of cactus fruit with a lower acid content is favoured in sensory tests. Sensory evaluation has been included in few studies on cactus pears and the need to conduct such studies is emphasised to determine consumer preference of different cultivars (Cantwell, 1986).

2.9 Sensory science in the food industry

In 1975, the Sensory Evaluation Division (SED) of the Institute of Food Technologists (IFT) defined sensory evaluation as a scientific discipline used to evoke, measure, analyse and interpret reactions to the characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch and hearing.

Sensory analysis is used in the food industry to establish differences and to characterise and measure sensory attributes of products. Various applications include: monitoring competition; product matching; product optimisation; process change; cost reduction and/or selection of a new source of supply; quality control; quality assurance; determining storage stability; product grading or rating; product sensory specification; raw materials specifications; advertising claims; correlation of sensory with chemical and physical measurements; process / ingredient / analytical / sensory relationships; consumer acceptance and/or consumer preference; and new product development, reformulation and/or cost reduction (SED IFT, 1981; Stone & Sidel, 2004).

Sensory evaluation methods are divided into two main groups, namely affective and descriptive tests. Affective tests involve untrained judges or consumers of a product, who evaluate preferences and/or acceptance and/or opinions of the specific product. Descriptive tests are performed by trained sensory panels and measure qualitative and/or quantitative characteristics of food products (Heymann, 1995). Some of the descriptive methods include Flavour Profiling (Baxter *et al.*, 2005), Texture Profiling (Bramesco, 2007), Quantitative Descriptive Analysis (QDA) (Rossi, 2001), Sensory Spectrum (Murray *et al.*, 2001), Quantitative Flavour Profiling (QFP) (Stampagnoni, 1993), Generic Descriptive Analysis (GDA) (Einstein, 1991) and Free Choice Profiling (FCP) (Orekovich *et al.*, 1991).

2.9.1 Free Choice Profiling

Free Choice Profiling (Williams & Langron, 1984) (FCP) is a descriptive technique that may decrease the time and money expenditures to formally train and maintain traditional descriptive panels. It was first developed by Williams & co-workers (Baines, Langron & Collins) in 1981 and first applied by Williams & Langron in 1984 for the evaluation of commercial port wines. Since then it has been successfully applied to a broad range of food products, including: meat patties (Beilken *et al.*, 1991); Parmiggiano Regiano cheese (Virgili *et al.*, 1994); cooked hams (Delahunty *et al.*, 1997); Chilean goat cheese (González Viñas *et al.*, 2007); ewe's milk cheese (Bárcenas *et al.*, 2004);

commercial black filter coffees (Narian *et al.*, 2004); Spanish unifloral honeys (González Viñas *et al.*, 2007); different fruit products like sweet orange gels (Costell *et al.*, 2007); flavour and odour of orange-based lemonades (Lachnit *et al.*, 2003) and chocolate (McEwan, 2007).

The technique differs from conventional descriptive testing in that the members of a taste panel describe perceived qualities of a product analyses in an individual manner, use their own list of terms to describe the sensory characteristics of that product (Oreskovich *et al.*, 1991). The panelist is allowed to create and use as many terms needed to describe the sensory characteristics of a set of samples (Meilgaard, Civille & Carr, 1999). Any sensory characteristics can be examined using FCP, implying that a product can be described in terms of a number of characteristics, such as appearance, flavour, aroma, texture or any combination of these (Oreskovich *et al.*, 1991).

However, panelists may find it difficult to express their sense perceptions which may make it hard to communicate with the other panelists on a panel. Another problem that may arise is when assessors find it difficult to generate an adequate vocabulary to fully describe samples (Guy *et al.*, 1989).

The number of assessors may also influence the outcome of a test (Guy *et al.*, 1989). According to Oreskovich *et al.* (1991), FCP routinely uses 8 to 20 panelists when evaluating products, which are comparable to conventional descriptive analysis techniques. It is possible to use a larger panel than in other descriptive methods, since no extensive training is required (Oreskovich *et al.*, 1991). One of the unique features of FCP is the statistical treatment of the scores from the panelists.

2.9.2 Generalised Procrustes Analysis

Generalised Procustes Analysis (GPA) is a function used to mathematically manipulate data (Gower, 1975; Schlich,1989; Oreskovich *et al.*, 1991, according to Lawless & Heymann, 1998). The GPA usually provides a consensus picture of the data from each individual panelist in two-or-three dimensional space. The technique is called Procrustes analysis in reference to Hellenic mythology. Procrustes, a nickname for Damastes or Polypemon (meaning "the stretcher"), was a robber who invited travellers to stay at his house (Kravitz, 1975). If the visitor did not fit his bed, he would either stretch them or cut off their legs to make the visitor "fit" the bed. His guests being thus incapacitated, Procrustes was able to help himself to his guests' possessions at his leisure (Lawless & Heymann, 1998).

In a sense, the GPA force fits the data matrices from the individual panelists into a single consensus space. The most important aspect of the GPA is that it allows the analyst to determine the terms used by individual panelists that appear to be measuring the same sensory attributes as the other judges. The goal of GPA is to blend the individual configurations into a common space. The analysis consists of three logical stages: first, translation to correct for variations by using different parts of the scale; secondly, rotation/reflection to remove variations for the differences in terms used; and thirdly, an isotropic scaling to correct for the range effect. The relationship among samples and assessors (including the consensus and individual configurations are provided by GPA (Rubico, 1992). Product samples can also be scored during assessment for preference, which can then be mapped onto the perceptual product space (McEwan & Thomson, 2007).

2.9.3 Sensory analysis on cactus pear fruit, cladodes and related products

Research on cactus pear fruit is mainly done in countries such as Italy (Gurrieri *et al.*, 2000), Egypt (El-Samahy *et al.*, 2007), Spain (Retamal *et al.*, 2006), Argentina (Mestrallet *et al.*, 2008), Mexico (Ruiz Pérez-Cacho *et al.*, 2006), Chile (Sáenz *et al.*, 2001) and also recently in South Africa (Potgieter, 2000; Snyman, 2006).

Gurrieri (2000) investigated the possibility of long term storage of cactus pears for their juice . The pH had been changed to a lower value to be according to the Italian law and thermal treatment was applied to increase long-term storage. A preference test was carried out to compare a red cultivar of cactus pear with commercially available pear- and peach juices (before the change of pH and thermal treatment). A ranking test was also carried out by a trained panel to compare a yellow cultivar of prickly pear juice with pear- and peach juices (after pH had been lowered and thermal treatment had been given). Descriptors used to rank on a scale from 1(extremely poor) to 9 (excellent) were colour, aroma, viscosity, acidity, sweetness, off-flavors and overall acceptability. The panel consisted of 41 panelists. Three samples were presented to the assessors in a random order. Sensory data was statistically analysed. The results of the preference test showed that 65.9% of the panelists preferred pear and peach juices to red prickly pear juice. The insufficient acceptability was correlated with too intense colour (mistaken for artificial), insipid taste and the presence of a vegetable aroma. The ranking test indicated that the descriptors (colour, aroma, viscosity, acidity, sweetness, off-flavors and overall acceptability) of the cactus pear showed significant differences versus the pear/peach subset. Gurrieri (2000) found that by optimising processing conditions and by various technological treatments, a cactus pear juice with a score closer to that of highly distributed peach and pear juices can be produced.

Cactus pears are difficult to peel because of the presence of glochids. Sáenz (2001) determined the sensory and microbiological characterisation as well as changes in gas composition during the storage of minimally processed cactus pears to increase the acceptability of cactus pears. Winter harvest cactus pears from Santiago, Chile were used. The cactus pears were washed, drained and peeled and then separated in two treatments (one with citric acid immersion to lower the pH and the other without). The fruit was packaged and stored in BB4 (EVA) and perforated bags and then centrifuged. Analysis was made based on gas composition, firmness and microbiological count. Sensory characteristics were determined by using a 1-9 point scale by a panel of 12 panelists to determine quality and a panel of 24 panelists to determine acceptability. The study was completely random within two factors (bags and immersion) and the results were analysed by Analysis of Variance (ANOVA) and the Duncan method. Almost all of the sensory attributes remained constant during the storage period.

Acceptability differed between the immersion treatments (better acceptance for the fruit without immersion and in BB4 bags) This finding was possibly due to the panelists' preference for the less acidic taste of this fruit. Sáenz (2001) stated that BB4 bags are recommended for storage of minimally processed cactus pears for 7 days, especially in regard of texture loss.

Freshness and convenience are demanded by the consumer. Studies are being done to minimise the procession of fruit and vegetables. In a study by Piga (2003), cactus pear fruits were peeled manually, placed in plastic boxes, sealed with a film with high permeability to gasses and kept at 4°C for 9 days to determine whether film packaging can increase the fruit quality of cactus pears. Chemical, physical, microbiological and sensorial parameters, total phenols, vitamin C and antioxidant capacity were determined after 3, 6 and 9 days. A total of 60 trays were prepared and after 3, 6 and 9 days, 20 trays were removed from the storage room for evaluation. Sixteen fruit from each lot were used for sensorial analysis. Five untrained panelists were used to evaluate overall appearance (1-very fresh, 2-fresh, 3-fair, 4-aged, 5-very aged), taste (5-very good taste, 4-good taste, 3-acceptable, 2-poor, 1-very poor), aroma (5-very good, 4- good, 3-satisfactory, 2-off-flavoured, 1- strongly off-flavoured), firmness (5-normal as at harvest, 4-good, 3-acceptable, 2-somewhat watery, 1-watery). Data was statistically analysed. Results showed that film packaging helped in maintaining high relative humidity inside the package, thus reducing the loss of fruit weight. The reduction in mass was slight during the experiment.

Research into edible films and coatings were done to increase food quality and decrease disposable packaging. The cactus pear mucilage was investigated as an edible coating to extend the shelf-life of strawberries. A panel of 16 trained judges carried out the sensory analysis on common varieties of strawberries coated with cactus pear mucilage films. Cactus stems were peeled and cubed and the samples were homogenised to prepare the edible coating. Two experimental coatings were formulated, M1-pure mucilage extract and M2 –mucilage extract and 5% wlw glycerol as a plasticizer. The strawberries were dipped in the coating solution for 30s, drained and dried in a forced-air dryer. The strawberries were stored in a refrigerator. For each treatment 50 fruits were coated and three replicas per treatment were analysed (1,3,5, 7 and 9 days for the sensorial analysis and, after 1, 5 and 9 days for the texture and colour properties). A preference test and an acceptability test with a nine-point hedonic scale were used. In the preference test the judges had to choose one preferred sample according to general preference. The acceptability test was carried out using semi-structured scales, scoring one (lowest) to nine (highest) for the attributes: visual appearance, colour, brightness, texture and taste. Data was statistically analysed. Findings were that, after the first day of storage, the panelists did not prefer the M2 coating and that the preference percentage for the M1 coating and uncoated samples were similar. The preference for uncoated strawberries decrease with storage time whereas, coated samples were the preferred choice for judges from the first week of storage (sample M2 presented a higher preference than sample M1). Textural analysis showed that cactus pear mucilage could have a protective effect on strawberries and resulted in an increased firmness of coated strawberries during storage (Del-Valle *et al.*, 2005).

A quantitative descriptive analysis method was used by Ruiz Pérez-cacho (2006) to determine the sensorial analysis of edible young cladodes of flat-stemmed spiny cacti (mainly of the *Opuntia* genus), named nopalitos. Four variants of nopalito (*Opuntia* spp.) from different regions of Mexico were used namely *Opuntia ficus-indica* Milpa Alta, *Opuntia ficus-indica* Atlixco, *Opuntia robusta* Larreguin and *Opuntia ficus* Copena V-I. Panel performance evaluation was carried out on three variants of nopal-verdura namely *Opuntia ficus-indica* Milpa Alta, *Opuntia ficus-indica* Atlixco and *Opuntia ficus* Copena V-I. Nopalitos were 30 days old and 20cm long. The cladodes were cleaned and scalded in a saline solution (2% NaCl) and then maintained in ebullition for 30min. The Nopalitos were then poured into a colander to drain after blanching. Finally, samples were washed with cold water. Each assessor received three and six portions of each sample for discriminatory test and sensory analysis respectively. Samples were served on plastic dishes covered by a film at room temperature and were coded with three-digit random numbers. Mineral water was provided to cleanse the palate between samples. A highly trained panel of five professional panelists was used to develop a new descriptive and discriminating language in a 20 ½ panel hours. A vocabulary of 22 terms was modified to 6 attributes namely luminance, boiled vegetable odour, acid taste, hardness, chewiness and palate coating. Results from the discriminatory test showed that three panelists were excellent with adequate discriminatory abilities between variants and two panelists were uncertain. Significant differences among the attributes were obtained by principal components analysis (PCA) and ANOVA. The first two principal components had Eigen values exceeding 1 (72.5% of variability). The first principal component was positively correlated with hardness and chewiness and negatively correlated with acid taste (46.6% of variance). Component two was positively related to luminance and palate coating and negatively to herb odour (25.8% of variance). The analysis of variance indicated that all assessors significantly used the attributes in a constant way.

The possibility of producing a new value-added snack-type extrudate based on cactus pear pulp concentrates was study by El-Samahay (2007). High temperature, short time (HTST) is a extrusion cooking technology with low cost and high efficiency to decrease the loss of nutrients during food processes. Half-ripened orange-yellow and red cactus pear fruits were collected from a cactus orchard in Al-sharqiyah governorate, Egypt. The fruits were washed, manually peeled, blended and sieved to separate the seeds from the pulp. The extracted pulp was tested for technological and chemical characteristics. The pulps were concentrated by evaporation under vacuum at 60°C until they reached 40°Brix using an evaporator. Rice was ground to get a homogenous particle size by using a laboratory mill. Samples consisted of 100% rice flour as the control and mixtures of rice flour with cactus pear pulp concentrate (95:5, 90:10, 85:15 and 80:20). A laboratory single-screw extruder was used to process the different formulations. Expansion ratio (ER) of extruded products may be due to the increase of dietary fiber content in cactus concentrates as well as the increase of viscosity of the cactus pear concentrate. Bulk density (BD) increased with increasing substitution levels of cactus pear concentrate. Sugars and dietary fibers, in replacing the starch content, resulted in an increased bulk density as well as a decrease in breaking strength (BS).

Sensory analysis was carried out by ten trained panelists for taste, crispness, chewiness, odor, colour, pore distribution and surface characteristics. Overall acceptability of the products was determined from the total scores of these attributes. Grades were given according to 86-100 (excellent), good (76-85), fair (61-75) and poor (50-60). The possible significance ($p \leq 0.05$) of treatment effect was determined by using ANOVA. Possible pair comparisons between means of different treatments were described by using Fischer's Least Significance Difference (LSD). Data showed that 5% and 10% substitution levels of concentrated cactus pulps are the best to produce extruded products with good functional, nutritional and sensory characteristics. Both pulps have high pH values suitable for food substitutions as well as a good content of sugar, crude protein, dietary fibers, pectin and ash.

El-Samahy (2008) produced canned cactus pear nectar to determine the heat resistance parameters of pectin methyl esterase. Heating penetration curves for heating and cooling processes were calculated. Mature yellow-orange cactus pear fruits (*Opuntia ficus-indica*) were washed thoroughly in running water to remove the thorns, manually peeled, cut and pulped in a pulping machine to separate the seeds from the pulp. The pulp was pasteurised at 85°C for 3 min and then cooled. The cactus pear pulp was diluted to 11.5°Brix. The typical nectar formula was 1: 0.325: 2 cactus pear pulp : sugar : water. Citric acid solution (10%) was added to adjust the nectar at pH 5. The nectar was then heated to 85°C, poured into cans and sealed. The basis of heat resistance parameters of pectin methyl esterase (PME), considered to be the most resistant enzyme, was used to evaluate the optimum thermal process of cactus pear nectar. It was found that the higher the total solid, the better quality of juice was acquired. Factors like Titratable acidity (TA) and pH affected the flavour of the canned cactus pear nectar. El-Samahy (2008) found that sugars were the major soluble solids of the cactus pear fruit and that ascorbic acid retention is a good indicator of high quality, because of its nutritional value. Ascorbic acid, colour index and cartenoids contents of canned cactus pear nectar were mostly affected by thermal processing. The canned cactus pear nectars before processing, processed at 100.9 °C/20min and processed at 110.2 °C/20min, were evaluated for taste, odour, mouth feel, appearance, colour and overall acceptability. Analysis was done by ANOVA which stated that there were significant differences between all attributes of raw cactus pear nectar and the processed samples at 100.9 °C/20min and/or 110.2 °C/20min. The cactus pear nectar processed at 110.2 °C for 20min was not acceptable in taste, colour, odour and mouth feel. Conclusions drawn from this study indicated that a thermal process at 100.9 °C for 20 min was suitable for cactus pear fruit nectar, because of the inactivation of the PME enzyme which resulted in no gas forming and the pH value was not affected in the cans.

Consumers prefer ready-to-eat foods, low in calories, cholesterol and fat. Ayadi (2009) found that powders obtained from spiny and spineless cladodes showed a great technological potential in water binding capacity (WBC) and fat absorption capacity (FAC). Cladodes from *O. ficus indica f. amyclaea* (spiny cladodes) and *O. ficus indica f. inermis* (spineless cladodes) in the area of Tunisia, collected between March and June 2007, were used for this study. Cladode powders were used in wheat flour at 5%, 10%, 15% and 20% levels. The following organoleptic characteristics of cakes were tasted by 45 untrained panelists: crust colour, crumb colour, grain, texture, eating quality and overall quality. The ratings were done on a 5-point hedonic scale ranging from 5 (like extremely) to 1 (dislike extremely) for each organoleptic characteristic. Cake slices were 2.5 cm in thickness and were compressed to 50% of original height. Sensory data was statistically analysed by using Ducan's test. Results obtained showed that cladodes flour has a significant effect in wheat dough properties ($p<0.05$). The increasing cladode flour levels decreased dough elasticity and increased tenacity, energy, adhesion, stickiness and hardness of dough. The cake colour became greener and the crust became darker after the addition of cladode flour.

Sensory evaluation showed that ice-cream with 5% of cactus pear pulp was very desirable and close to the control sample without the cactus pear pulp (El-Samahy *et al.*, 2009). This interesting finding can lead to the production of new products of ice-cream using cactus pear pulp as a fruit substitute. Half ripened red cactus pear fruits were collected from a specialised orchard located in Egypt. The fruits were washed, manually peeled and blended, followed by the separation of the seed from the pulp through a sieve. The pulp was pasteurised and then concentrated. Fresh buffalo's milk, skim milk powder, gelatin, fresh cream and sugar were the ingredients used to make the ice-cream. The basic ice-cream mix contained 0.5% gelatin, 8%fat, 10.5% milk solids non-fat (MSNF), 16% sucrose. Concentrated cactus pear pulp was added to the basic cream mix at 0,5%, 10% and 15% level. The control sample consisted of the basic ingredients without the cactus pear pulp. Sensory evaluation of the ice-cream samples were carried out by staff members and semi-trained panelists. Results are presented as means, plus or minus standard deviation from three replicas of each experiment, except colour attributes. The possible significance among mean values of sensory evaluation was done by ANOVA. Obtained data showed clearly that cactus pear pulp is rich in nutrients and is a good source of energy. Pulp contents of polysaccharides such as fibers, pectin and mucilaginous components decrease flow behaviour and increase viscosity. Findings were that cactus pear fruit may be a suitable source of natural additives and or substituted ingredients for the making of foods like ice-cream.

The increase of shelf life and improving stability of products with a high lipid content e.g. peanuts can be done by coating with cactus pear- and "algarrobo pod" syrup (Mestrallet *et al.*, 2009). Selected and clean fruit weighing 500g was added with 125g sugar, boiled in 200ml water for 1 hour. The cooked fruit was cooled down, filtered and boiled for another hour. Three batches of cactus pear and "algarrobo" pod syrups were prepared. Descriptive analysis was done by a total of 12 trained panelists between the ages of 18-64. Panelists were selected according to natural dentition, non-food allergies and non-smokers, consumers of roasted peanuts and/or peanut products at least once a month, availability for all sessions, interest in participating and ability to verbally communicate regarding the product. The panelists had to have a perfect score in a taste sensitivity test and the ability to identify 5 of 7 commonly found food flavours before being qualified as a panelist. The panelists were trained in four sessions during four days, each training session lasted for 2 hours. Descriptive analyses were used during the training and evaluation sessions. The attributes' definitions were based on a peanut-lexicon. An average panel rating with standard deviation within 10 points was created by the panel by using a nine-point hedonic scale. All samples were evaluated under fluorescent light at room temperature. Three-digit coded plastic cups with lids were used for ten grams of product sample. Panelists evaluated a warm-up sample plus 12 samples per day. Samples were tested using a complete randomised block design and data was registered on paper ballots. Data was analysed by using InfoStat software to calculate means and standard deviations. ANOVA and Duncan's test were used to identify significant differences in sensory attribute rating and chemical analysis measurements. Correlation between dependent variables from chemical and sensory analysis was calculated by the Pearson coefficient. Second order polynomial regression equations in the regression analysis were used to determine if time had an effect on sensory attributes and peroxide value (PV). Attributes used in sensory analysis were appearance (brown colour, roughness), aromatics (roasted peanut, oxidized, cardboard, and raw/beany), taste (sweetness, salty, sour and bitter) and texture (hardness, crunchiness and tooth pack). Results showed that roasted peanuts coated with syrups indicated higher intensity ratings of brown colour, roughness, sweetness and saltiness and lower intensity rating of raw/beany flavour than roasted peanuts. Variables of interest in this study were PV, oxidized, cardboard and roasted peanut flavours, because of changes with storage time. This study indicated that the addition of syrup coating provided protection against lipid oxidation.

In an attempt to find more applications for cactus pear fruit in South Africa, Frey *et al.* (2009) evaluated the suitability of the fruit of seven cactus pear cultivars for the making of jellies. Fruit of the cultivars Direkteur, Ficus-Indice, Muscatel, Skinners Court, Turpin, Vryheid and Monterey were used in this study. The fruits were peeled, juice was extracted and the juice mixed and processed into jellies by using a standardised method. Seven trained panelists did descriptive analysis in triplicate. The textures of the jellies were compared with three controls (water, orange juice and orange juice+pectin) by using a consensus lexicon and ten point scale. Data was analysed by using a Fischer's LSD at $p<0.001$ to determine which cultivars differed significantly from one another concerning the sensory attributes and the physical analysis. Descriptors generated were cloudiness, smoothness, pectin content, runniness and cutting edge. Scores for the jellies were generally low compared to the control samples. No significant difference between the seven cultivars for descriptors smoothness, cutting edge, pectin content and runniness was found. There was a significant difference between the seven cultivars in the physical texture analysis. Frey *et al.* (2009) found that Ficus-Indice had the highest viscosity and line spread value and that Monterey (beetroot-like taste in raw state) had an extremely pleasant flavour, when using the standardised processing method.

It has shown that semi-naïve assessors could successfully be used to gain information on 40 prickly pear cultivars in South Africa. Free choice profiling was used as a sensory analysis tool to investigate the ability of semi-naïve consumers to describe and perceive the taste of 40 prickly pear cultivars in South Africa (Jordaan, 2008; Swart, 2009). Some of the attributes used to describe cactus pear fruit were cucumber, kiwi, sweet, fruity, tropical, melon, banana, pear, bitter and salty. Conclusions drawn from GPA stated that semi-naïve assessors were successful in distinguishing between cultivars for human consumption and cultivars used for animal fodder.

2.10 Conclusion

Research has shown that sensory analysis is essential to determine consumer acceptance and preference. FCP give the untrained assessor the opportunity to express his own opinion regarding the product analysed. The FCP strategy can yield important insights into consumer differentiation of products and relate preference to sensory character (Narain, 2003). This cost effective technique becomes more efficient in product development and is applied to a great variety of developmental products such as chocolate, cooked hams, commercial black filter coffees and strawberry yoghurt. Generalised Procustes Analysis manipulates data obtained from the sensory analysis mathematically and provides a consensus picture of the data from each individual panelist in two- or three dimensional spaces. Sensory analysis on cactus pear fruit and cladodes is limited, but product development carried out on cactus pear fruit has become more popular and food scientists are more interested in this nutritious fruit. Cactus pear products analysed by using sensory analysis include cactus pear juice, minimally processed cactus pears, edible cactus pear film coatings, cactus pear snack-type extrudates, canned cactus pear nectar, cactus pear pulp in ice-cream, cactus pear jellies and cactus pear cladode flour.

2.11 Aim

The aim of this study was to determine the fruit quality of cactus pear fruit. Chemical and sensory quality attributes were evaluated for two agricultural seasons (2007 and 2008). The influence of factors such as especially rainfall and temperature on quality was determined. Furthermore, sensory analysis was used to distinguish among the available 33 cultivars, not only for their taste, but also to establish the cultivar most stable to varying environmental conditions. The study determined whether sensory quality of cactus pear fruit was influenced by the chemical parameters by attempting the correlation of the chemical data with the sensory analysis.

CHAPTER 3

MATERIALS AND METHODS

3.1 Trial site and lay-out

The Waterkloof germplasm collection is located in the Bloemfontein district in the Free State. This semi-arid area is located 1 348 m above sea level (m.a.s.l.) and receives 556 mm annual rainfall on average. The orchard is eight years old. Standard orchard practices such as weeding, pruning, pest- and disease control, as recommended, are followed (Potgieter, 2000). This site hosts 42 South African cactus pear varieties that are being evaluated for use as fruit, fodder and dual purpose use. The trial is laid out in a fully randomised design with two replications of each treatment. Treatments include 42 cactus pear cultivars. There are 14 rows, each with six plots. Individual plots have five plants which will be used for data analyses. The spacing is 5.3 m, adding up to the total plant population of 420 for the two replications (Potgieter, 2000). Climatic data was captured via an automatic weather station (Mike Cotton Systems), installed 50 m from the site. Mean daily values for temperature (°C) and rainfall (mm) were summarized as monthly values (Fouche, 2009).

3.2 Cactus pear cultivars

Cultivars included in the study are from two species, namely *Opuntia ficus-indica* and *Opuntia robusta*. Thirty-two cultivars, suitable for human consumption, are from *Opuntia ficus-indica* spp., with only one cultivar from *Opuntia robusta,* namely Robusta, which is mainly used as fodder. Robusta has been included in this study as a control parameter and served an additional *Opuntia* specie (Table 3.1). Cultivars included in this study served as both chemical and sensory parameters.

Image 3.1. Various cactus pear cultivars. Front: Fresno; Middle: Nudosa; Back: Algerian.

3.3 Fruit harvesting and collection:

Fruit was harvested and evaluated over two agricultural seasons: 2007 and 2008. The fruit was picked at 50 % colour break stage (50 % of the fruit was at 50 % colour break stage). All of the fruit was therefore at the same stage of ripeness (Avenant and Fouche, 2008).

Table 3.1 Cactus pear cultivars used in this study.

Cultivar	Pulp Colour	Consumption	Cultivar	Pulp Colour	Consumption
Meyers	Purple	Human	R1251	Orange	Human
Rossa	Pink	Human	American Giant	White	Human
Roedtan	Orange	Human	**Robusta**	Red	**Animal**
Algerian	Pink	Human	R1259	Orange	Human
Santa Rosa	Orange	Human	Cross X	Orange	Human
Morado	White	Human	Zastron	White	Human
Robusta x Castillo	Orange	Human	Ofer	Orange	Human
Muscatel	Green/White	Human	Malta	Orange	Human
Sicilian Indian Fig	Pink	Human	Amersfoort	Green/White	Human
Tormentosa	Orange	Human	Schagen	White	Human
Turpin	Orange	Human	Nudosa	Orange/Red	Human
Corfu	White	Human	Roly Poly	White/Red	Human
Fresno	Green	Human	Postmasburg	Green/White	Human
Vryheid	Green/White	Human	Direkteur	Khaki/Yellow	Human
Gymno Carpo	Orange	Human	Van As	White	Human
R1260	Orange	Human	Messina	Green/Yellow	Human
Blue Motto	Khaki/yellow	Human			

3.4 Physical/Chemical analysis

3.4.1 Physical/Chemical analysis of fresh fruit

3.4.1.1 Fruit mass and pulp percentage.

Three fruit of each cultivar was weighed. The cut and tear method was used for peeling the fruit, by slicing the two distal ends, approximately 0.5 cm thick, along the longitudinal axis. The peel was then carefully torn from the pulp. The peel and pulp was weighed separately and then frozen for further analysis (not longer than two months) (Saenz, 2002).

3.4.1.2 Total soluble solids (TSS) content.

Three fruit of each cultivar was weighed. A manual piston press was used to press out the juice. Total soluble solids were measured by means of a hand-held ATAGO N-1α (°Brix 0-23 %) refractometer and expressed in degrees Brix (°Brix). The juice was frozen at a temperature of -18 °C (for not longer than one month) and was used for sensory analysis (De Wit *et al.*, 2010).

3.4.2 Physical/Chemical analysis of fruit pulp:

The following procedures were executed on the thawed pulp fraction for each cultivar:

3.4.2.1 Liquid fraction and pH

A food blender was used to homogenize the pulp fraction of each cultivar. After the pH was measured with a Hanna 8521 pH meter, the homogenized samples were centrifuged in a Beckman JA-21 centrifuge at a speed of 5000 rpm for 10 minutes, to separate the liquid from the solid matter. The juice was then filtered through a sieve (500 µm), divided into four aliquots and frozen for further analysis (De Wit *et al.*, 2010).

3.4.2.2 Determination of titratable acidity (expressed as percentage citric acid)

The titratable acidity (TA) was determined according to the method of James (1995). An aliquot of 10 ml of the thawed filtrate was diluted to 80 ml with distilled water, 0.3 ml phenolphthalein indicator was added and titrated to a faint pink end-point with 0.1 M NaOH.

The following calculation was used to determine % citric acid:

$$\frac{T \times 192}{3 \times 1000} = \% \text{ (m/m) Citric acid}$$

Where T = titre (in ml) of 0.1 M NaOH required to neutralize the acidity in 10 ml cactus pear juice [192 is the molecular mass of citric acid]. Titratable acidity determined in the pulp filtrate, was recalculated to percentage of the total fruit weight (De Wit *et al.*, 2010).

3.4.2.3 Determination of Total Soluble Solids and Titatrable Acid Ratio

The TSS and TA ratio was determined by dividing the percentage TA into the °Brix value of TSS (Duru and Turker, 2005).

3.4.2.4 Determination of sugar content

A Waters Breeze High Performance Liquid Chromatography system determined the sugar content of the pulp, by using a Waters Sugar Pak 1 (300× 7.8 mm) column at 48 °C with a differential refractive detector. The mobile phase was de-ionized water and elution at 1 ml/min. The samples were filtered through Cameo 0.45 µm nylon filters. Twenty µl of each sample was subsequently injected into the system. Quantification was done with sucrose, fructose and glucose as standards (Riaz and Bushway, 1996). The content of glucose and fructose in the filtrate, were recalculated to percentage of the total fruit weight (De Wit *et al.*, 2010).

3.4.3 Statistical analysis

Data obtained from methods used to determine physical/chemical parameters were entered into a Excell spreadsheet. Three replicates were entered for each cultivar used to determine the physical/chemical parameters. Data were analyzed using XLSTAT software (XLSTAT, 2007). Means and standard deviations were calculated. Analysis of variance (ANOVA) was used to detect significant differences ($p < 0.05$) and measurement of physical/chemical analysis. Fischer multiple comparison test was used to calculate LSD values. The Pearson coefficient was used to calculate correlation between dependant variables from physical/chemical and sensory analysis (De Wit *et al.*, 2010).

3.5 Free Choice profiling

3.5.1 Cactus pear juice samples

Thirty-three cactus pear cultivars were collected from an orchard outside Bloemfontein (as discussed in 3.1 and 3.2 above). The fresh cactus pear fruit was refrigerated at 4°C before peeling. The juice was extracted by a manual piston press. The juice was poured into 250 mℓ plastic juice bottles (Freepak, Bloemfontein), sealed and frozen at -18 °C (not longer than one month), until the sensory test was conducted.

3.5.2 Panel training

A group of ten consumer panelists were selected to participate in the FCP study, based on their taste and smell acuity, interest, ability to discriminate between the four basic tastes and availability for the entire study. The ten panelists had no experience in descriptive sensory evaluation, but had tasted cactus pear fruit before. No vocabulary development was carried out; each panelist used his/her own descriptive words for the taste attributes.

An unstructured line scale, with appropriate anchors, ranging from zero (0) denoting not, (e.g. not sweet) to fifteen (15) denoting extreme (e.g. extremely sweet) was constructed and used to evaluate the different samples. In order to ensure that panelists were not influenced in any way, no information with regard to the nature of the samples was provided. Panelists were informed not to use cosmetics (like lipstick) and to avoid exposure to foods and fragrances at least one hour before the evaluation sessions. Three evaluation sessions were conducted.

3.5.3 *Sample preparation, serving and evaluation procedures*

Applicable juice samples were removed from the freezer 24 hours before tasting and thawed at 4 °C. All samples were served and evaluated according to the sensory principles and methods described in the ASTM Manual on Descriptive Analysis Testing for Sensory Evaluation (ASTM Manual Series: MNL 13, 1992) (Hootman, 1992).

Panelists received 30 ml samples per product and 11 cultivars were tested each day. The cactus pear fruit juice was diluted with Dairy Belle's *Real Juice* apple (100% apple juice) (Tiger Food Brands limited, Bryanston) in a ratio of 250:100 ml, because of limited juice sample volumes. This specific brand was chosen for its bland taste, as not to influence the distinctive aroma of each cultivar. Samples were prepared on the day before analysis, stored at a temperature between 2-6 °C, and left at room temperature (± 22 °C) for 30 minutes before assessment.

The samples were served: one at a time; in a 40 ml clear plastic cup (Plastform Consol Ltd., Johannesburg); on a white polystyrene tray; at 22 °C; under red fluorescent light; and in individual sensory booths. All samples were served blinded, coded (3-digit codes) and the serving order randomized to exclude any bias due to the position effect. Clover's *Aquartz* mineral (Clover Danone Beverages Ltd, Roodepoort) water was provided as palate cleansers before the start of evaluation and between samples.

Four evaluation sessions per day were scheduled, with a total of eight cultivars for three of the four sessions and nine cultivars for the last session. The whole range of 33 cultivars were tasted per day. The whole process was repeated two days later. Two replications were considered the absolute minimum to ensure reliability and validity of results. Panelists were rewarded at the end of each evaluation session with refreshments for their participation.

3.5.4 *Test methodology*

With reference to the objective of the study, FCP was used in order to determine whether differences exist between the 33 cactus pear fruit juice samples. Free Choice Profiling (Williams and Langron, 1984) is a descriptive technique that may decrease the time and money expenditures to formally train and maintain traditional descriptive panels. The technique differs from conventional descriptive testing, in that the members of a taste panel describe perceived qualities of a product in an individual manner, using their own list of terms to describe the sensory characteristics of that product. Any sensory characteristics can be examined using FCP, implying that a product can be described in terms of a number of characteristics, such as appearance, flavour, aroma, texture, or any combination of these (Oreskovich *et al.,* 1991). One of the unique features of FCP is the statistical treatment of the scores from the panelists.

Samples were scored on unstructured line scales, using the assessors' own vocabularies, anchored at the ends by the terms "not present/none" and "extremely/very high". Data were recorded on paper ballots and entered into worksheets for analysis.

3.5.5 *Statistical analysis*

Recorded data was entered into a Microsoft Excel 2003 worksheet and analyzed by GPA, using Xlstats (Version 7.5.2). Generalized Procrustes Analysis (Gower, 1975), was used to provide information on the inter-relationships between samples and assessors (Arnold and Williams, 1986; Oreskovich *et al.*, 1991). The main objectives were to obtain an insight into the basic cognitive factors that the consumers used to distinguish between products, as well as the relationships between products in these factors (Hauser and Koppleman, 1979). Generalized Procustes Analysis (GPA) is a statistical technique used to mathematically manupilate data (Gower, 1975; Schlich,1989; Oreskovich *et al.*, 1991, according to Lawless and Heymann, 1998). The GPA usually provides a consensus picture of the data from each individual panelist in two-or-three dimensional space (Lawless and Heymann quoted by

Kravitz, 1975). The relationship among samples and assessors (including the consensus and individual configurations) are provided by GPA (Rubico and McDaniel, 1992). The GPA consisted of three logically distinct steps: to eliminate the effect of use of different parts of the scales, the centroids of each assessor's data matrix were matched; isotropic scale changes removed differences in the scoring range used by different assessors; and by rotation and reflection of the axes, configurations were matched as closely as possible (Arnold and Williams, 1986). A perceptual space was produced for each assessor, which was matched as closely as possible with other assessors. A consensus configuration was then calculated as the average of individual configurations and simplified to a reduced dimensional plot by PCA.

The interpretation of descriptive sensory evaluation was simplified with the assistance of the multivariate statistical procedure, Principal Component Analysis (PCA). The smallest number of latent variables, called principle components, was identified by using PCA. These principle components explained the greatest amount of observed variability. Residual errors, or the distances between the assessors' individual configurations and the consensus, were then used to calculate co-ordinates for plotting the assessors, to identify outliers or groups (Jack, 1994).

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Physical/Chemical analysis on fruit pulp

4.1.1 Analysis of Variance (ANOVA) for treatments and interactions

The influence of cultivar, season and cultivar X season interaction on fruit quality attributes is represented in Table 4.1. Highly significant differences (at $p < 0.001$) were observed among the 33 different cultivars for all the tested attributes observed in both seasons, indicating that genetic differences among cultivars have a significant influence on fruit quality. Felker *et al.* (2005) also found that that the variation in fruit quality is related to genetic factors. Highly significant differences existed for all of the attributes tested between the two seasons (2007 vs. 2008). This observation is a clear indication that seasonal changes, i.e., the microclimate, plays a significant role in fruit quality. The cultivar X season interaction was highly significant for most of the attributes tested, indicating that cactus pear varieties will react differently to different environmental conditions. From Table 4.1 it is evident that not only the cultivar and agricultural season, but also the interaction between cultivar and season had significant influences on fruit quality. These results are in accordance with results obtained by different authors, namely that fruit quality is highly influenced by environmental characteristics, climate (Inglese *et al.*, 1995) and orchard management and may change from year to year (Ochoa *et al.*, 2006; Mokoboki *et al.*, 2009).

4.1.2 Mean values for physical/chemical attributes

Since the project encompasses both sensory and physical/chemical evaluation of fruit quality, the following physical/chemical attributes, important for eating quality, will be discussed: fruit mass, pulp %, sugar content (°Brix, glucose and fructose) and acidity of the pulp (TA % and pH). Fruit quality is based on sugar content, peel colour, fruit weight, pulp weight and seed content (Cantwell, 1995). Mean values, least significant difference (LSD) values as well as the coefficient of variance (CV) values for all the attributes among all the 33 cultivars for both seasons are indicated in Table 4.2. The CV value is an indication of the variation among cultivars and must be less than 10% (De Wit *et al.*, 2010 ; Labuschagne, 2010).

Table 4.1. ANOVA for the influence of cultivar, season and cultivar × season interaction on fruit quality attributes.

Treatment	Cultivar	Season	Cultivar X Season
Fruit mass (g)	$p<0.001$	$p<0.001$	$p<0.001$
Pulp %	$p<0.001$	$p<0.001$	$p<0.001$
TSS (°Bx)	$p<0.001$	$p<0.001$	$p<0.001$
Pulp pH	$p<0.001$	$p<0.001$	$p<0.001$
Pulp TA%	$p<0.001$	$p<0.001$	$p<0.001$
Pulp Glucose (mg/g)	$p<0.001$	$p<0.001$	$p<0.001$
Pulp Fructose (mg/g)	$p<0.001$	$p<0.001$	$p<0.001$

Table 4.2 Mean values for attributes of cultivars for season 2007 and season 2008

Cultivar X Year	Fruit mass (g) 2007	Fruit mass (g) 2008	% pulp 2007	% pulp 2008	TSS (°Brix) 2007	TSS (°Brix) 2008	% TA pulp 2007	% TA pulp 2007	TSS/TA 2007	TSS/TA 2008	Pulp pH 2007	Pulp pH 2008	Pulp Glucose g/100g 2007	Pulp Glucose g/100g 2008	Pulp Fructose g/100g 2007	Pulp Fructose g/100g 2008
R1251	108.07	130.06	59.97	49.17	11.80	13.33	0.44	0.32	26.82	41.66	6.26	6.19	41.33	46.33	28.33	32.67
R1259	121.77	121.64	58.50	55.14	13.13	13.73	0.46	0.40	28.54	34.33	5.89	6.69	25.33	51.00	22.33	21.00
R1260	110.28	134.53	59.57	46.84	12.20	12.70	0.45	0.50	27.11	25.40	5.93	6.71	48.00	43.33	30.00	19.33
Algerian	88.51	134.60	66.98	53.66	10.33	12.07	0.64	0.51	16.14	23.67	5.40	6.87	31.00	34.67	28.33	35.33
American Giant	90.21	130.17	55.98	49.79	11.80	12.50	0.31	0.54	38.06	23.15	6.02	6.75	31.00	34.67	23.00	25.67
Amersfoort	109.91	119.49	47.10	42.14	12.83	13.30	0.69	0.55	18.59	24.18	5.21	5.85	34.33	30.00	28.33	29.00
Blue Motto	118.05	137.33	49.73	44.31	13.40	12.30	0.25	0.28	53.60	43.93	7.18	6.43	34.33	33.33	31.00	23.67
Corfu	70.42	73.35	43.42	36.06	13.00	9.87	0.32	0.24	40.63	41.13	6.83	7.55	30.33	40.33	18.67	23.67
Cross X	111.39	141.29	59.29	47.28	12.33	13.70	0.66	0.52	18.68	26.35	5.85	4.97	42.33	47.00	30.33	32.33
Direkteur	116.13	111.95	53.85	48.13	12.10	10.37	0.89	0.36	13.60	28.81	7.08	7.13	33.00	47.33	25.33	27.00
Fresno	91.11	91.11	49.25	49.25	13.80	13.80	0.36	0.38	38.33	36.32	5.34	6.79	44.67	47.67	29.67	18.67
Gymno Carpo	107.74	134.01	60.00	51.36	11.93	11.73	0.47	0.46	25.38	25.50	6.18	6.81	40.67	35.00	32.33	26.33
Malta	115.79	129.98	61.52	53.29	12.73	11.80	0.55	0.38	23.15	31.05	5.87	6.25	31.33	42.33	22.67	32.00
Messina	103.32	123.34	45.30	44.25	14.07	13.57	0.37	0.76	38.02	17.86	6.19	6.10	38.00	38.33	40.67	19.33
Meyers	106.85	124.25	59.81	53.81	11.87	12.00	0.65	0.41	18.26	29.27	5.12	6.56	34.67	35.00	24.00	28.00
Morado	100.21	84.31	61.14	45.40	11.77	10.40	0.77	0.45	15.29	23.11	6.09	6.26	37.00	29.67	24.00	32.00
Muscatel	72.55	138.50	36.20	48.75	10.87	14.87	0.80	0.28	13.59	53.11	6.35	6.77	28.33	36.33	25.00	32.00
Nudosa	171.87	173.25	56.46	43.12	10.60	9.63	0.42	1.01	25.24	9.54	6.55	5.38	32.67	53.00	30.00	44.33
Ofer	118.87	136.69	57.53	48.88	11.79	12.40	0.38	0.44	31.02	28.18	6.30	5.91	41.67	41.33	33.67	33.67
Postmasburg	137.90	137.40	53.01	49.03	12.93	13.33	0.56	0.45	23.08	29.62	6.34	5.88	30.00	30.00	26.67	26.67
Robusta	136.13	186.04	45.27	45.84	10.60	8.43	1.47	0.27	7.21	31.22	4.30	6.28	36.67	23.33	16.67	26.00
Robusta Castillo	94.44	118.66	58.44	55.13	10.73	13.70	1.40	0.48	7.66	28.54	5.55	6.77	18.67	19.33	26.33	13.67
Roedtan	95.05	108.78	57.25	50.90	9.40	11.83	1.12	0.34	8.40	34.79	5.32	5.81	36.00	37.67	28.00	25.00
Roly Poly	143.50	97.75	70.51	38.18	11.13	11.93	0.39	0.34	28.54	35.09	6.03	5.46	31.00	24.67	26.33	29.00
Rossa	108.03	109.72	59.14	56.28	10.73	11.87	0.92	0.37	11.66	32.08	5.33	6.48	37.00	35.33	26.33	31.33
Santa Rossa	124.06	142.55	61.40	59.85	12.33	12.57	0.77	0.21	16.01	59.86	5.42	6.31	42.67	42.33	30.67	31.67
Schagen	123.21	131.16	58.40	53.12	13.53	12.20	0.66	0.43	20.50	28.37	5.33	6.67	45.67	45.67	28.67	28.67
Sicilian Ind Fig	101.32	101.32	58.47	58.47	11.90	11.90	0.60	0.50	19.83	19.83	6.13	6.13	40.33	40.33	31.33	31.33
Tormentosa	140.56	119.43	59.57	53.44	11.90	13.13	0.55	0.45	21.64	29.18	5.61	5.55	24.67	48.00	20.33	34.00
Turpin	109.84	121.51	59.45	55.06	12.23	14.37	0.53	0.57	23.08	25.21	5.66	5.98	47.00	37.67	30.67	23.67
Van As	105.09	129.10	61.84	52.48	13.30	13.23	0.45	0.18	29.56	73.50	5.87	5.81	30.33	38.67	23.00	24.00
Vryheid	121.43	125.65	50.57	52.19	12.73	14.73	0.42	0.22	30.31	66.95	6.35	6.71	33.33	51.33	30.33	40.33
Zastron	77.59	107.35	52.63	48.12	12.47	13.33	0.37	0.28	33.70	47.61	6.39	6.88	43.67	48.33	27.67	21.00
Average	110.64	124.32	52.66	52.47	12.07	12.49	0.61	0.48	19.79	26.02	5.92	6.33	35.67	39.25	27.29	28.06
Significance (p)	p < 0.001		p < 0.001		p < 0.001		p < 0.001		p < 0.001		p < 0.001		p < 0.001		p < 0.001	
MSE	282.14		25.55		0.66		0.03		59.57		0.06		3.17		1.66	
LSD (0.05)	27.13		8.16		1.31		0.28		12.47		0.41		2.88		2.08	
CV	22.35		15.49		11.88		67.50		50.24		10.44		21.21		20.53	

4.1.3 Influence of cultivar (genotype) on fruit quality

4.1.3.1 Fruit mass

The cactus pear fruit is oval shaped with an average weight of 100 - 200 g (Cantwell, 1995). Fruit mass or size is a very important factor determining fruit quality, to give the best value for money to both the producer and the consumer. Fruit size is a function of cell number, volume and density (Scorza *et al.*, 1991) Cactus pear fruit mass is affected by the cladode load (Wessels, 1988; Brutsch and Zimmerman, 1993; Inglese *et al.,* 1995), water availability (Barbera, 1984), ripening time (Nerd and Mizrahi, 1993; Barbera, 1995), environment (Mashope, 2007) and number of seeds (Barbera *et al.,* 1994), and is genetically controlled (Felker *et al.*, 2005). Certain varieties naturally produce larger fruit regardless of cladode load, time of bud emergence and it is therefore concluded that fruit mass is genetically controlled (Mashope, 2007). Fruit with viable seeds are best for export (Barbera, *et al.*, 1994). The export fruit mass in South-Africa must exceed 120 g (Brütsch and Zimmerman, 1993; Inglese *et al.*, 1995), but Potgieter and Mkhari (2002) stated that the mass of cactus pears should be greater than 140 g for export potential. Furthermore, he also recommended that the cactus fruit mass should be greater than 100 g for small mass, greater than 120 g for medium mass, greater than 145 g for large mass and greater than 180 g for extra large mass, for fruit production potential in South Africa. The range for commercial cultivars in Mexico is between 67 g and 216 g (Saenz, 2000).

Statistically significant differences between the cultivars Nudosa and Roly Poly; Nudosa and the rest of the cultivars for season 2007 and Roly Poly together with Tormentosa regarding fruit mass and the rest of the cultivars for season 2007 were observed (Table 4.2). Nudosa (171.87 g), Roly Poly (143.50 g) and Tormentosa (140.56 g) produced the heaviest fruit during 2007, while Corfu (70.42 g) and Muscatel (72.55 g) produced fruit with the lowest mass (Table 4.2). In 2008, the varieties with the highest fruit mass were Robusta (186.04 g), Nudosa (173.25 g) and Santa Rossa (142.55 g). This cultivars also statistically significant differed from the rest of the cultivars for season 2008. It was observed that Corfu (73.35 g) and Fresno (91.11 g) had the lowest fruit mass during 2008. The average fruit mass for Nudosa, Roly Poly and Tormentosa in 2007, as well as Robusta, Nudosa and Santa Rossa in 2008, is higher than the recommended fruit mass for export potential of 140 g.

These results are in accordance with results reported by Mashope (2007) who studied the quality parameters on cactus pear cultivars of season 2000 and 2001 in Limpopo. She found that the cultivars with the highest fruit mass was Nudosa with a fruit mass of 227.10 g , Tormentosa with a mass of 185.11 g and X28 (179.17 g). Therefore it was concluded that certain varieties naturally produce larger fruit and that fruit mass must be genetically controlled.

4.1.3.2 Percentage pulp

The pulp is edible and sweet, and consists of 84-90 % water and 10-15 % reducing sugars (Piga, 2004). Cantwell (1995) stated that the juicy pulp contributes 60-70 % of the total fruit weight. This range is due to the differences in cultural practices, fruit load, climate and harvesting season (Barbera *et al.,* 1994). The pulp % should not be below 55-60 % for export markets (Inglese *et al.,* 1995). Potgieter (2000) and Potgieter and Mkhari (2002) suggested that the pulp for production potential should be more than 50 % in South Africa.

Statistically significant differences between the cultivars regarding pulp % were observed (Table 4.2). The highest percentage of pulp in 2007 was observed in fruit from Roly Poly (70.51 %), Algerian (66.98 %), while fruit from Malta (61.52 %), Morado (61.14 %), Santa Rossa (61.4 %) and Van As had almost the same % of pulp (Table 4.2). The varieties that produced fruit with the lowest pulp percentage in 2007, was Muscatel (36.2 %) and Corfu (43.42 %). Roly Poly statistically differed from the rest of the cultivars for season 2007.

In 2008, the highest % pulp was observed in fruit from Santa Rossa (59.85 %), Rossa (56.28 %) and Robusta X Castillo (55.13 %). The lowest pulp % values were observed in Corfu (36.06 %), Roly Poly (38.18 %) and Amersfoort (42.14 %). The varieties that produced fruit with the highest % pulp in 2007 and 2008, had % pulp values higher than the 55 % required for export potential. Muscatel (2007), Corfu (2008) and Roly Poly (2008) had values lower than 40 %.

Mashope (2007) studied the quality parameters of cactus pear cultivars for season 2000 and 2001 in Limpopo and found that the cultivars with the highest pulp % were Malta with a pulp % of 60.61 %, Gymno Carpo with a pulp % of 59.62 % and Meyers with a pulp % of 59.55 %. Those with a low % pulp were Skinners Court (54.58 %), Ficus-indice (52.46 %) and Nepgen (51.26 %). This variation, between the cultivars grown in Limpopo Province and the cultivars from the present study grown in the Free State, may be due to the different agro-ecological environments.

4.1.3.3 Total soluble solids

Total soluble solids (TSS) are an indication of total sugar content, measured in °Brix. In the last two weeks of flesh development, sugars (mostly glucose and fructose) build up and the optimum values at harvest time range from 13-15 % (Slawomir, 2002). Gregory *et al.* (1993) found that *Opuntia* clones, for consumers in Africa and Mexico, ranged in sugar content from 11 % to 14.4 %. Fruit quality is mostly determined by the sugar content for consumers (Inglese et al., 1995). The fruit lose over 60 % of water by transpiration, which causes an increase in the soluble solids' levels in the cell vacuoles and a decrease in the acidity levels (De la Barrera and Nobel, 2004). Total soluble solids content in cactus pears should not be below 13 °Brix, to meet the minimum criteria for production potential in South Africa (Potgieter and Mkhari, 2002). A fertilizer application can improve the sugar content of the fruit (Potgieter and Mkhari, 2002).

According to Table 4.2, statistically significant differences between the cultivars regarding total soluble solids were observed. The cultivars with the highest TSS contents in 2007 were Messina (14.07 °Bx), Fresno (13.8 °Bx), Van As (13.3 °Bx) and Schagen (13.53 °Bx), while those with the lowest TSS contents were Roedtan (9.4 °Bx) and Algerian (10.33 °Bx). In 2008, the highest TSS was observed in Muscatel (14.87 °Bx), Vryheid (14.73 °Bx) and Turpin (14.37 ° Bx). The cultivars with the lowest °Bx values in 2008 were Robusta (8.43 ° Bx), Nudosa (9.63 °Bx) and Corfu (9.87 °Bx). All the cultivars with the highest TSS contents observed for 2007 and 2008 had values high enough for production potential in South Africa.

A large variation in the TSS content from the present study was observed for cultivars grown in the Limpopo province (Mashope, 2007), where cultivars with the highest TSS value were Ofer (14.63 °Bx), Sicilian Indian Fig (14.56 °Bx) and Skinners Court (14.47 °Bx). Varieties that had the lowest TSS values were Nudosa (11.67 °Bx), Gymno Carpo (12.23 °Bx) and Cross X (12.37 °Bx). A possible explanation for this variation may again be the difference in agro-ecological conditions between the two regions.

4.1.3.4 Pulp TA

Opuntia cultivars have very low acidity values (expressed as 0.05 % - 0.18 % citric acid). Citric acid is the major organic acid in cactus pear fruit, followed by malic acid, quinic, shikimic and oxalic acids, which are also typical. Isocitric, fumaric, glycolic and succinic acids are found in trace amounts (Moßhammer *et al.*, 2006). Piga (2004) indicated that the average % TA value is between 0.05 and 0.18 %. A higher TA value contributes to a preferred sensorial attribute (Corales-Garcia *et al.*, 2006).

Statistically significant differences between the cultivars regarding pulp TA were observed (Table 4.2). The highest values in pulp TA, observed in 2007, were for

Robusta (1.47 %), Robusta X Castillo (1.4 %) and Roedtan (1.12 %), while the lowest values were Blue Motto (0.25 %), Corfu (0.32 %) and American Giant (0.31 %). In 2008, the highest pulp TA values were observed in Corfu (0.24 %) and Nudosa (1.01 %), with the lowest values for Van As (0.18 %), Santa Rossa (0.21 %) and Vryheid (0.22 %). The values reported in this study are much higher than those reported by Piga (2004) (0.05 - 0.18 %). De Wit *et al.* (2010) also found that % TA values, obtained from cactus pear cultivars in Waterkloof, Cradock and Oudtshoorn in South Africca were higher than the reported values of 0.05 % - 0.18 % reported for cultivars from Chile (Saenz, 2000) . This finding confirmed that the environment plays an important role in the % TA in cactus pear fruit from different cultivars. Potgieter and Mkhari (2002) stated that there are a huge range of agro-ecological regions in South Africa. An incomplete understanding of their effect and the performance of different cactus pear varieties necessitate cultivar evaluation in each region. Studies done to determine the fruit quality of cactus pear fruit, indicating the TA values of the fruit, are scarce in South Africa. Studies were mostly done in other countries.

4.1.3.5 Ratio between Titratable Acid and Total Soluble Acid

According to Essa and Salama (2002), the TSS/acid ratio is the major analytical measurement for quality in prickly pear juice and are correlated with sweetness, but not so closely with flavour.

According to Table 4.2, highly statistically significant differences occurred between cultivars Van As (73.5 g/100g) and the rest of the cultivars of season 2008 and Vryheid (66.95 g/100g) and the rest of the cultivars of 2008. Cultivars Santa Rossa (59.86 g/100g) and Muscatel (53.11 g/100g) also had statistically significant different values compared with cultivars of season 2008. The cultivars with the highest TSS/acid for season 2008 were Van As (73.5 g/100g), Vryheid (66.95 g/100g) and Santa Rossa (59.86 g/100g). Cultivars Nudosa (9.54 g/100g), Messina (17.86 g/100g) and Sicillian Indian Fig (19.83 g/100g) had the lowest TSS/acid value for season 2008. Season 2007 had a lower average TSS/acid value (19.79 g/100g) compared with season 2008 (26.02 g/100g). Cultivars Blue Motto (53.6 g/100g) and Corfu (40.63 g/100g) had statistically significant difference compared with the cultivars of season 2007 and these two cultivars had also the highest TSS/acid value for season 2007. The cultivars with the lowest TSS/acid value for season 2007 were Robusta (7.21 g/100g), Robusta ×Castillo (7.66 g/100g) and Roedtan (8.4 g/100g). These results showed that there were a positive correlation between the TSS/acid values and the TSS values (Cultivar Nudosa had the lowest TSS/acid value and TSS value for season 2008 and cultivar Roedtan had the lowest TSS/acid and TSS value for season 2007; Muscatel had the highest TSS/acid and TSS value for season 2008). There were a negative correlation between the TSS/acid values and the TA values (cultivar Nudosa had the highest TA value and the lowest TSS/acid value for season 2008; cultivars Van As, Santa Rossa and Vryheid had the lowest TA values and the highest TSS/acid values for season 2008; cultivar Roedtan had the highest TA value and the lowest TSS/acid value for season 2007; cultivars Blue Motto and Corfu the lowest TA values and the highest TSS/acid values for season 2007).

4.1.3.6 Pulp pH

According to Saenz and Sepulvuda (2001), cactus pear fruit has a low acidity (pH ≥ 4.5). The pH values of green pulp vary between 5.3 - 7.1 and the values of purple pulp between 5.9 - 6.2. Fruit products must be acidified with citric acid, which is the main organic acid in the fruit, to prevent spoilage (Stintzing *et al*., 2001). The peel is reported to be more acidic than the pulp, which has a very low acidity of 0.05 - 0.18% citric acid equivalents (Moßhammer *et al*., 2006). The mean pH values reported for Mexico ranged from 6.4 to 7.1. It was also found that varieties of cactus pear fruit with lower pH (< 5) generally had lower sugar contents; pH increased with sugar content as the fruit became more mature (Parish and Felker, 1997).

According to Table 4.2, statistically significant differences between the cultivars regarding pulp pH were observed. The highest pulp pH values in 2007 were observed in Blue Motto (7.18), Direkteur (7.00) and Nudosa (6.55). The cultivars with the lowest pulp pH values for the same season were Robusta (4.3), Meyers (5.12) and Amersfoort (5.21). In 2008, the cultivars with the highest pH values were Corfu (7.55), Direkteur (7.13) and Zastron (6.88). The cultivars with the lowest pulp pH values in 2008 were Cross X (4.97) and Nudosa (5.38). The average pH pulp value of cultivars for 2007 was 5.92 and the value for 2008 was 6.33. These findings are in accordance with the values reported in literature (Saenz and Sepulveda, 2001).

4.1.3.7 Pulp glucose content

Sugar is the sole metabolite for the brain and nerve cells, and is present in the cactus pear as free sugar, directly absorbable by the body (Saenz, 2000). Parish and Felker (1997) stated that great variability between accessions in maturity relationships are determined through sugar content. The relationship between fruit pH and sugar content are a useful characteristic in predicting fruit maturity as judged by sugar content (Parish and Felker, 1997)

Table 4.2 indicated that statistically significant differences between the cultivars regarding pulp glucose content were observed. Varieties that had the highest pulp glucose content (in g/100g) in 2007, was Turpin (47.00), R1260 (48.00) and Schagen (45.67), while the lowest values were observed for Robusta X Castillo (18.67), R1259 (25.33) and Tormentosa (24.67). In 2008, the cultivars with the highest pulp glucose values were Nudosa (53.00), Vryheid (51.33) and R1259 (51.00). The lowest values were observed for Robusta X Castillo (19.33), Robusta (23.33) and Roly Poly (24.67). These values are lower than the reported 6.0 – 6.4 % (Gurrieri *et al.,* 2000).

4.1.3.8 Pulp fructose content

The total sugar content of the cactus pear varies from 6 % to 14 % . According to Duru and Turker (2005), sucrose is found in a very small amount, glucose composes 53 % of total sugar content and the remainder (47 %) is fructose. The low level of sucrose is related to invertase activity (Duru and Turker, 2005). Fructose is also easily absorbable and sweeter than both glucose and sucrose (Saenz, 2000).

According to Table 4.2, statistically significant differences between the cultivars regarding pulp percentage were observed. Cultivars with the highest amount of pulp fructose (in g/100g) in 2007 were Messina (40.67), Ofer (33.67), Gymno Carpo (32.33) and Sicilian Indian Fig (31.33), while the lowest values were observed in Robusta (16.67) and Corfu (18.67). In 2008, the cultivars with the highest concentration pulp fructose were Nudosa (44.33 mg/g), Vryheid (40.33 mg/g) and Algerian (35.33 mg/g). The lowest values (in mg/g) were observed for Robusta X Castillo (13.67), Fresno (18.67) and Messina (19.33). The pulp fructose values are lower than the reported 5.4 – 6.0 % (Gurrieri *et al.,* 2000).

4.1.4 Influence of season on fruit quality

The weather conditions of the two seasons are represented in Table 4.4. The orchard under study was maintained under dry-land conditions, with rain as the only source of water.

According to Table 4.4, temperature conditions, namely the average temperature and the maximum and minimum temperatures, did not differ significantly between the two growth seasons, however, there was a large difference observed in the rainfall measured between the two seasons. In 2008, rainfall was 91.1 ml more than that measured in 2007. The higher rainfall in 2008 had significant influences on some of the quality parameters tested, like fruit mass, pulp %, TSS, pulp TA, pulp pH, pulp glucose and pulp fructose (Tables 4.1 and 4.2).

Table 4.3 Weather conditions for seasons 2007 and 2008 (Fouche, 2009).

	Growth seasons					
Weather Conditions	January 2007	February 2007	**Average**	January 2008	February 2008	**Average**
Average temperature (degree Celsius)	24	24.3	**24.15**	22.9	20.5	**21.7**
Maximum temperature (degree Celsius)	32.3	32.9	**32.6**	35.8	32.5	**34.15**
Minimum Temperature (degree Celsius)	7.5	6	**6.75**	11.3	9	**10.15**
Rainfall (millimeter)	15.5	8.4	**11.95**	92.5	113.6	**103.05**

4.1.4.1 Fruit mass:

Rainfall was significantly higher in 2008 (as indicated in Table 4.4). Higher rainfall had a significant influence on fruit mass: the average fruit mass of 2008 was 13.68 g more than in 2007. Table 4.2 indicated that statistically significant differences between the cultivars regarding fruit mass were observed between season 2007 and 2008. The average value for the fruit mass of 2007 was 110.64 g and for 2008 was 124.32 g. Mokoboki *et al.* (2009) found that the decrease in fruit mass over two seasons might be due to low rainfall and temperature in the second season. Felker *et al.* (2005), compared the fruit parameters of 12 *Opuntia* clones grown in Argentina and the United States. He found that the rainfall in the last two months prior to fruit maturation, was 110 and 290 mm in Argentina versus 86 and 13 mm in the U.S.A. The fresh weight of fruit and % pulp were significantly higher in Argentina, with the higher rainfall at the end of the fruit maturation period. Mashope (2007) found that there was a decrease in fruit mass during a lower rainfall in the second season, when two seasons 2000 and 2001 were compared. Higher rainfall caused an increase in fruit size and a higher % pulp content (Mashope, 2007). These results were supported by findings of Karababa *et al.*, (2004) and Bekir (2006), who reported that size and weight of fruit was influenced by locality, season and environment. These findings explain the increase of fruit mass in 2008.

4.1.4.2 Percentage pulp :

Table 4.2 indicated that statistically significant differences between the cultivars regarding pulp % were observed between season 2007 and 2008. The average pulp % is also influenced by the rainfall pattern during the growth season: the average pulp % for cultivars 2007 was 55.99 % and the value for 2008 was 49.28 %. These results, indicated by Table 4.2, showed that the peel of the fruit determined the higher fruit mass in 2008. These values also showed that the peel % was influenced by the rainfall. It was reported that in periods of higher rainfall during the growth season, fruit tend to store water in the peel, thus the increased % of peel and the decreased % of pulp, as was observed by Mokoboki *et al.*, (2009).

4.1.4.3 TSS:

Statistically significant differences between the cultivars regarding TSS were observed between season 2007 and 2008 (Table 4.2). The average °Brix value of cultivars for 2007 was 12.07 and 12.49 for 2008. These findings can be explained by the relatively small temperature difference in season 2007 and 2008 (only 2.35 °C difference between season 2007 and 2008) (Fouche, 2009). Table 4.2 also indicated that rainfall did not influence the °Brix value, because of the small difference in average °Brix value for season 2007 and 2008. Mashope (2007) found that TSS increased from 12.68 to 14.36 from season 2000 to 2001, due to lower rainfall in 2001. Cactus pear fruit grown in dry areas was sweeter than those grown in humid areas (Modragon-Jacobo, 2001). Total soluble solids concentration was positively correlated with cladode Mg concentration. Furthermore, there was a significant negative correlation between TSS and cladode P and Zn concentrations (Mashope, 2007). As mentioned earlier, Felker *et al.* (2005) compared the fruit parameters of 12 *Opuntia* clones grown in Argentina and the United States. He found that the rainfall in the last two months prior to fruit maturation was 110 and 290 mm in Argentina and 86 and 13 mm in the U.S.A. The absolute fruit sugar concentrations and the ranking of the varieties for fruit sugar was virtually the same in both climates, indicating the stability for fruit sugar.

4.1.4.4 Pulp TA:

Statistically significant differences between the cultivars regarding pulp TA were observed between season 2007 and 2008 (Table 4.2). The average % pulp TA content for 2007 was 6.08 and the content for 2008 was 4.8 (Table 4.2). Rainfall in 2007 was significantly lower than rainfall in 2008 (Table 4.4). A possible explanation may be that the higher rainfall in 2008, which produced larger and heavier fruit, might have caused the sugars and acids to be more diluted.

4.1.4.5 Pulp pH:

Statistically significant differences between the cultivars regarding pulp pH were observed between season 2007 and 2008 (Table 4.2). The average pH pulp value of cultivars for 2007 was 5.92 and the value for 2008 was 6.33 (Table 4.2). These results indicated a difference in pH of 0.39. As a result, the cactus pear cultivars in 2008 had a higher °Brix value, and a higher glucose and fructose content, with a lower TA value. Gregory *et al.* (1993) found that cultivars with low pH values (less than five), had also the low sugar values and that there is a significant relationship between sugar content, pH and acidity. It was reported by

Duru and Turker (2005), that, as TSS and total sugar increase, the total percentage TA decrease.

4.1.4.6 Pulp glucose values:

Statistically significant differences between the cultivars regarding pulp glucose values were observed between season 2007 and 2008 (Table 4.2). The average pulp glucose content for 2007 was 35.67 mg/g and the content for 2008 was 39.25 mg/g (Table 4.2). These results, together with the TSS values are an exception, since it would be expected that the glucose values should be lower in 2008, due to the higher rainfall.

4.1.4.7 Pulp fructose values:

Statistically significant differences between the cultivars regarding pulp fructose values were observed between season 2007 and 2008 (Table 4.2). The average fructose content for 2007 was 27.29 mg/g and the average content for 2008 was 28.06 mg/g (Table 4.2). These results showed that the average fructose content was stable when comparing seasons 2007 and 2008. These results also followed the same trend as was observed for the TSS content and glucose content.

4.1.5 Influence of interaction between the season and the cultivars.

The influence of the interaction between the cultivar and the season (cultivar X season) were significant on all of the parameters tested, especially the parameters important for eating quality. Highly significant differences ($p < 0,001$) were observed for fruit mass, pulp %, TSS, pulp pH, pulp TA, pulp glucose content and pulp fructose content. These significant differences are an indication of the influence of different season conditions on fruit quality, as was discussed above, thus an indication that cultivars will react differently in varying weather conditions, such as rainfall and temperature. Varieties that were recommended for commercial cultivation in the Mokopane district of the Limpopo Province in South Africa were Gymno Carpo, Malta, Algerian, Morado, Meyers and Roedtan (Mashope, 2007).

The cultivars with the highest/best values regarding physical/chemical parameters are highlighted in Table 4.6, in an attempt to identify the cultivars which performed the best regarding eating-quality, during the two seasons 2007 and 2008 at Bloemfontein.

Table 4.4. Cultivars with best values for physical/chemical quality parameters.

Parameter	Cultivar 2007	Value	Cultivar 2008	Value
Fruit mass (g)	**Nudosa**	171.87	Robusta	186.04
Pulp %	Roly Poly	70.51	Santa Rossa	59.85
TSS (°Brix)	**Messina**	14.07	Muscatel	14.87
Pulp Ph	Blue Motto	7.18	Corfu	7.55
Pulp TA (%) (lowest)	Blue Motto	2.54	Van As	1.82
Pulp glucose (mg/ml)	Turpin	47.00	**Nudosa**	53.00
Pulp fructose (mg/ml)	**Messina**	40.67	**Nudosa**	44.33

According to Table 4.4, Nudosa performed the best regarding fruit mass, pulp glucose and pulp fructose. Messina performed the best regarding TSS and pulp fructose content, while Blue Motto had the best acidity levels (pH and TA). Cultivars from the Free State Province with best values for physical/chemical quality parameters for season 2007 and 2008 differ from the Limpopo cultivars with the best physical/chemical quality parameters stated by Mashope (2007). These results suggest and conclude that season, as well as environment, had an influence on fruit quality.

4.2 Free Choice Profiling

Amongst the ten panelists, FCP generated 21 descriptors for the attribute taste (Table 4.7). The four basic tastes namely sweet, sour, bitter and salty were included, as well as various vegetable and fruit flavours. Examination of the descriptors indicated that consumers used words such as "prickly pear" or "typical prickly pear aroma" to describe the same attribute perception. A possible reason for this, is that the product was unusual for the participants, making it difficult to describe the product. Furthermore, no guarantee exists that all the assessors used the descriptors in the same way or attached the same importance to them in the discrimination amongst the samples.

The lack of panel training was also reflected by the use of elementary words to describe the assessors' perception of the juice. According to Deliza (2004), training of assessors would improve reproducibility of results and lead to the use of more specific sensory terms. Precisely defined vocabularies are, however, not needed for describing of products in order to reveal relationships and differences between samples (Deliza, 2004). Descriptors like "nutty", "beetroot", "metallic", "raw potato", "pungent", "melon" and "vegetable" were used by only one assessor, making them hard to interpret. Most of the assessors used descriptors like "sweet", "prickly pear", "pear" and "fruity".

Table 4.5 List of the idiosyncratic descriptors developed by ten semi-naïve panelists to describe the taste attribute of 33 cactus pear cultivars, as well as their frequency of use for seasons 2007 and 2008.

Descriptor	Frequency of use for season 2007	Frequency of use for season 2008
1.Sweet	390	390
2.Sour	209	202
3.Bitter	188	202
4.Fruity	142	248
5.Cucumber	114	79
6.Prickly pear	97	171
7.Salty	63	71
8.Banana	70	90
9.Grassy	50	52
10.Watery	43	57
11.Watermelon	25	85
12.Pear	19	83
13.Rubber/plastic	20	34
14.Astringent	15	92
15.Vegetable	14	25
16.Melon	9	47
17.Pungent	9	11
18.Raw potato	8	12
19.Metallic	6	11
20.Beetroot	7	8
21.Kiwi fruit	4	27

Table 4.6 indicated which cultivar had the most frequently-used attribute for seasons 2007 and 2008. The results were determined by the score for each attribute given, by using the hedonic scale by each panelist for each cultivar tasted.

Table 4.6 Cultivars which correlated with the most frequently-used attributes.

Attribute	Cultivar 2007	Cultivar 2008
Sweet	Fresno	Nudosa
Sour	Robusta	Sharsheret
Bitter	Robusta	Robusta
Fruity	Sharsheret	Roly Poly
Prickly pear	Malta and Amersfoot	Ficus Indice

Table 4.6 shows the descriptor which correlated most likely with a specific cultivar, according to the panelists. The five most frequently-used attributes were sweet, sour, bitter, fruity and prickly pear, with the corresponding cultivars for 2007 being Fresno, Robusta, Sharsheret, Malta and Amersfoort. For season 2008, the corresponding cultivars changed to Nudosa, Sharsheret, Robusta, Roly Poly and Ficus Indice, respectively.

The PANOVA summary of the efficiency of each GPA transformation, in terms of reduction of the total variability, is shown in Table 4.7. The scaling ($p \leq 0.0001$), rotation ($p \leq 0.0001$) and translation ($p \leq 0.0001$) transformations were significant. These transformations, performed by the GPA, corrected the differences between the individual assesor's judgements (Arnold and Williams, 1986) as follows: the rotation step corrected the differences in terms used (the interpretation effect); the translation step corrected the level effect; and the isotropic scaling step corrected the range effect.

Table 4.7 PANOVA table for the taste attribute of 33 cactus pear cultivars for season 2007 and 2008.

Source	DF	Sum of squares	Mean squares	F	Pr >F
Scaling	9	1059.8	117.75	158.7	< 0.0001
Rotation	2079	10733.18	5.16	6.96	< 0.0001
Translation	198	11172.24	56.42	76.05	< 0.0001

According to the eigenvalues (% by which variation is explained in a plot), 75.34 % of the variation was explained by dimension 1, and 7.44 % of the variation by dimension 2 (Table 4.8). The first two factors allowed a representation of 82.78 % of the initial variability of the data. Figure 4.1 shows the importance of every factor on its own, as well as the accumulating values. Although 82.78 % is a fair result, the plots which follow should be interpreted with care, as some information might be hidden in the next factors. For the purpose of this study, only dimensions 1 and 2 will be discussed.

Table 4.8 Eigen values showing the variability corresponding to each axis for the taste attribute of 33 cactus pear cultivars for season 2007 and 2008.

	F1	F2
Eigen value	15.493	1.530
Variability (%)	75.335	7.442
Cumulative %	75.335	82.777

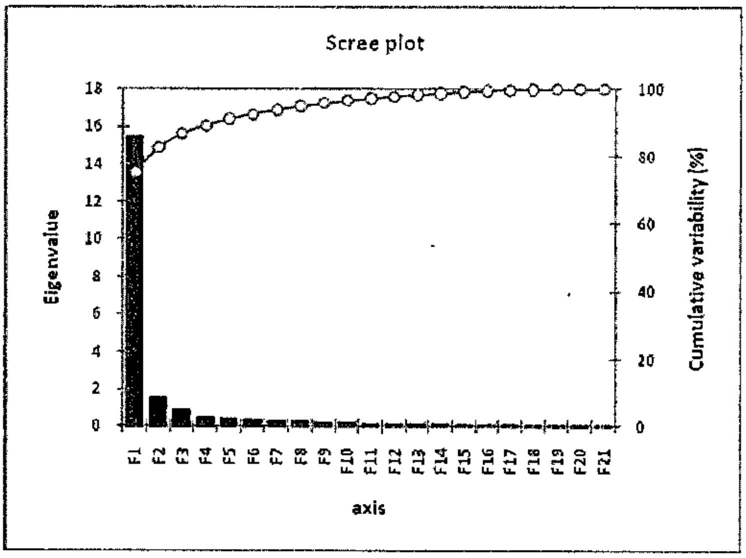

Figure 4.1 Scree plot of eigen values of FCP for the taste attribute done on 33 cultivars of cactus pears for season 2007 and 2008.

Table 4.9 lists the descriptors which had correlations with the two dimensions of average space generated by GPA. The first principal component was positively correlated with "cucumber", the only descriptor to coincide with a value higher than 0.5. The descriptors "sweet", "bitter", "fruity", "astringent", "watermelon", "prickly pear", "melon", "watery" and "pear" were negatively correlated to the first component (values ≥ 0.5). No descriptors had values ≥ 0.5 and were positively correlated with the second dimension. "Bitter", "pungent", "raw potato", "beetroot" and "vegetable" were negatively correlated with the second dimension. The higher % of the variation being explained by the first dimension (75.34 %) meant that the taste attributes that were closer to dimension 1 (horizontal) were major determinants of variation in the cactus pear cultivars. All the cultivars of season 2007 and 2008 tasted sweet.

Table 4.9 Descriptors having correlations with the two dimensions of average space generated by GPA, for the taste attribute of 33 cultivars of cactus pears for season 2007 and 2008.

Dimension	Correlation	Descriptors with values ≥ 0.5
1	+	Cucumber
	-	Sweet, bitter, fruity, astringent, watermelon, prickly pear, melon, watery, pear
2	+	
	-	Bitter, pungent, raw potato, beetroot, vegetable

Figure 4.2 is the GPA biplot of the FCP of 33 cultivars for the taste attribute, of 2007 (A) and 2008 (B). From this biplot, it was clear that the assessors could clearly distinguish between the two seasons 2007 and 2008 (75.34 %). The 33 cultivars from season 2007 were all situated to the right side of the figure, with season 2008 to the left side. The two cultivars used mainly for animal feed, Robusta and Monterey, were placed at the bottom right side and were characterized by descriptors "sour", "pungent", "vegetable", "bitter", "beetroot" and "raw potato". Only 7.44 % of the variation was explained by dimension 2, referring to the descriptors used to describe "Robusta" and "Monterey". The assessors were not successful in distinguishing between the other descriptors.

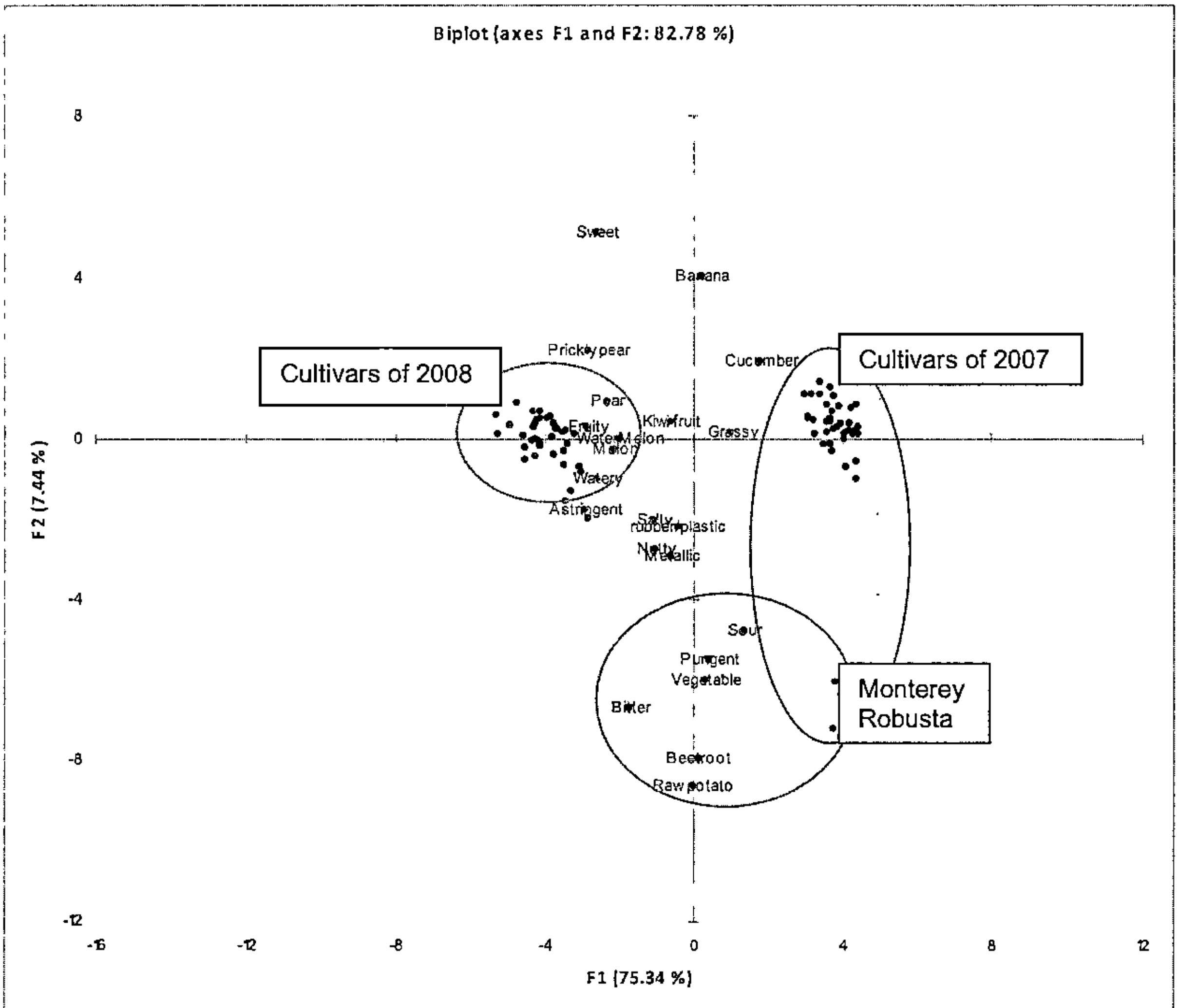

Figure 4.2 Generalized Procustes analysis biplot of FCP for descriptors of the taste attribute of 33 cultivars for seasons 2007 and 2008.

The 16 cactus pear cultivars most commonly consumed by humans in South Africa are Gymno Carpo, Sharsheret, R1251, Tormentosa, Ofer, Algerian, Berg x Mexican, Malta, Turpin, Meyers, Nudosa, Zastron, Skinners Court, Van As, Monterey and Roedtan (Fouche, 2009). The PANOVA for the taste attribute of these 16 cactus pear cultivars for season 2007 and 2008 seasons is presented in Table 4.10. All transformations, scaling, rotation and translation were significant.

Table 4.10 PANOVA table for the taste attribute of the 16 cactus pear cultivars most commonly consumed by humans in South Africa for season 2007 and 2008.

Source	DF	Sum of squares	Mean squares	F	Pr > F
Scaling	9	396.055	44.006	62.627	< 0.0001
Rotation	2079	4661.272	2.242	3.191	≤ 0.0001
Translation	198	4878.185	24.637	35.063	< 0.0001

The GPA analysis biplot of FCP for the taste attribute of the 16 cactus pear cultivars most commonly consumed by humans in South Africa for season 2007 (A) and 2008 (B), is found in Figure 4.3. Seventy seven point seven two percent of the variation is explained by the first dimension and 6.26 % by dimension 2, giving a representation of 83.98 % of the initial variability of the data. For clearer distinction, samples from season 2007 were identified with the letter A and samples from season 2008, with the letter B.

Table 4.11 Correlation between dimensions and factors for 16 cactus pear cultivars most commonly consumed by humans in South Africa for season 2007 (A) and 2008 (B).

Dimension	Correlation	Descriptors with a value ≥ 0.5
1	+	Cucumber
	-	Sweet, bitter, fruity, astringen, watermelon, prickly pear, melon, watery, pear
2	+	
	-	Bitter, pungent, raw potato, beetroot, vegetable

Again it was clear that the assessors could clearly distinguish between the two seasons (77.72 %). The 16 cultivars from season 2007 (A) were again all situated at the right side of the figure, with season 2008 (B) at the left side.

When looking at the values of the descriptors ≥ 0.5, only “cucumber” was positively correlated to dimension 1, i.e. season 2007 (A). Descriptors that were negatively correlated with dimension 1, i.e. season 2008 (B), included “sweet”, “bitter”, “fruity”, “astringent”, “watermelon”, “prickly pear”, “melon”, “watery” and “pear”. Only 6.26 % of the variation was explained by dimension 2, indicating that the assessors were not successful in distinguishing between the cultivars on the basis of the taste descriptors.

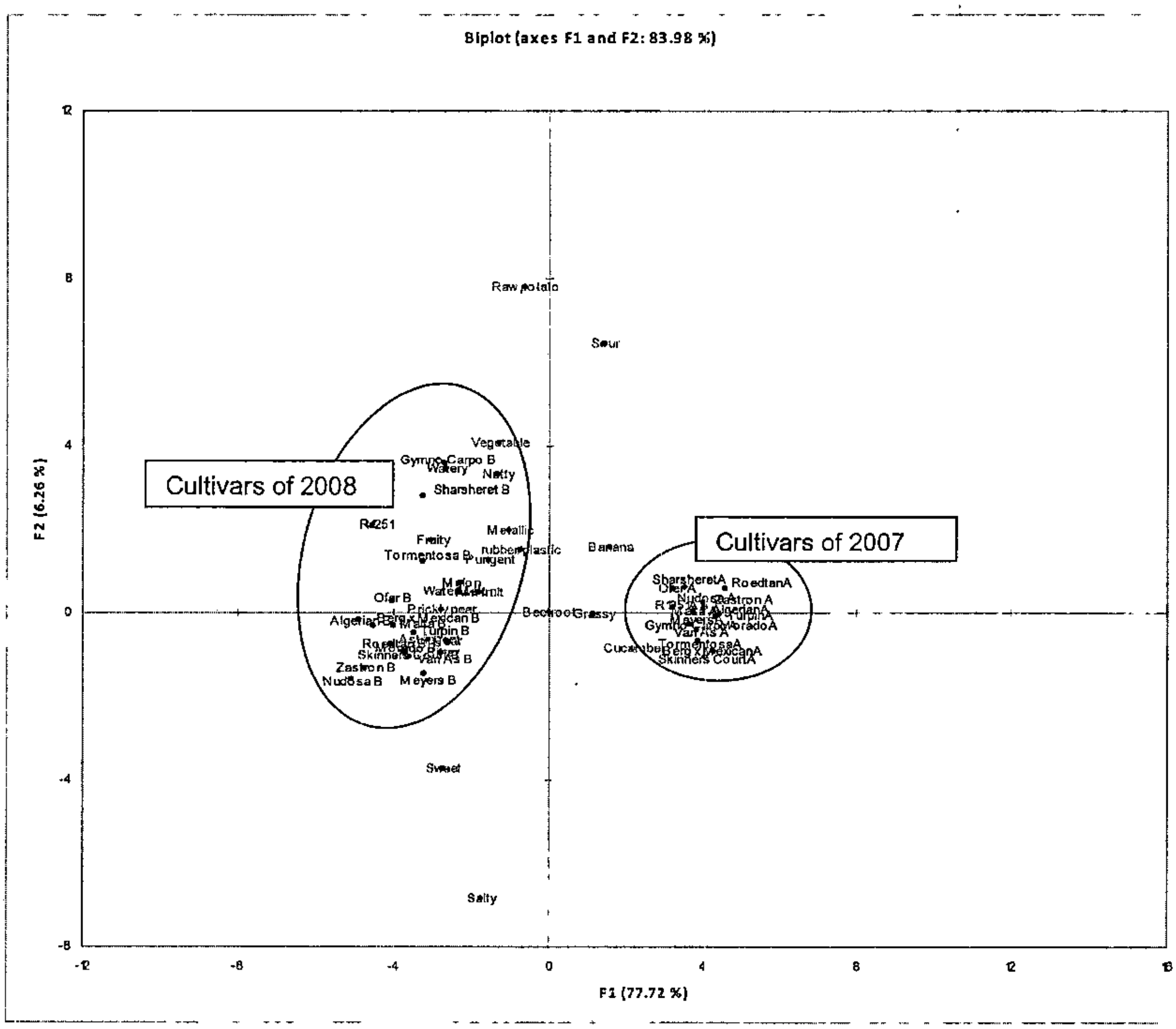

Figure 4.3 Generalized Procustes analysis biplot of FCP for the taste attribute of the 16 cactus pear cultivars most commonly consumed by humans in South Africa for season 2007 (A) and 2008 (B).

According to Fouche (2009), the top nine consumer cactus pear cultivars in South Africa are Skinners Court, Meyers, Morado, Nudosa, Malta, Van As, Algerian, Berg x Mexican and Gymno Carpo. From the PANOVA for these cultivars (Table 4.14) for seasons 2007 and 2008, it can be seen that again all transformations, even rotation, were significant.

Table 4.12 PANOVA table for the taste attribute of the top nine consumed cactus pear cultivars in South Africa for seasons 2007 and 2008.

Source	DF	Sum of squares	Mean squares	F	Pr > F
Scaling	9	261.830	29.092	27.796	< 0.0001
Rotation	2079	2795.109	1.344	1.285	< 0.0001
Translation	198	2792.843	14.105	13.477	< 0.0001

Presented in Figure 4.4 is the GPA biplot of the FCP for the taste attribute of the nine cactus pear cultivars, most commonly consumed by humans in South Africa, for season 2007 (A) and 2008 (B). In this case, 75.34 % of the variation is explained by the first dimension and 7.56 % by dimension two, adding up to a total representation of 82.89 % of the initial variability of the data. Again the capitals A and B are used to facilitate identification of the samples from seasons 2007 and 2008, respectively.

Like in the first two cases, the assessors could again clearly distinguish between the two seasons (75.34 %). The nine cultivars from 2007 (A) season were this time situated on the left side of the figure, with season 2008 (B) on the right side. When looking at the values of the descriptors ≥ 0.5 (Table 4.15), "cucumber" and "sour" were negatively correlated to dimension 1, i.e. season 2007(A). Descriptors that were positively correlated with dimension 1, i.e. season 2008 (B), included "sweet", "kiwi", "bitter", "fruity", "salty", "astringent", "watermelon", "prickly pear", "melon", "watery" and "pear" . Only 7.56 % of the variation was explained by dimension two, indicating that the assessors were again unsuccessful in distinguishing between the cultivars on the basis of the taste descriptors. The only cultivar that was slightly separated from the rest in the season 2008, was Gymno Carpo, which was being described as "watery".

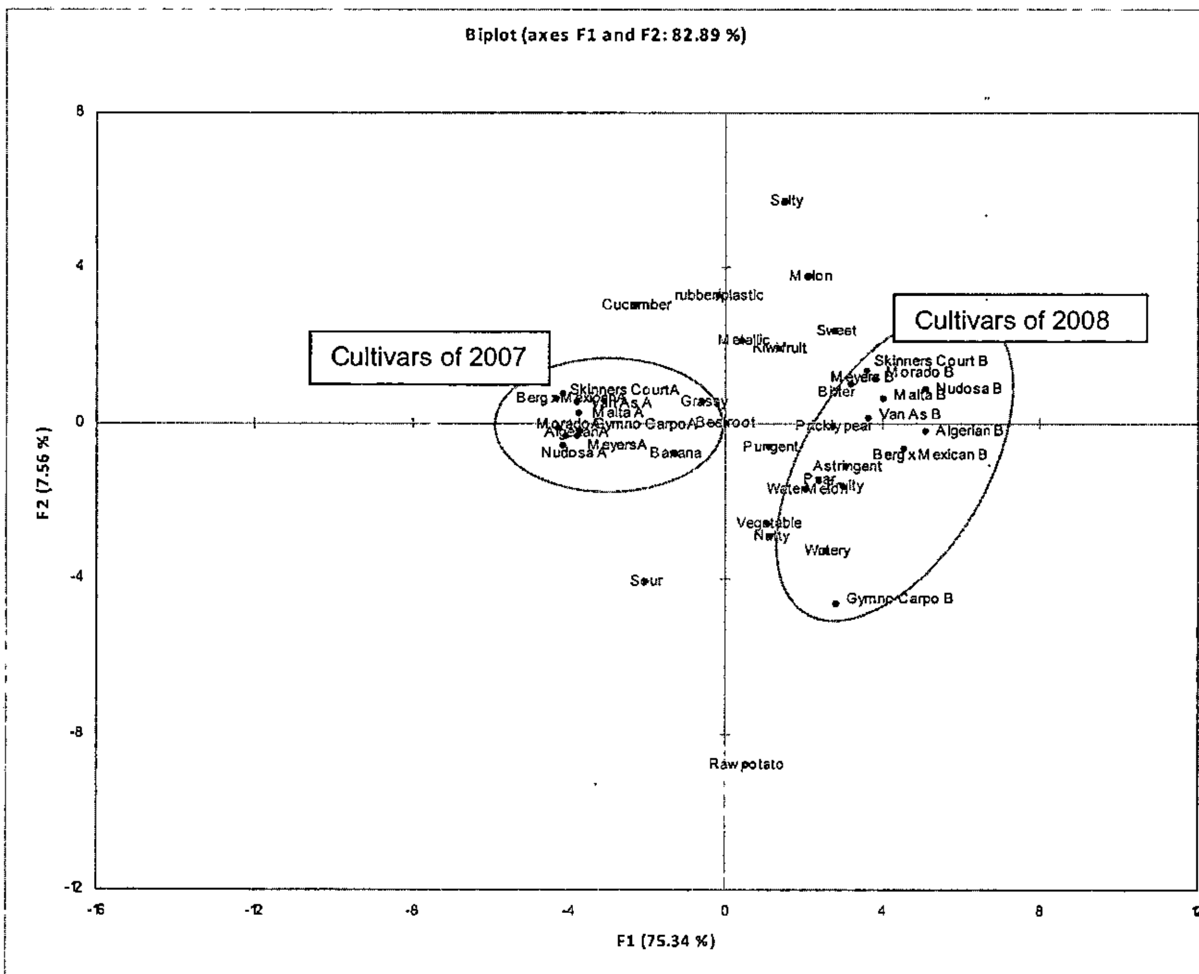

Figure 4.4 Generalized Procustes analysis biplot of FCP for the taste attribute of the top nine consumer cactus pear cultivars in South Africa for season 2007 (A) and 2008 (B).

Table 4.13 Descriptors having correlations with the two dimensions of average space generated by GPA, for the taste attribute of 9 cultivars of cactus pears for season the 2007 and 2008.

Dimension	Correlation	Descriptors with values ≥ 0.5
1	+	cucumber, sour
	-	sweet, kiwi, bitter, fruity, salty, astringent, watermelon, prickly pear, melon, watery, pear

Gonzáles - Viñas (2007) used FCP to describe the sensory characteristics of Spanish unifloral honeys. The sensory panel consisted of 12 untrained panelists without experience in sensory analysis. The panelists tasted three replicates of ten commercial honeys made from different source flower source. Gonzáles - Viñas (2007) also found it difficult to interpreted the large difference between the assessors' needs to be significant. Jordaan (2008) used FCP to investigate how ten untrained panelists described and perceived the taste of 40 cactus pear cultivars found in South Africa. A number of 22 descriptors were generated. The conclusion drawn from this study was that there was no guarantee that all the assessors used the descriptors in the same way, or indeed attached the same importance to them in discriminating amongst the samples. It was also difficult for the panelists to distinguish between the 40 cactus pear cultivars.

4.3 Pearson significance levels and correlation coefficients

Since part of the aim of the study was to investigate if a relationship existed between the physical/chemical and sensory quality, an attempt was made to correlate the physical/chemical parameters with that of the sensory attributes obtained by FCP. Pearson significance levels, as well as correlation coefficients were determined. The correlation coefficients between the physical/chemical parameters and the taste attributes are indicated in Table 4.16. The first row of each attribute explains the type of correlation, i.e. positive or negative, as well as the % of correlation.

A positive correlation means that when the levels of one parameter increases, the level of the other parameter (or attribute) will increase as well, while a negative correlation implies that when the level of one attribute increases, the level of the other parameter will decrease.

Table 4.14 Pearson significance levels and correlation coefficients between taste attributes and physical/chemical parameters

Physical/ Chemical parameters	**Sensory attributes**									
	Sweet		**Bitter**		**Sour**		**Fruity**		**Prickly pear**	
Fruit mass (g)	0.1390	NS	0.2656	*	-0.0991	NS	0.2117	NS	0.1647	NS
% pulp	-0.3561	**	**-0.5728**	***	0.2080	NS	**-0.5213**	***	-0.4259	**
Brix°	0.2059	NS	-0.0905	NS	-0.3465	**	0.1689	NS	0.2142	NS
Pulp pH	0.3227	**	0.1969	NS	-0.2453	NS	0.2921	*	0.3547	**
% pulp TA	-0.2167	NS	0.1083	NS	0.2592	*	-0.1904	NS	-0.1575	NS
Pulp Glucose g/100g	0.2477	*	0.0784	NS	-0.0688	NS	0.2386	NS	0.2431	NS
Pulp Fructose g/100g	0.2636	*	-0.1329	NS	-0.1153	NS	0.1624	NS	0.1740	NS

Keys:

NS Not Significant

* significant at $p < 0.05$

** significant at $p < 0.01$

*** significant at $p < 0.001$

The correlations that were significant at $p < 0.05$, were: the correlation between the taste attribute "bitter" and the physical/chemical parameter fruit mass (positive correlation); "fruity" and pulp pH (positive correlation); "sour" and % pulp

TA (positive correlation); "sweet" and pulp glucose (positive correlation); and "sweet" and pulp fructose (positive correlation).

The correlations that were significant at $p < 0.01$, were: the correlation between the taste attribute "sweet" and the physical/chemical parameter % pulp (negative correlation); "prickly pear" and % pulp (negative correlation); "sour" and °Brix (negative correlation); "prickly pear" and pulp pH (positive correlation); and "sweet" and pulp pH (positive correlation).

The correlations that were significant at $p < 0.001$, were: the correlation between the taste attribute "fruity" and the physical/chemical parameter % pulp (negative correlation); and "bitter" and % pulp (negative correlation).

There was a positive correlation between the taste attribute "bitter" and the physical/chemical parameter of fruit mass (Table 4.15) at $p < 0.05$. According to Table 4.2, Robusta had the highest fruit mass value for both seasons 2007 and 2008, with a value of 186.04 g. The taste attribute "bitter" was more likely given to Robusta by the taste panel (Table 4.8). "Bitter" is defined as the taste associated with caffeine (Heymann, 1995). Sensory analysis on the juice of *Opuntia robusta* was carried out with untrained panelists by Gurrieri *et al.* (2000). The results showed that 65.9 % of the panelists found the juice unacceptable for its insipid taste and the presence of vegetable aroma. It must also be kept in mind that Robusta, from the genus *Opuntia robusta,* is mainly cultivated for animal fodder production (Snyman, 2006).

There was a positive correlation at $p < 0.05$ for the taste descriptor "fruity" and pulp pH. "Fruity" was frequently used by the panel during both seasons (Table 4.6). Because a FCP panel was used and no definition for the term "fruity" was available, it was decided to use a general definition. According to the Cambridge Advanced Learners Dictionary (2008), "fruity" refers to a smell or taste of fruit. Fruits are usually associated with sweet and sour tastes and smells, therefore, acidity and sugars will play major roles (Beaulieu and Baldwin, 2002). Sharsheret was characterized by the panel during season 2007 as being fruity and Roly Poly during season 2008. Since Sharsheret was not available for physical/chemical testing, Roly poly will be used in the discussion. Pulp pH for Roly Poly was 5.46 (Table 4.2). The average pH of a cactus pear fruit should be 5.3 – 7.1 at the time of harvest (Saenz and Sepulveda, 1991). Percentage TA for Roly Poly 2008 was 3.36 %, which was relatively low and corresponded with the high pH. Pulp fructose (29 mg/g), pulp glucose (26.33 mg/g) and °Brix (11.93) were in the range reported for production potential (Gregory *et al.*, 1993). However, Roly Poly is not one of the top nine cultivars consumed in South Africa, showing that the descriptor "fruity" is not an indication of consumer acceptability.

Percentage pulp TA had a positive correlation with the taste descriptor "sour". Sour is defined as the taste associated with tartaric acid (Heymann, 1995). As mentioned in the previous discussion, sourness is a fundamental taste characteristic of many fruits. In the 2007 season, the panel associated the term "sour" with Robusta, with a % pulp TA of 14.68, and a very low pH of 4.3 (Table 4.2). The following season (2008), Robusta again was the cultivar associated with sourness. However, % pulp TA for this season was 2.69 and the pH was 6.29, which was in contrast to the physical/chemical finding of the previous season and the panel. This can be explained by the fact that for season 2008, the °Brix value was very low (8.43) compared to the values of the rest of the cultivars of season 2008 , which could be due to the high rainfall in this season (Table 4.4), resulting in the dilution of sugars and acids (De la Barrera and Nobel, 2004).

The descriptor "sweet" had a positive correlation with pulp glucose at $p < 0.05$. A definition for "sweet" is the taste of sucrose in water (Heymann, 1995). Like mentioned earlier, "sweet" is characteristic and often most important for fruit quality (Inglese *et al.,* 1995). During the 2007 season, Fresno was most frequently associated with this descriptor by the panel and had a °Brix of 13.8 (Table 4.2). Pulp glucose was very high at 44.68 mg/g. Nudosa was the panel's most frequently associated cultivar for 2008 for this descriptor and had a °Brix and pulp glucose content of respectively 9.63 °Brix and 53.00 mg/g.

"Sweet" also had a positive correlation with pulp fructose at $p < 0.05$. The same cultivars as in the previous discussion were involved. For Fresno (2007), the pulp fructose was 29.67 mg/g and for Nudosa (2008), it was 44.33 mg/g. The reported pulp fructose values for cactus pears should be 5.4 - 6 % (54 - 60 mg/g) (Gurrieri *et al*,. 2000). Along with the pulp glucose and °Brix, the total effect was achieved of a very sweet taste.

At $p < 0.01$, a negative correlation between "sweet" and % pulp was observed. Fresno (2007) had a very low % pulp at 49.25, while Nudosa (2008) had a % pulp of 43 (Table 4.2). Degrees Brix for Fresno was 13.8 and 9.63 for Nudosa, the latter, being very low. In 2007 there was less rainfall (Table 4.4), resulting in sweeter fruit.

A negative correlation existed between the descriptor "prickly pear" and % pulp at $p < 0.01$. The descriptor is not easy to define and it can just be said that it is a flavor associated with cactus pear which is melon-like (Saenz, 2000). Like in the case of "fruity", sourness and sweetness, would play an important role. The correlation between "sweet" and % pulp has already been discussed in the previous paragraph and it was decided that sourness in this case was not applicable.

The taste descriptor "sour" and ° Brix had a negative correlation at $p < 0.01$. In the discussion on the positive correlation of "sour" with % pulp TA, it was already mentioned that Robusta (2007) had a very low °Brix of 10.6 and a very high % TA of 14.68 % (Table 4.2), resulting in extreme sourness. Sharsheret (2008) was not available for physical/chemical testing.

"Prickly pear" had a positive correlation with pulp pH at $p < 0.01$. As suggested earlier, this descriptor is strongly associated with the descriptor "sweet". Fresno (2007) had a pulp pH of 5.34, while Nudosa (2008) had a pulp pH of 6.79, which was relatively high (Table 4.2). Fresno had a high °Brix (13.8), while the glucose was 44.67 mg/g, which also was very high. On the other hand, Nudosa's ° Brix was relatively low, but the glucose was very high (53.00 mg/g).

"Fruity", or "sweet" and "sour", as previously explained, was negatively correlated with % pulp at $p < 0.01$. The correlation between "fruity"/"sweet" has already been discussed. Robusta can be used as an example to explain this finding. Robusta (2007) had a % pulp of 45, a pH of 4.3 and a % pulp TA of 14.68 (Table 4.2). The overall average values for these parameters for 2007 were 52.66 for % pulp, 5.92 for pulp pH and 6.08 for % TA. These values indicated that Robusta (2007) had a lower than average % pulp and pH, and a higher than average % TA value.

A negative correlation existed between the descriptor "bitter" and % pulp. "Bitter" is defined as the taste associated with caffeine (Heymann, 1995). Robusta (2007) and (2008) had a pulp % of 45.27 and 45.84 respectively. The low °Brix of 10.6 (2007) and 8.43 (2008), along with the low glucose (36.67 / 23.33 mg/g) and fructose values (16.67 / 26.00 mg/g), explain the high values of bitterness indicated by the panel.

Nudosa (2008) was most frequently correlated with the descriptor "sweet" by the panel (Table 4.6) and also had the higher pulp glucose (53 mg/ml) and pulp fructose (44.33 mg/g) (Table 4.2). Van As had the lowest pulp TA of 1.82 % in 2008 (Table 4.4). Skinners Court and Berg X Mexican were not available for analyses. The others, Meyers, Morado, Malta, Algerian and Gymno Carpo had rather mediocre average values for the two seasons for pulp glucose and pulp fructose: 34.8 / 36.13 mg/g pulp glucose (2007 / 2008) and 25.2 / 28.47 mg/g pulp fructose (2007 / 2008) (Table 4.2).

5. CONCLUSION

Cactus pear fruit has been known as an attractive and rich food for centuries and as knowledge of its nutritive value grows, interest in expanding its possibilities rose accordingly (Gurrieri, 2000; Saenz, 2000). This plant is characterised by a high potential of biomass production with very low water consumption, owing to its crassulacean acid metabolism (CAM) and is therefore extremely drought tolerant (Gurrieri, 2000; Felker, 2005).

The content of proteins, carbohydrates, minerals, and vitamins in the fleshy cladodes is nutritionally significant (Gurrieri, 2000) and scientific evidence provides the benefits from the consumption of cactus pear fruit in humans, especially the non-nutritive components as potentially active antioxidant phytochemicals (Livrea, 2006).

South Africa has one of the greatest genetic pools (germplasms) of 78 cactus pears cultivars and is the only country where original Burbank cultivars are still available. All the varieties currently grown in South Africa were developed from original material. The main production areas in South Africa are in the summer rainfall areas (Oelofse, 2006). Although cactus pears are widely consumed; their sensory characteristics have received little attention (Ruiz Pérez – Cacho, 2006).

Sensory analysis can be done by using FCP to generate descriptors of the product tasted (Kittel, 2008). The technique differs from conventional descriptive testing in that the members of a taste panel describe perceived qualities of a product analyses in an individual manner and use their own list of terms to describe the sensory characteristics of that product (Oreskovich *et al.,* 1991). The panelists require less training and this reduces time expenditure. The method takes into account minor individual variation while accentuating those panelists who respond differently from the rest (Rubico, 1992). The resulting data is then transformed using General Procrustes Analysis (GPA) to a consensus configuration to reveal the relationships between samples (Kittel, 2008).

The aim of this study was to determine the fruit quality of cactus pear fruit of the Waterkloof germplasm collection, located in the Bloemfontein district in the Free State province. Chemical and sensory quality attributes were evaluated for two agricultural seasons (2007 and 2008). The influence of factors especially such as summer rainfall and temperature on quality was determined. Furthermore, sensory analysis was used to distinguish among the available 33 cultivars, not only for their taste, but also to establish the cultivar most stable to varying environmental conditions. The study determined whether sensory quality of cactus pear fruit was influenced by the chemical parameters by attempting the correlation of the chemical data with the sensory analysis.

Highly significant differences (at probability level $p<0.001$) were observed among the 33 different cultivars for all the tested attributes observed in both seasons, indicating that genetic differences among cultivars have a significant influence on fruit quality.

Highly significant differences existed for all of the attributes tested between the two seasons (2007 vs. 2008). The significant difference in rainfall between season 2007 and 2008 is a clear indication that seasonal changes, that is the microclimate, plays a significant role in fruit quality. The different environmental conditions during growth season had a significant influence on most of the chemical parameters important for eating quality, namely fruit mass, pulp percentage, sugar content of pulp, as well as pulp acidity (% TA and pH). Findings from Felker (2002), Karababa *et al.,* (2004), Bekir *et al.,* (2006), Mashope (2007) and Mokoboki (2009), explain the increase of fruit mass in 2008.

The cultivar X season interaction was highly significant for most of the attributes tested, indicating that cactus pear varieties will react differently to different environmental conditions. Higher rainfall had a significant influence on fruit mass, pulp %, pulp TA, pH and glucose: the average fruit mass of 2008 is 13.68 g more than the average fruit mass of 2007; the average pulp percentage for cultivars 2007 was 55.99 % and the value for 2008 was 49.28 %; the average percentage pulp titratable acid content for 2007 was 6.08 and the content for 2008 was 4.8; the average pH pulp value of cultivars for 2007 is 5.92 and the value for 2008 is 6.33; the average glucose pulp content for 2007 was 35.67 mg/g and the content for 2008 was 39.25 mg/g. It was evident that not only the cultivar as well as the agricultural season, but also the interaction between the cultivar and the season had significant influences on fruit quality. These results are in accordance to results obtained by different authors, namely that fruit quality is highly influenced by environmental characteristics, climate (Inglese *et al.,* 2002) and orchard management and may change from year to year (Ochoa *et al.,* 2006; Mokoboki *et al.,* 2009).

The best preferred cultivar regarding chemical fruit quality attributes was Nudosa, performing the best regarding fruit mass, pulp glucose and pulp fructose. Messina performed the best regarding °Bx - and fructose pulp content, while Blue Motto had the best acidity levels (pH and TA). These results suggest and conclude that season as well as environment has a significant influence on fruit quality.

Concerning the sensory quality analysis:

The five most frequently used attributes were sweet, sour, bitter, fruity and prickly pear, with the corresponding cultivars for 2007 being Fresno, Robusta, Sharsheret, Malta and Amersfoort. For season 2008, the corresponding cultivars changed to Nudosa, Sharsheret, Robusta, Roly Poly and Ficus Indice, respectively. The FCP technique could only be used successfully to distinguish between the two seasons (77.72%), but not between the cactus pear cultivars.

The final aim of the study was to determine whether sensory quality of cactus pear fruit was influenced by the chemical parameters by attempting the correlation of the chemical data with the sensory analysis:

A positive correlation at $p < 0.05$ for the taste descriptor "fruity" and pulp pH was observed. Fruits are usually associated with sweet and sour tastes and smells, therefore, acidity and sugars will play major roles which influence the pH (Beaulieu *et al.*, 2002).

Opuntia robusta had a significant influence when attempting the correlation of the chemical data with the sensory analysis and influenced the following findings: a positive correlation between the taste attribute "bitter" and the chemical parameter fruit mass at $p < 0.05$; Percentage pulp TA had a positive correlation with the taste descriptor "sour"

($p < 0.05$); The taste descriptor "sour" and ° Brix had a negative correlation at $p < 0.01$; A negative correlation existed between the descriptor "bitter" and % pulp ($p < 0.001$).

Fresno and Nudosa had significant influence when attempting the correlation between the chemical data - pulp glucose, pulp fructose, % pulp and the sensory attribute sweet, fruity and prickly pear in the following findings: the descriptor "sweet" had a positive correlation with pulp glucose and fructose at $p < 0.05$; a negative correlation at $p < 0.01$ between the taste attributes "prickly pear" and "sweet" and % pulp was observed; "prickly pear" had a positive correlation with pulp pH at $p < 0.01$.

This study indicated that there were chemical and sensory quality differences between the cultivars. Season had a definite influence on the chemical and sensory fruit quality parameters: prominent interactions between seasons and cultivars, namely cultivar X season interactions were observed.

Free Choice profiling may not have been the best sensory method to use to describe the sensory quality of the cultivars, because of the large number of samples. It may also have been advisable to reduce the number of attributes used by the individual panel members.

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SUMMARY

The cultivation of cactus pears requires low input and it has been grown widely in drier areas of South-Africa as fodder crop, particularly for times of serious drought. Cactus pears also serve as a source of inexpensive nutritious food for lower income groups

Sugar is the main determent of taste of the cactus pear cultivar and content value range from 10 °Brix to 17 °Brix. Glucose is the predominant sugar with fructose as the second sugar, thus the fruit pulp is very sweet. The pulp of the cactus pear cultivar consists of a high pH value (> 4.5) and low acidity level (0.03-0.12 %), (Saenz-Hernandez, 1985; Brutch, 1993; Piga, 2004; Salim, 2009).

The aim of this study was to determine the fruit quality of cactus pear fruit. Physical/chemical and sensory quality attributes were evaluated for two agricultural seasons (2007 and 2008). The influence of factors such as rainfall and temperature on quality was determined. Furthermore, sensory analysis was used to distinguish among the available 33 cultivars, not only for their taste, but also to establish the cultivar most stable to varying environmental conditions. This study determined whether sensory quality of cactus pear fruit was influenced by the physical/chemical parameters by correlating the physical/chemical data with the sensory analysis.

There were highly significant differences observed in terms of physical/chemical composition ($p < 0.001$) among 33 different cactus pear cultivars in South Africa, for seasons 2007 and 2008. This finding indicated that genetic differences among cultivars as well as seasonal changes have a significant influence on fruit quality. It was evident from this study that not only the cultivar and agricultural season, but also the interaction between the cultivar and season had significant influences on fruit quality.

The best preferred cultivar, regarding physical/chemical fruit quality attributes, was Nudosa, performing the best regarding fruit mass and pulp glucose. Messina performed the best regarding °Bx. Nudosa and Messina performed the best regarding pulp fructose content, while Blue Motto had the best acidity levels (pH and TA).

Sensory analysis, used to determine whether the consumer could distinguish among the available 33 cultivars was done by using the FCP technique and it was clear that the consumers could only successfully distinguish between the two seasons (77.72 %) , but not among the 33 different cactus pear cultivars. The fodder cultivar, Robusta, was an exemption and could be clearly distinguished from the other 32 cultivars.

The sensory quality of cactus pear fruit obtained from the consumers was indeed influenced by the physical/chemical parameters. Cultivars like Robusta, Fresno and Nudosa had been significantly influenced by seasonal differences. The physical/chemical data and the sensory attributes were correlated.

Keywords: cactus pear; physical/chemical parameter; sensory analysis; fruit mass; pulp %; pulp pH; total soluble solids; titratable acid; glucose; fructose

OPSOMMING

Die kweek van turksvye is eenvoudig en dit kan in droër areas van Suid-Afrika geplant word, waar dit kan dien as veevoer. Turksvye is 'n bekostigbare, voedsame voedselbron vir laer-inkomste groepe.

Glukose, as die primêre suiker, saam met fruktose, wat dien as die sekondêre suiker, gee aan turksvye 'n kenmerkende soet smaak. Suikerwaarde varieer van 10 tot 17 °Brix. Die pulp het 'n hoë pH waarde (> 4.5) en 'n lae suurheidsgraad (0.03 – 0.12 %).

Die doel van die studie was om die vrugkwaliteit van turksvye te bepaal. Fisies/chemiese en sensoriese kwaliteit was ge-evalueer vir seisoene 2007 en 2008. Daar was ook bepaal wat die omgewingsinvloede, naamlik reënval en temperatuur, op truksvye het. Sensoriese analise was toegepas deur die tegniek, "Free Choice Profiling", om te bepaal of die verbruiker tussen die smaak van 33 verskillende kultivars kon onderskei en sodoende ook die kultivar te identifiseer wat die meeste stabiel was in veranderde omgewingstoestande. Afleidend was daar bepaal of sensoriese kwaliteit van truksvye deur die fisies/chemiese eienskappe van die truksvy beinvloed deur die analise van fisies/chemiese data met die sensoriese resultate te korreleer.

Daar was betekenisvolle verskille ($p < 0.001$) tussen die 33 kultivars in Suid-Afrika in terme van fisies/chemiese samestellling vir seisoene 2007 en 2008. Hierdie bevinding toon dat truksvye geneties verskil en dat seisoensverandering 'n merkwaardige invloed op vrugkwaliteit het. Die studie het getoon dat vrugkwaliteit nie net deur die kultivar en seisoen beinvloed word nie, maar ook deur die interaksie tussen die kultivar en die seisoen.

Die beste kultivar, ten opsigte van chemiese vrugkwaliteits-kenmerke, was Nudosa, wat die beste vertoon het betreffende vrugtemassa, pulp glukose. Messina het die beste gevaar ten opsigte van °Brix. Nudosa en Messina het die beste gevaar ten opsigte van pulp fruktose, terwyl Blue Motto die beste suurheidsvlakke gehad het (pH en TA).

Sensoriese analise het getoon dat die verbruiker in staat was om tussen die 33 kultivars van 2007 en 2008 te kon onderskei, maar nie tussen die 33 afsonderlike kultivars nie. Robusta, wat as veevoer gebruik word, was 'n uitsondering en kon afsondelik van die 32 ander kultivars onderskei word.

Sensoriese kwaliteit van truksvye word betekenisvol beinvloed deur die fisies/chemiese eienskappe van die truksvy. Kultivars soos Robusta, Fresno en Nudosa was betekenisvol beinvloed deur seisoensverandering. Daar was 'n korrelasie tussen die fisies/chemiese kenmerke en sensoriese resultate.