NUTRITIONAL COMPOSITION, DESCRIPTIVE SENSORY ANALYSIS AND CONSUMER ACCEPTABILITY OF PRODUCTS DEVELOPED FROM *Agave americana* FLOWERS

by

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GLOSSARY OF ABBREVIATIONS

a*	Colour ordinate – redness value
ACC	Agave chocolate cake
AFS	Agave flour stew
AFSB	agave flour steamed bread
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
APEC	Asian Economic Pacific Community
ASTM	American Society for Testing and Materials
b*	Colour ordinate – yellowness value
β	Beta
BPAF	Blanched pickled agave flower
BSFAF	Blanched stir fried agave flower
BSAF	Blanched steamed agave flower
Ca	Calcium
CQA	caffeolquinic acid
cm	Centimeter
d	Day
°C	Degrees Celsius
DSA	Descriptive sensory analysis
e.g.	For example
etc.	Etcetera
F.A.O	Food and Agricultural Organisation
FCC	Flourless chocolate cake
Fe	Iron
FFDM	Fat free dry matter
g	Gram
GC	Gas chromatograph
GI	Glycemic Index
GLS	glucosinolates
h	Hour
HIV	Human immunodeficiency virus
i.e.	That is
K	potassium
kg	Kilogram

kJ	Kilo Joule
ℓ	Litre
L*	Colour ordinate – lightness value
LDL	low density lipoproteins
LSD	Least significant difference
m	Meter
mg	Milligram
mm	Millimeter
min	Minute(s)
ml	Millilitre
‘n	And
ND	Not determined / detected
NS	Not significant
p	Significance level
P	Phosphorus
%	Percentage
PCA	Principal component analysis
ppm	Parts per million
OECD	Organisation for Economic Cooperation and Development
QDA	Quantitative descriptive analysis
R	Rand
RE	Retinol equivalent
s	Second/s
SI	Saturation index
Sign	Significance
SL	Significance level
supp	Supplement
TDA	Total daily allowance
TZSB	Traditional Zulu steamed bread
µg	Microgram
UPAF	Unblanched pickled agave flowers
USFAF	Unblanched stir fried agave flowers
USAF	Unblanched steamed agave flowers
<	Less than
>	More than

CHAPTER 1

INTRODUCTION

In many African countries, including Lesotho, there is an ever increasing problem of food insecurity. However, hardy plants, like *Agave americana,* are abundantly available in Lesotho and can be used as a food crop (CSIR News, 2008). According to Felger and Moser (1970), the Seri people from Cerén (El Salvador) used eight species of agave flowers as a major source of food, specifically sugar. Furthermore, the agavaceae is among the 62 species of flowers which are eaten raw in salads, and among the 55 species which are fried for preparing side-dishes, vegetarian stuffed balls and omelettes in Sicily (Lentini & Francis, 2007).

Indigenous African leafy vegetables have recently been attracting research attention, not only in terms of their inherent nutritional quality, but also for the healing power of some of these plants (Kimiywe, Waudo, Mbithe, & Maundo, 2007). Diversification of diet through increased utilization and consumption of these vegetables would go a long way in alleviating hunger and malnutrition (Kimiywe *et al*., 2007).

Flowers are generally used as a garnish and/or trimmings for various meals and cold buffet foods, while the petals decorate salads, sweet meals, fruit and ice cream sundaes and drinks. In addition to the aesthetic appearance, they also correspond to a specific taste and smell of served food (Scherf as cited by Mlcek & Rop, 2011). In addition to the above-mentioned applications, edible flowers may also be used for other culinary purposes like baking and the flavouring of sauces, jellies, syrups, vinegar, honey, oils, teas, flower-scented sugars, candied flowers, wine and flavoured liqueurs. Even a small amount of edible flowers may often improve the health condition of consumers (Mlcek & Rop, 2011). Broccoli, cauliflower and globe artichoke are the most commonly used flowering vegetables (Lintas, 1992).

A number of edible flowers in Southern Africa have been indicated by several researchers (Fox & Young, 1982; F.A.O, 1988; Roberts, 2000). Roberts (2000) describes the use of 44 different flowers in various recipes, including soups, salads, teas, desserts and drinks. In addition, Mildred (2009) reflects on the qualities and nutritional value of flowers, as well as the preparation thereof in food dishes.

Flowers are good sources of important nutrients. Broccoli, being greener, rates higher in nutritive value than cauliflower and is a good source of iron (Fe), phosphorus (P), vitamins A and C, and riboflavin (Bennion & Scheule, 2004). Cauliflower is also a good source of vitamin C. Artichoke is a good source of minerals, particularly potassium (K), calcium (Ca), P and dietary fibre (Lintas, 1992).

Flowers can be divided into three major components: pollen; nectar; and petals. Pollen is a very rich source of proteins, amino acids and carbohydrates (Parkison & Pacini, 1995; Weber as cited by Mlcek *et al*., 2011), saturated and unsaturated lipids (Dobson as cited by Mlcek *et al*., 2011), carotenoids (Lunau as cited by Mlcek *et al*., 2011) and flavonoids (Wiermann & Gubatz as cited by Mlcek *et al*., 2011). Nectar contains a balanced mixture of fructose, glucose and sucrose, amino acids (mainly proline), proteins, inorganic ions, lipids, organic acids, phenolic substances, alkaloids and terpenoids (Nicolson, Nepi & Pacini as cited by Mlcek *et al.*, 2011). Petals and other parts of flowers are an important source of vitamins (yellow flowers are usually a very good source of vitamin A), minerals and antioxidants (Mlcek *et al*., 2011).

Like the other species of the *Brassica* family, broccoli is a rich source of health promoting phytochemicals (Bahorun *et al*. and Chun *et al*. as cited by Koh, Wimalasiri, Chassy, & Mitchell, 2009). Fifty-six percent of case-controlled studies demonstrated a strong association between increased broccoli consumption and the protection against cancer (Verhoeven *et al*. as cited by Koh *et al*., 2009). This protective effect has largely been attributed to the complement of phytochemicals in broccoli, which include vitamins C and E, the flavonols quercetin and kampferol, the carotenoids ß-carotene and lutein, and the glucosinolates (Podsędek, 2007). Research on the nutritional composition of different species of agave flowers have shown that the crude protein content of A*gave salmiana* is similar to that of commonly consumed legumes, seeds and edible leaves. The limiting amino acid for *A*. *salmiana* is lysine (Sotelo, López-Garcia, & Basurto-Peña, 2007). Young shoots of *A. americana* are used as vegetable and are also pickled (Verma & Chauhan, 2005).

Agave flowers contain fructans, which function as prebiotics in the body (Boguslavsky, Barkhuysen, Timme, & Matsane, 2009). The leaves and sap of *A. americana* contain saponins, inulin, fructans and steroidal glucosides. They also contain dietary fibre, fructose, glucose, proteins, essential amino acids like lysine, tryptophan, histidine, phenylalanine, and vitamins B and C. The main mineral contents of *A. americana* leaves are Fe, Ca and P (Islas-Lopez *et al*., 2005; Pard as cited by Rivera *et al*., 2010). Inulin, derived from agave flowers, has a potential prebiotic effect, as it increases the growth of bifidobacteria and lactobacilli (Gomez *et al*., 2009)

The first aim of this study was to determine the nutritional composition of the *A. americana* flowers and to compare it to the nutritional composition of the most commonly eaten flower vegetables.

The following hypothesis was formulated:

Domesticated and wild vegetables provide an improved diet in terms of nutritional value and diversity, and supplement the food needs of the poorest households (Orech, Aagarrd, & Friis, 2007). According to Rivera, Bocanegra-Garcia and Monge (2010), traditional plants are potential nutraceuticals or functional foods that could have potential use as therapeutic substances. A hypothesis for nutritional composition would thus be that the flowers of the agave plant would be as beneficial to humans, as are commonly eaten flowering vegetables.

The second aim was to determine the effect of different treatments on the sensory quality of the *A. americana* flowers.

The following hypothesis was formulated:

Cooking improves the palatability of vegetables, flavour and texture. Over-processing of vegetables like cutting green vegetables thinly, should be guarded against as it destroys vitamin C (Bennion & Scheule, 2004). A hypothesis for sensory quality characteristics would thus be that different treatments would have different effects on the sensory profile of the flowers. The sensory profile for the blanched/pre-treated flowers would also differ from the profile for the untreated/unblanched flowers, which, in turn, would also differ between different treatments.

The third aim was to develop products, incorporating fresh as well as dried flowers, to add variety to the application of the flowers, as well as to the diet of local people and health conscious consumers.

The following hypothesis was formulated:

Traditional plants, being potential nutraceuticals or functional foods, could be used as therapeutic substances (Rivera *et al*., 2010) and these benefits are transferred to processed products. There is an increasing demand for healthy and nutritious food, and this contributes to a continuous need for new food products by consumers (Zink, 1997; Deliza, Rosenthal, & Silva, 2003; Allende, Tomas-Barberan, & Gil, 2006). The hypothesis for developing products containing agave flowers, either fresh or dried, would thus be that more applications, as well as better availability, in the case of dried or preserved flowers, would be possible.

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CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

There has been an increased recognition around the world of the importance of wild or cultivated food plants, as sources of micronutrients. More recently, the role of these biologically diverse species has been highlighted in maintaining human and environmental health, particularly in relation to global food security (Nesbitt, Mcburney, Broin, & Beentje, 2010). According to Rivera *et al*. (2010), traditional plants are potential nutraceuticals or functional foods (foods that have positive physiological effects beyond their function of providing nutrients) that could have potential use as therapeutic substances. Nordeid, Hatloyi, Folling, Lied and Oshaug (1996) concluded that traditional and locally produced foods are important nutrient contributors to the diet. Furthermore, knowledge of traditional foods is important for sustaining their development and utilization. It is important to know the prevailing traditional food in the area and how they can be improved for better sustainable food security or nutrition. Traditional foods provide food at all times and at times of food scarcity (Ohiokpehai, 2003).

The availability of indigenous vegetables has declined drastically, because of excessive cultivation of field crops, which includes chemical elimination of wild vegetables and habitat change. There is also growing ignorance among young people about the existence of these nutritionally rich foods (Odohav, Beerkrum, Akula, & Baijnath, 2007). This decline in the use of indigenous vegetables by many rural communities has resulted in poor diets and increased incidence of nutritional deficiency disorders and diseases in many parts of Africa (Kwapata & Maliro, 1995).

In 1993, Prasad, Mapetla and Phororo listed 90 indigenous food plants that were known to be consumed. They named the main reasons for the decline in their consumption to be perceptions of people, drought, modern farming systems, soil erosion and overgrazing, human settlement, over-harvesting, burning of fields and wild fires. Only older people, especially older women, use the same indigenous vegetables which are also mostly used by rural people. Lephole (2004) gave the reasons for the poor usage of these food plants as the following: difficulty of collection, as it is becoming scarce; shrinkage during the cooking process; bitter taste; association with poor rural communities; and preference of exotic species. It is also said that the younger generation has developed a fear of snakes and other wild animals, while girls fear their skins will be scratched by bushes and thorns in the *veld,* as they collect vegetables. Indigenous food plants are also far from reach, as most are found in the *veld*, while some take too long to prepare, compared to modern food (Shava, 1999).

Traditional vegetables account for 10% of the world's higher plants; however, they are underutilised in favour of introduced non-native vegetables (Rubaihayo as cited by Odohav, Beerkrum, Akula, & Baijnath, 2007). The elderly claim that indigenous foods keep them healthy and living longer. Modern diets are lamented as the reason for poor health amongst the youth, while earlier, deaths of the youth were unheard of and it was rare for people to go to hospital. Problems such as high blood pressure, stroke, etc. were also unknown (Shava, 1999). Traditional vegetables grow wild and are readily available in the field, as they do not require any formal cultivation. Communities in Africa have a long history of using traditional leafy vegetables to supplement their diets (Chweya & Eyzaguirre, 1999).

Both domesticated and wild traditional leafy vegetables are sources of Ca, Fe and zinc (Zn). Domesticated and wild vegetables play a role in livelihoods, in providing an improved diet in terms of nutritional value and diversity, and in supplementing the food needs of the poorest households, as well as in times of famine. These vegetables are predominantly used to supplement relish in meals and they have been established to contain significant nutritional value. Traditional leafy vegetables are important in improving health and elevating household food security (Orech, Christensen, Asgaard-Hnsen, & Estambale, 2007).

Compared to conventional cultivated species, wild vegetables are hardy, require less care and are a rich source of micronutrients. Unfortunately, wild vegetables are currently underutilised, and have been neglected by researchers and policy makers. Their promotion and integration into human diets could assist in their protracted use and consequent conservation (Flyman & Afolaya, 2006).

2.2 CLASSIFICATION OF VEGETABLES

Studies have shown different classifications of vegetables (Gates, 1987; Lintas, 1992; Jean & Fisher, 2009). Lintas (1992) classified vegetables according to the portion of the plant used for food and its specific nutritive value, while Gates (1987) classified vegetables by the parts of the plant they come from, their flavour and colour. Jean and Fisher (2009) classified fruits and vegetables into homogenous clusters based on their food component profiles, botanic family, colour groupings, part of the plant, total antioxidant capacity and according to botanic families by clusters. The classifications of fruits and vegetables are offered to nutrition professionals as a means to group fruits and vegetables more accurately and to help researchers who are developing food frequency questionnaires for clinical studies. They may also be useful for instructors to teach students about food composition and to help dieticians in providing dietary guidance to patients and client (Pennington & Fisher, 2009).

Leafy vegetable, e.g. lettuce, spinach, African spinach, turnips and cabbage, are valuable sources of minerals (Fe and Ca), vitamins (A, C, K, and riboflavin) and cellulose. Young, tender, growing leaves contain more vitamin C than mature plants. The green outer leaves of lettuce and cabbage are richer in vitamin A, Ca and Fe than the white inner leaves; the thinner and greener the leaf, the higher its nutritive value. Green vegetables are generally low in kilojoules (Whitney, Cataldo, & Rolfes, 2002; Uusiku *et al*. 2009).

Stem or stalk vegetables, like celery, bamboo shoots, cardoon, fennel and asparagus also contain minerals and vitamins in proportion to the green colour. Asparagus is a particularly good source of folic acid (Duckworth, 1966; Lintas, 1992; Falls & Bailey, 2008; Lee Gallagher as cited by Mahan & Escott-Stump, 2008) and also contains minerals like Cu, Mn, Fe, Co, Na, K, and Ca (Negi, Singh, Rawat, & Pnadey, 2009).

Carrots, beetroot and turnips are examples of root vegetables, while potatoes, onions, chives, leek and shallot are examples of tuber and bulb vegetables. Yellow and orange varieties are rich in β-carotene, the precursor of vitamin A. The deeper the yellow colour, the higher the β-carotene content. Root vegetables, in general, are good sources of thiamin and minerals. Potatoes contain some vitamin C and can add significantly to the total daily allowance (TDA) when it is consumed in sufficient quantities. Onion is an outstanding example of a bulb vegetable and contains a moderate amount of vitamin C (Duckworth, 1966; Lintas, 1992).

Tomato and pepper are the most common fruit vegetables, and both are rich in vitamin C. Other fruit vegetables include cucumber, squash, pumpkin and eggplant. Deep green or yellow colour indicates high β-carotene content (Whitney & Rolfes, 2002; Whitney *et al.,* 2002).

Broccoli, cauliflower and globe artichokes are the most commonly used flowering vegetables. Broccoli, being greener, rates higher in nutritive value than cauliflower and is a good source of Fe, P, vitamins A and C, and riboflavin. Cauliflower is also a good source of vitamin C. The outer leaves of cauliflower and broccoli are much higher in nutritive value than the flower buds and should be cooked or used in salads. Artichoke is a good source of minerals, particularly K, Ca, and P, and has a high dietary fibre content (of which 50% is soluble) (Lintas, 1992; Podsędek, 2007).

2.2.1 Common flowering vegetables

2.2.1.1 Artichokes

The artichoke is a perennial vegetable, also called globe artichoke, whose edible immature flower head is formed of a fleshy base, or heart, surrounded by scaly leaves (Figure 2.1). The heart is eaten after the inedible hairy central core (choke) has been removed, while the bases of the leaves are also edible. Originating from Sicily, the artichoke was first regarded in France mainly as a remedy for various ailments. At the beginning of the 18th century, Louis Lemery said in his *Treatise on Food*: "Artichokes suit elderly people at all times, and those of a phlegmatic and melancholy disposition" (Courtine, 1994). It was also reputed to be an aphrodisiac and women were often forbidden to eat it. Catherine de' Medici, who was fond of artichokes, encouraged their cultivation in France (Courtine, 1994).

Figure 2.1: Globe artichoke; purple artichoke; flowering artichoke

The globe artichoke (*Cynara cardunculus* var. *scolymus* L. Fiori), which has diuretic properties, has the highest energy, total carbohydrates and fibre contents of the flowering vegetables (Table 2.1). It is also superior to them in Fe, Mg, Na, P and Cu contents (Table 2.1) and is a traditional component of the Mediterranean diet (Lattanzio, Kroon, Linsalata, & Cardinali, 2009; Lombardo, Pandino, Mauromicale, Knodler, Carle, & Schieber, 2010). The edible parts of the artichoke are one of the richest dietary sources of bioactive phenolic compounds (Fratianni, Tucci, De Palma, Pepe, & Nazzaro, 2007; Ceccarelli, Curadi, Picciarelli, Martelloni, Sbrana, & Giovannetti, 2010; Lombardo *et al*., 2010; Gouveia & Castilho, 2012; Negro, Montesano, Grieco, Crupi, Sarli, De Lisi, & Sonate, 2012), and also contain high qualities of inulin, fibres and minerals. A high content of flavones are present in the leaf of the globe artichoke, while the floral stem is rich in caffeoylquinic acid (Menin, Comino, Moglia, Dolzhenko, Portis, & Lanteri, 2010; Gaetano, Lombardo, & Mauromiicale, 2013).

Table 2.1: Nutritional composition of well-known edible flowering vegetables (Wolmarans, 2010)

Nutrient per 100g edible portion	Unit	Flowering vegetable		
		Artichoke**	Broccoli*	Cauliflower*
Moisture	%	84.9	91.8	88.5
Energy	kJ	242	133	181
Proteins	g	3.3	1.8	3.8
Total fat	g	0.2	0.2	0.2
Cholesterol	mg	0	0	0
Total carbohydrates	g	5.1	3.4	3.1
Fibre	g	5.4	2.2	3.3
Sugar	g	2.5	2.8	2.6
Ca	mg	44	17	49
Fe	mg	1.3	0.5	1.2
Mg	mg	60	19	33
P	mg	90	45	87
K	mg	370	304	384
Na	mg	94	12	14
Zn	mg	0.49	0.32	0.66
Cu	mg	0.23	0.07	0.15
Mn	µg	0.26	0.33	0.29
Vit A	RE	18	2	66
Thiamin	mg	0.07	0.07	0.11
Riblofalvin	mg	0.07	0.02	0.08
Niacin	mg	1.0	0.9	1.5
Vit B6	mg	0.12	0.13	0.17
Folic acid	µg	68	23	49
Vit B12	µg	0.0	0.0	0.0
Pantothenic acid	mg	0.34	0.72	0.85
Biotin	µg	4.1	9.2	18.5
Vit C	mg	12	70	94
Vit D	µg	0.00	0.00	0.00
Vit E	mg	0.19	0.04	0.02

*raw
**cooked, globe and French varieties

Artichoke leaf extracts have long been used in folk medicine, particularly for liver complaints. In various pharmacological test systems, artichoke leaf extracts have exhibited hepato-protective, anti-carcinogenic, anti-oxidative, anti-bacterial, anti-HIV, bile expelling and urinative activities, as well as the ability to inhibit cholesterol biosynthesis and LDL oxidation (Fratianni *et al*., 2007; Lattanzio *et al.,* 2009). These extracts may also help to reduce total cholesterol in adults, with mild to moderate hypercholesterolemia (Bundy, Walker, Middleton, Wallis, & Simpson, 2008; Ceccarelli *et al*., 2010).

According to Mentel, Cieślik, Walkowska and Sieja (2012), globe artichokes are a rich source of carbohydrates, ash, vitamin C, Na, K and Mg. The intake of a diet rich in artichoke would provide a beneficial effect on health (Gil-Izquierdo, Gil, Conesa, & Ferreres, 2001), because they are a good dietary source of antioxidants (Luts, Henríquez & Escobar, 2011). According to Sidrach, García-Cánovas, Tudela, José, and Rodríguez-López (2005), aspartic proteinases from flowers of artichokes *(Cynara scolymus L.)* have also been used as coagulants in the manufacture of several traditional Spanish and Portuguese cheeses.

2.2.1.2 Broccoli *Brassica oleraceae* L.var. *italica* Plecnk.

Broccoli is believed to be native to the Mediterranean area and Asia Minor, and has been very popular in Italy since the Roman Empire. It is mostly grown for the clusters of unopened flower buds and tender flower stalks (Figure 2.2). The central head is usually harvested when still tight and compact, with no opened flowers. A good quality broccoli should have a dark to bright green colour with completely closed flower buds. Some broccoli cultivars may have a purplish-green colour, which is not undesirable (Nunes, 2008).

Figure 2.2: green broccoli, Romanesco broccoli; purple broccoli

From Table 2.1 it can be seen that broccoli contains on average 91.8% water, 1.8 g protein, 0.2 g lipids, 3.4 g carbohydrates and 2.2 g fibre. Broccoli is a good source of Mn, containing on average 330 µg/100 g fresh weight. It also contains about 2.8 g sugar per 100 g fresh weight. Raw broccoli florets contain the following amino acids: glutamine; proline; asparagine; valine; arginine; isoleucine; threonine; and leucine (Murcia, López-Ayerra, Martínez-Tome, & García-Carmona, 2001).

Broccoli contains glucosinolate compounds, which are responsible for the characteristic flavour of this vegetable. Although some of these compounds may have bitter tastes, they have been associated with beneficial anti-carcinogenic properties. Fifty six percent of case-controlled studies demonstrated a strong association between increased broccoli consumption and the protection against cancer (Verhoeven *et al*. as cited by Koh *et al*., 2009; Czapski, 2009; Appendino & Bardelli, 2010). Podsędek (2007) attributed this protective effect to the phytochemicals in broccoli, which include vitamins C and E, the flavonols quercetin and kampferol, the carotenoids ß-carotene and lutein, and glucosinolates.

There is, however, a great variation in the glucosinolate content between broccoli genotypes; this content affects the flavour of broccoli and, in general, consumers prefer broccoli that has a sweet, crisp and characteristic broccoli flavour, rather than broccoli that has an intense bitter, pungent and green or grassy flavour. Lower intensities of bitter and pungent flavours were associated with glucosinolate content of 30-35 mg/100 g fresh weight or less (Nunes, 2008).

In addition, broccoli contains 70 mg vitamin C/100 g fresh weight and 9.2µg biotin/100 g fresh weight (Table 2.1) (Wolmarans, 2010).

2.2.1.3 Cauliflower *Brassica oleracea* L. var. *botryt*

Cauliflower is grown in many countries like India, China, Europe, Italy, America, United Kingdom, Spain, Poland, Germany and Pakistan, for its highly suppressed prefloral fleshy apical meristem branches called "curd" (Figure 2.3). The word cauliflower comes from Latin term *caulis* and *floris*, meaning stem or stalk and flower, respectively (Sharma, Singh, Chabel, & Tripathi, 2008). It was eventually brought to the Eastern Mediterranean region, where it became fully domesticated and started giving rise to a wide range of cultivated forms. So, like other cultivated forms of the cabbage group, the cauliflower is also believed to be a descendent of the wild cabbage (*Brassica oleracea.* var. *sylvestris.*), which is still found growing wild in the coastal area of the Mediterranean sea and western Europe (Sharma *et al.,* 2008).

Figure 2.3: white cauliflower; coloured cauliflower

From Table 2.1 it can be seen that cauliflower contains on average 88.5% water, 3.8 g protein, 0.2 g lipids, 3.1 g carbohydrates and 3.3 g fibre. Cauliflower is a good source of K, containing on average 384 mg/100 g fresh weight. It also contains about 94 mg vitamin C and 66 RE vitamin A per 100 g fresh weight (Table 2.1). Cauliflower with green inflorescences is a good source of protein (Kmiecik *et al*., 2007), as in 1 kg of the edible parts of green cauliflower; the total content of amino acids is 24.32 g, of which essential amino acids constitute 44%. Eppendorfer and Bille (1996) reported that in white cauliflower the percentage of amino acids in their total content was 37-48%. In analyzing the total amino acids content of green cauliflower florets, glutamic acid constituted 18% and aspartic acid 11%. Five to seven percent were leucine, lysine, tryptophan, valine, arginine, serine, proline, glycine and alanine, and 3-4% isoleucine, phenalanine and histidine. Total sulphuric amino acids constituted 2.4%. Glutamic and aspartic acids also predominate in other vegetable species (Lisiewska, Kmiecik, & Korus, 2008). Green cauliflower was found to contain more dry matter, vitamin C, total carotenoids, β-carotene, and polyphenols than white florets (Kmiecik *et al*., 2007).

Carbello-Hurtado, Gicquel & Esnault (2012), indicated that the main glucosinolates found in cauliflower are sinigrin (average of 5.39 $\mu mol.g^{-1}$) and glucoiberin (4.76), followed by glucobrassicin (1.97). These three glucosinolates represented, on average, approximately 74% of the total glucosinolates (33%, 29%, and 12%, respectively). Of the six major cauliflower glucosinolates that were analysed for antioxidant activity, only glucoraphanin was not detected in these samples (Carbello-Hurtado *et al.,* 2012). Glucobrassicin (29–30% of the total GLS), glucoiberin (12–43%) and progoitrin (16–37%) are the main glucosinolates in cauliflower florets (Volden, Bengtsson, & Wicklund, 2009).

2.2.1.4 Consumption patterns of edible flowers

In 1971, the consumption of vegetable flowers was 1.5 million stems (a meager 7 stems per capita) in the United States. Over the next two decades, there was a steady increase in consumption, but from 1990 onwards, domestic production fell so that by 2000, it was only a third of that in the 1980s. This fall accompanied a considerable fall in consumption, from a high of 12 stems per capita per year in 1993, to only nine stems per capita in 2000 (Reid, 2005). Cauliflower and broccoli, being the most popular flowering vegetables, are produced in large amounts. From 2006 to 2009, the top three countries for the production of cauliflower and broccoli were China, India and Italy (USDA, 2013), with China and India producing 71% (14 000 000 tons per annum) (F.A.O., 1999). Other major producers of cauliflower are France, Italy, United Kingdom, United States of America, Spain, Poland, Germany and Pakistan (Sharma, *et al*., 2008).

The production value of flowers has been rising worldwide, from an estimated $11 billion to $60 billion in 2003. Europe is traditionally a larger producer and trader, with a stable production value of about $10 billion, while North America has a production value of about $6.5 billion since 2002. In Asia production capacity is growing rapidly in several countries and the same tendency is seen in Africa. Oceania, however, remains a small producer (van Uffelin & de Groot, 2005).

Like Australians, South Africans do not have a culture for buying edible flowers. Purchasing trends are confined to special occasions, and per capita flower consumption is relatively low (NICUS, 2007). South Africa's per capita consumption expenditure on edible flowers averages approximately R3.04. Australia's per capita consumption expenditure on flowers is estimated at between R48 and R58 per annum (Karigal as cited by Van Rooyen *et al*., 2001). By contrast, Switzerland has the highest per capita consumption expenditure in the world, averaging R385.53 (Van Rooyen, *et al*., 2001). The most important influence that home demand has on competitive advantage is the mix and the character of the household buyer's needs (Porter as cited by Van Rooyen *et al*., 2001).

One way of improving the per capita consumption of vegetables is to increase its production. Another alternative would be to use locally available wild flora, as it has not been fully exploited as a means of reducing the load on production of conventional food plants. Many underutilised plants are far superior sources of nutrients, texture and have medicinal properties, besides having high yield potential (Parvathi & Kumar, 2002).

2.2.2 Other flowering vegetables of the world

Maynard and Hochmuth (2006) compiled a table of the edible flowers most commonly consumed in the world (Table 2.2). This table includes 23 flowers, including well known flowers such as chrysanthemums, marigolds, begonias, carnations, gladiolas, lilies, roses, tulips, poppies, violets and pansies. Also named are flowers from various herbs, such as rosemary, coriander, basil, fennel, dill, chervil, mustard, mint, marjoram, oregano, sage and thyme. Some vegetable and fruit flowers are also found in Table 2.2, including dandelion, marigold, squash, daylily, nasturtium, calendula, radish, tulip, violet and safflower. Most of the flowers are used in salads, desserts, soups, fruit juices,

Table 2.2: Botanical names, common names, flower colour and taste of some edible flowers (Maynard & Hochmuth, 2006)

Family	Botanical name	Common Name	Flower colour	Aroma	
Agavaceae	*Yucca filamentosa L.*	Century plant family Yucca	Creamy white with purple tinge	Slightly bitter	
Allicaceae	*Allium schoenaprasum L.*	Onion family Chive	Lavender	Onion, strong	
	Allium tuberosium Rottl. ex. Sprengel	Chinese chive	White	Onion, strong	
	Tulbaghia violaceae Harve	Society garlic	Lilac	Onion	
Apiaceae	*Anethum graveolens L.*	Carrot family Dill	Yellow	Stronger than leaves	
	Anthriascus cerefolium (L.) Hoffm.	Chervil	White, pink, yellow, red, orange	Parsley	
	Coriandrum sativum L.	Coriander	White	Milder than leaf	

	Foenuculum vulgare Mill.	Fennel	Pale yellow	Licorice, milder than leaf	
Asteraceae	*Bellis perennis L.*	English daisy	White to purple petals	Mild to bitter	
	Calendula officinalis L.	Calendula	Yellow, gold, orange	Tangy and peppery	
	Carthamus tinctorius L.	Safflower	Yellow to deep red	Bitter	
	Chamaemelum nobilis Mill.	English chamomile	White petals, yellow centre	Sweet apple	
	Chrysanthemum coronarium L.	Garland chrysanthem um	Yellow to mild	Mild	
	Chicorium intybus	Chicory	Blue to Lavender	Similar to endive	

	Dendranthema x grandifolium Kitam	chrysanthemum	Various	Strong to bitter	
	Leucanthemum vulgare lam.	Oxeye daisy	White yellow centre	mild	
	Tagetes erecta L.	African marigold	White, gold	Variable, mild to bitter	
	Target tenuifolia Cav.	Signet marigold	White, yellow, gold, red	*Citrus, milder than T. erecta*	
	Taraxicum officianle L.	Dandelion	Yellow	Bitter	
Begonaicea	*Begonia tuberhybrida*	Begonia family Tuberous begonia	Various	Citrus	
Boraginaceae	*Borago officinalis L.*	Borage family Borage	Blue, purple, lavender	Cucumber	

Brassicaceae	*Brassica spp.*	Mustard family mustard	Yellow	Tangy to hot	
	Eruca vesicaria Mill.	Arugula	White	Nutty, smoky	
	Raphanus sativus L.	Radish	White, pink	Spicy	
Caryophyllaceae	*Dianthus spp.*	Pink family Pinks	Pink, white, red	Spicy, cloves	
Cucurbitaceae	*Cucurbita pepo L.*	Gourd family Summer squash, pumpkin	Yellow	Mild, raw squash	
Fabaceae	*Cercis Canadensis L.*	Pea family Redbud	Pink	Bean-like to tart apple	
	Phaseolus coccineus L.	Scarlet runner bean	Bright orange to scarlet	Mild raw bean	

	Pisum sativum L.	Garden pea	White, tinged pink	Raw pea	
	Trifolium pretense L.	Red clover	Pink, lilac	Hay	
Geraniaceae	*Pelargonium spp. L'Hérit*	Geranium family Scented geraniums	White, red pink, purple	Various, e.g, apple, lemon spice, etc	
Iridaceae	*Gladiolus spp. L.*	Iris family Gladiolus	Various	Mediocre	
Lamiaceae	*Hyssopus offcinalis L.*	Mint family Hyssop	Blue, pink, white	Bitter, similar to tonic	
	Lavandula augustifolia Mill.	Lavender	Lavender, purple, pink, white	Highly perfumed	
	Melisa officinalis L.	Lemon balm	Creamy white	Lemony, sweet	

	Menthe spp. L.	Mint	Lavender, pink, white	Minty	
	Monardoa didyma L.	Bee balm	Red, pink, white, lavender	Tea-like	
	Ocimum basilicum L.	Basil	White to pale pink	Spicy	
	Origanum vulgare L.	Oregano	White	Spicy, pungent	
	Origanum majorana L.	marjoram	Pale pink	Spicy, sweet	
	Rosmarinus officinalis L.	rosemary	Blue, pink, white	Mild rosemary	
	Salvia rutilans Carr.	Pineapple sage	Scarlet	Pineapple/ sage overtones	

	Salvia officinalis L.	Sage	Blue, purple, white, pink	Flowery sage	
	Satureja hortensis L.	Summer savoury	Pink	Mildly peppery, spicy	
	Satureja Montana L.	Winter savoury	Pale blue to purple	Mildly peppery, spicy	
	Thymus spp.L.	Thyme	Pink, purple, white	Milder than leaves	
Lilaceae	*Hemerocallis fulva L.*	Lily family Daylily	Tawny orange	Cooked asparagus/ zucchini	
	Muscari neglectrum Guss. Ex. Ten	Grape hyacinth	Pink, blue	Grapery	
	Tulipa spp. L.	Tulip	Various	Slightly sweet or bitter	

Malvaceae	*Abelmochus esculentus (L.) Moench.*	Okra	Yellow, red	Mild, sweet, slightly mucilaginous	
	Alcea rosa L.	Hollyhock	various	Slightly bitter	
	Hibiscus rosa-sinesis L.	Hibiscus	Orange, red, purple	Citrus, cranberry	
	Hibiscus syriacus L.	Rose of sharon	Red, white, purple, violet	Mild, nutty	
Myrtaceae	*Acca sellowiara O. Berg*	Myrtle family Pineapple guava	White to deep pink	Papaya or exotic melon	
Oleaceae	*Syringe vulgaris L.*	Olive family Lilac	White, pink, purple, lilac	Perfume, slightly bitter	
Papaveraceae	*Sanguidorba minor Soep.*	Poppy family Burnet	Red	Cucumber	
Rosaceae	*Malus spp. Mill.*	Rose family Apple, crabapple	White to pink	Slightly floral to sour	

Rubiaceae	*Galium odoratum (L.) Scop*	Madder family Sweet woodruff	White	Sweet, grassy, vanilla	
Rutaceae	*Citrus limon (L) Burm.*	Lemon	White	Citrus, slightly bitter	
	Citrus sinensis (L) Osbeck.	Orange	White	Citrus, sweet/strong	
Tropaeolaceae	*Tropaeolum majus L.*	Nasturtium family Nasturtium	Variable	Watercress, peppery	
Violaceae	*Viola odorata L.*	Violet family Violet	Violet, pink, white	Sweet	
	Violate X wittrockiana Gams.	Pansy	Various, multicoloured	Stronger than violets	
	Viola tricolor L.	Jonny-jump-up	Violet, white, yellow	Stronger than violets	

omelets, curries, biscuits and as side dishes (Roberts, 2000). Table 2.2 reflects the abundance of eye catching colours in different types of flowers, ranging from violet, orange, red, white, pink and white.

2.2.3 Flowering vegetables of Southern Africa

Roberts (2000; 2014) compiled a list of common flowers, their applications, as well as recipes that can be made using different flowers, in Southern Africa (Table 2.3). Some of the flowers are similar to the ones in Table 2.2 and include flowers like coriander, daylily, nasturtium, mint, squash, violet and yucca. According to Roberts (2000; 2014), these flowers are used in a variety of dishes like health tea, soup, salads, curries, sauces and as seasonings in cake making.

Table 2.3: Edible flowers in Southern Africa and their applications (Roberts, 2000; 2014)

Botanical name	**Common name**	**Applications**	
Pimpinella anisum	Anise	On salads, savoury dishes, fruity desserts	
Monarda didyma	Bergamot	In bean dishes, stews and soups	
Borago officinalis	Borage	In cordials, salads, desserts	

Fagopyrum esculentum	Buckwheat	On cakes, salads, vegetable dishes	
Calendula officinalis	Calendula	On omelets, curries and desserts	
Dianthus caryophyllus	Carnation	In wines, fruit juices, pickles	
Chamaemelum nobile	Chamomile	For making tea, syrup, fruit jellies	
Allium schoenoprasum	Chives	In salads, pasta dishes, vegetable dishes	
Coriandrum sativum	Coriander	In curries, soups, sauces, vinegar, vegetable dishes	
Centaurea cyanus	Cornflower	In sauces, pasta dishes, desserts	

Hemerocalis	Day lily	In vegetables dishes, salads	
Sambucus nigra	Elder flowers	In making fritters, lemonade, desserts	
Oenothera biennis	Evening primrose	In soups, stews, teas, pickles	
Foeniculum vulgare	Fennel	In making tea, salads, toddies, soups	
Fushia *corimbiflora*	Fuchsia	In vegetable dishes, salads, desserts	
Gardenia jasminoides	Gardenia	Can be tucked into raw rice, oats or sago. In salads, nourishing drinks, desserts	
Gladiolus hybrids	Gladiolus	In salads, soups, stews, sandwiches	

Althaea rosen	Hollyhock	In pancakes, scones, salads	
Lonicera	Honeysuckle	In fruit salads, energy drinks, syrup	
Jasminum	Jasmine	In making syrup, tea, desserts	
Lavandular anguistifolia	Lavender	In biscuits, side and vegetable dishes	
Linum usitatissimum	Linseed	In salads, fruit salads, stir fries, on desserts, cakes, cool drinks, soups	
Medicago sativa	Lucerne	For making energy drinks, soups, in vegetable dishes	

Mentha	Mint	In desserts and vegetable dishes	
Brassica alba	Mustard	In salads, pickles, curries, on sandwiches	
Myrtus communis	Myrtle	In making pepper, stir fried desserts, cheese spread	
Trapaeolum majus	Nasturtium	In salad vinegar, dips, salads	
Citrus	Orange blossom	In puddings, iced tea, fairy butter	
Viola lutea	Pansy and Viola	In making desserts and side dishes	

Prunus persica	Peach blossom	In making desserts, fruit salads	
Papaver rhoeas	Poppy	In making brandy, vinaigrette, muffins	
Cucubita	Pumpkin, squash and marrow	In soups, salads, vegetable dishes	
Eruca vesicaria	Rocket	In curries, soups, vegetable dishes	
Rosa	Rose	In syrup, jellies, drinks	

Rosamrinus	Rosemary	In stews, roast, marinades	
Salvia officinalis	Sage	In making side dishes, soups, drinks	
Helianthus annuus	Sunflower	In sauces, marinates, salads	
Tulipa	Tulip	In syrup, sandwich fillings, salads	
Viola odorata	Violet	In desserts, syrup, liqueur	

Aponogeton	Waterblommetjie	In stews, soups, stir fries	
Nymphaea	Water lily	In salads, desserts, drinks	
Wisteria sinensis	Wisteria	In fritters, salads, vegetable dishes	
Ichillea millefolium	Yarrow	In fish dishes, stir fries, stews	

Yucca gloriosa	Yucca	In soups, desserts, vegetable dishes	

2.2.4 Flowering vegetables of Lesotho

In Lesotho it is more a case of eating the flowers as a vegetable, rather than using it for decoration of novelty products. In their cuisine, the Basotho like to eat leaves more than flowers and they don't garnish or decorate their dishes when serving the food (Ramasike, 2013). According to Lephole (2004), the Basotho consume dandelion and watercress leaves, not flowers. Fox and Young (1982) made a compilation of the vegetables consumed in Southern Africa, indicating their distribution and applications. In Lesotho, only eight flower vegetables were detailed, without recipes on how to prepare it for vegetable dishes (Table 2.4) (Fox & Young, 1982).

Table 2.4: Edible flowers of Lesotho and their applications (Fox & Young, 1982)

Botanical name	Common name	Applications	
Rhus engleri Britt.	Velvet	As a beverage, as a relish	
Asclepias eminens (Harv.) Schltr.	*Montsokoane*	Eaten whole as a herb, eaten raw as a vegetable	

Asclepias multicaulis (E.Mey.) Schltr.	*Lenkileng*	Flowers are eaten raw or cooked	
Europhorbiaceae	Milkweed	To give a pleasant taste to sour milk, dried latex used as a chewing gum	
Trifolium africanam Ser. Var.	Cape clover	Eaten raw as a vegetable	
Gunnera perepensa L.	River pumpkin	Eaten raw as a vegetable	
Tubalbaghia alliaceae L.	Wild garlic	Eaten as a cooked vegetable and regarded as delicacy	
Epilobium hirsutum L.	Salt of the shepherds	Sap licked from the flowers	
Portulaca quadrifida L.	Purslane	As a salad	

2.2.4.1 Agave (*Agave americana)*

Meuninck (2000) describes *A. americana* as long, sword-like, stiff, fibrous leaves, shooting skyward in circular cluster; three m high flower stalks grow from the leaf cradle, with clusters of yellow flowers. The genus *Agave* belongs to the Family *Agavaceae*, which has more than 300 species (Ramirez, Gomez-Ayala, Jaques-Hernandez, & Vasquez, 2006). *Agave americana* is one of the 136 species of leaf succulents, forming part of 650 tropical and sub-tropical plants in the Agavaceae family (Nobel, 1988; Nobel, 1994). This plant originates from Mexico and is one of a few species able to grow in the arid regions of Southern Africa, using grassulacean arid metabolism and producing fructans as the principal reserve carbohydrate (Ravenscroft *et al*., 2009). Common names include century plant, maguey or American aloe. It is characterized by fleshy, rigid and hard-surfaced leaves growing directly out from the central stock to form a dense rosette. The leaves of various species range in length from 1 - 2 m, and in most species, the edges of the leaves contain sharp spines or thorns (Zwane *et al.,* 2011)

2.2.4.2 Distribution

The plant is found mainly in Mexico, Central America, Spain, Western North America, South America and the Caribbean Island, Cerén (El Salvador). The agave plant was introduced to Europe and Africa by the Spanish in the 16th century and it now grows naturally in the arid climates of the Mediterranean countries, India and Pakistan (Msahli, Chaabouni, Sakli, & Drean, 2007).

Agave is furthermore found in the APEC (Asian Pacific Economic Community) countries, developing countries, Latin America, America, North America, the OECD (Organisation for Economic Co-operation and Development) countries, threshold (poor) countries, Anglophone (Five countries in West Africa, including Nigeria), Africa, Commonwealth of Nations, Southern Africa and Africa South of Sahara (Smith & Figueiredo, 2011).

2.2.4.3 Cultivation

The agave plant is propagated by detaching the well-rooted suckers appearing at the base, or by plantlets formed on the flower spike (Gilman, 1999) (Figure 2.4). *Agave tequilana* var. *azul* is normally propagated asexually through offsets or suckers formed on rhizomes. Sexual reproduction in *A. tequilana* normally begins in February or March, when the vegetative apical meristem retracts or sinks, marking the transition from vegetative apical meristem to floral meristem. Once initiated, inflorescence or 'quiote', which is covered with bracts, undergoes a period of rapid growth until reaching a height of around 5 - 6 m. At a height of around 4 m, lateral branched or umbels begin to form on the inflorescence (Escobar-Guzmán, Hernández, Vega, & Simpson, 2008). Plants can also multiply by basal sprouts that grow around the mother plant or by seeds, at 20 ºC, at the beginning of spring (Rivera *et al*., 2010).

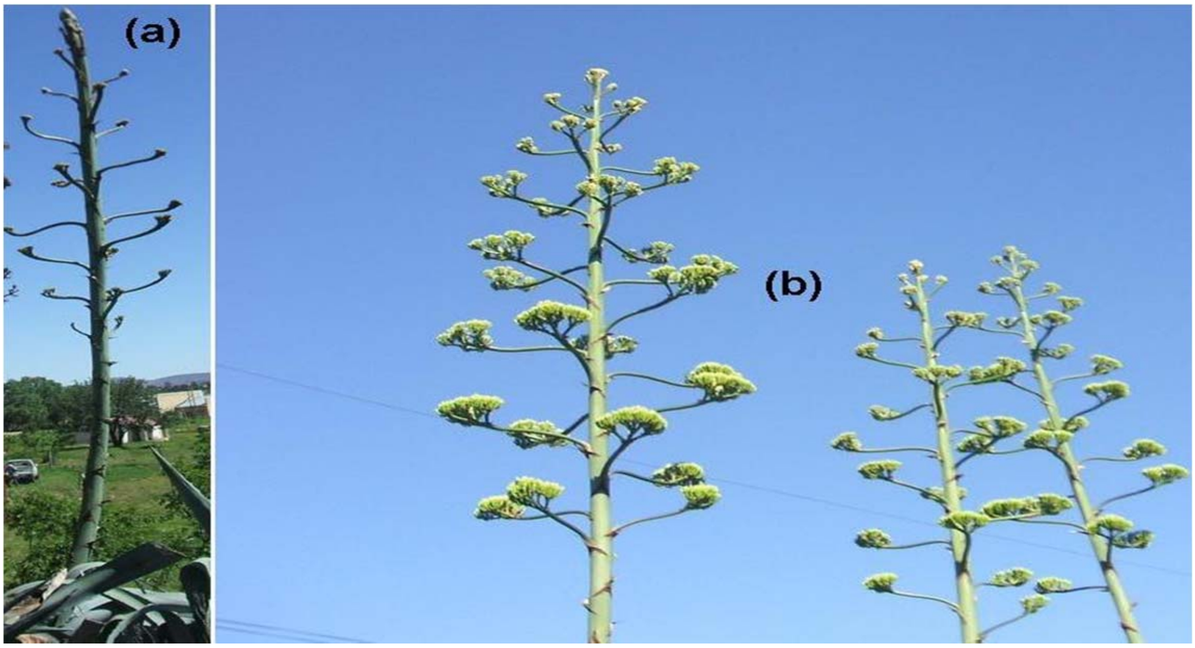

Figure 2.4: A*gave americana* at different stages of flowering
(a) The whole plant with leaves at the base of the plant and the flower buds towards the top part of the plant, at the initial stage of flowering
(b) The flowers of the plant at later stages of flowering

2.2.4.4 Plant components

The plant is composed of roots, leaves, branches, sap, stem, flowers and nectar. Furthermore, it has a large rosette of thick fleshy leaves, generally ending in a sharp point and with a spiny margin (Jagadeesh, 2006; Zwane, Msarirambi, Magagula, Dlamini, & Bhebhe, 2011).

2.2.4.5 Flower

The flowers are yellow-green in colour and have the following morphometric characteristics, with the average length of each part in brackets: floral length (11 cm); corolla length (3.5 cm); corolla diameter (6 cm); ovary length (3 cm); tube length (0.7 cm) and tube diameter (2 cm) (Silva-Montellano & Eguiarte, 2003). The corolla refers to the petals of the flower, which typically form a whorl within the sepals (at the base of the flower), enclosing the reproductive organs. Each flower has six pollen carriers, about 9 cm long, rising 5.5 cm above the corolla and five petals (Figures 2.5 and 2.6) (Silva-Montellano & Eguiarte, 2003).

Figure 2.5: Various plant components of *A. americana* (Picturing Plants, 2011)

Figure 2.6: *Agave americana* flowers during various stages of flowering.

2.2.4.6 Applications

In the past, according to Tšolo (2009), Basotho children used to eat the nectar, found inside the flowers of *A. americana*. Delta Wild (2003) showed that indigenous cultures have employed many species of *agave* in a multitude of ways: food; medicine; soap; cordage insulation; and building materials. Jagadeesh (2006) also listed the different parts of the plant (roots, leaves, sap and stem), as well as their uses, including food, diuretic, fibre, fodder and detergent. Young shoots of *A. americana* are used as a vegetable and are also pickled (Verma & Chauhan, 2005). In Thailand these plants have a variety of uses, varying from ropes, fibres, mescal or tequila (distilled liquors), ornamental and medicinal to fences, while it is also used as pulque (sap from the living agave plant, consumed fresh or fermented) in Mexico (Nobel, 1988; Nobel, 1994). In Mexico, agave, along with cactus pear, are used as vegetables and fruits, forage, fuel, live fences, medicine, cosmetics and they also help to prevent soil erosion (Brieceño, 2005). An *A. americana* plant can be "bought" for a season to extract the plant sap. Just before flowering, the core is cut out of the plant and a hole is made in the base. Plant sap collects in this hole and is harvested twice a day for about a month (Van Den Eynden, Cueva, & Cabrera, 2003). *Agave americana* is one of the 500 more widely used medicinal plants in several countries (Lozoya as cited by Monterosas, Ocampo, Jimenez-Ferrer, Jimenez-Aparicio, Zamilpa, Gonzalez-Cortazar, Tortoriello, & Herrera-Ruiz, 2013).

Cooked *agave* is eaten in several ways (Zwane *et al.,* 2011); flat cakes or patties are made from outer slices of the blackened heart. To eat, one simply dissolves a cake in water and then drinks everything, except the pieces of charred pulp (Felger & Moser, 1970). Seeds of the plant are ground into flour or used with cereal flours when making bread, while the flower stalk is roasted or used like asparagus. Sap from the cut flowering stem is used as syrup (Gentry, 1982).

The leaves of the plant are used to produce fibre, saponins and other chemical compounds with several applications in the industries of paper manufacturing and cosmetics. The core is used to obtain industrial alcohol, spirituous beverages, high fructose syrups, fructans and sugar substitutes (Narvàez-Zapata & Teyer, 2009; Zwane *et al.,* 2011). Hecogenin, tigogenin, agava saponin E and H are saponins which have been isolated and identified in *A. americana* (Peana *et al.,* Yokosuka *et al. and* Jin *et al; as* cited by Monterosa-Brisson *et al.,* 2013). Inulin from the agave plant has been reported to be more soluble in cold water when compared to inulin extracted from chicory, thereby giving it a wider application in the food industry (Cooper, 1995; Petrovsky, 2005). Agave contains 90% fructose, indicating a low glycemic index (GI), so it can be useful as a sugar alternative (Kuhnlein, 2004).

2.3 SENSORY PROFILING

2.3.1 Sensory profile of flowering vegetables

From a study done by Schönhof, Krumbei, and Brückner (2004), it was found that consumers did not prefer cauliflower and broccoli cultivars with low sugar contents. The researchers therefore suggested that masking the bitter taste, caused by a group of glucosinolates, by raising the sugar content would increase consumer acceptability. Another result for this study was that purple and dark colours did not correspond to the consumer's aesthetic expectations, either with broccoli or cauliflower. In the case of cauliflower, a not too intense green colour was found to be acceptable (Schönhof *et al*., 2004). In research done by Brückner, Schönhof, Kornelson and Schrödter (2005), it was concluded that the consumer panel preferred cauliflower samples with greater sweetness, juiciness and cauliflower flavour. Sweetness, crispiness and intensity of broccoli and cauliflower flavour were the most important attributes for broccoli acceptability. More intense bitter, pungent and green/grassy notes reduced acceptability. A large majority of consumers indicated a greater preference for both broccoli and cauliflower samples which had more sweetness and broccoli/cauliflower flavour, and low intensities of bitter and pungent notes. Glucosinolate content affected sweetness, as well as bitter and pungent notes.

According to Batty-Julien and Helias (2011), the key attributes on the sensory characteristics of the globe artichoke are damp hay odour, artichoke odour and flavour, melt in the mouth texture and bitter taste. The Camus cultivar could be distinguished from the Castel cultivar by a less earthy odour, a different texture (less firm, less crunchy, less fibrous and pastier), and a less intense dried fruit flavour. Camus artichokes had a less gritty texture, a more intense butter flavour and a more bitter taste. The bitter taste of artichokes is usually attributed to the presence of polyphenols such as cynarin and lactones like cynaropicrin (Batty-Julien & Hélias, 2011).

2.3.2 Sensory profile of agave flowers

From the literature it is clear that almost no research has been done on the sensory aspects of the agave flower. Semuli (2010) did a consumer panel on the influence of different preparation methods on the acceptability of the flowers. Twenty five consumers, male and female, who had never tasted agave flowers before, used a nine-point hedonic scale to respond to the question “how much do you like or dislike the sample?” Each respondent received one two cm piece of the flower per treatment. The different treatments included: freshly steamed; freshly stir-fried; pickled for one week; stir-fried frozen blanched (one week); steamed frozen blanched (one week); pickled (three months); stir-fried unblanched frozen (three months); and stir-fried blanched frozen (three months). For the steaming and stir-frying treatments, the flowers were lightly flavoured with salt and pepper. Sunflower oil was used for the stir-frying and the pickled samples were kept in a brine of vinegar, salt and pickling spices.

The cooking methods resulted in some weight loss of the flower buds. Stir-frying resulted in the highest percentage weight loss (4.0%), while steaming recorded the lowest weight loss (2%). The flowers tasted best when the buds were completely opened, not before, and cooking resulted in the buds to open (Figure 2.7) (Semuli, 2010).

In this sensory test, there was a significant ($p < 0.05$) difference for the overall liking between the eight agave flower treatments tasted. The most liked sample was the three month old pickled flowers with the highest mean value of 5.92, which corresponded to between “neither like nor dislike” and “like slightly”. The least acceptable treatment (3.72) was categorized as between “dislike moderately” and "dislike slightly" on the nine-point hedonic scale (Semuli, 2010). This treatment was the three month old unblanched frozen samples, being stir-fried, lightly salted and peppered, in sunflower oil. It was commented by some panel members that these specific samples were very sour, indicating the possible presence of enzymes in the plant tissue, causing off-flavours or sourness (Bayindirli, 2010).

Figure 2.7: Steamed flower buds of *A. americana*, now revealing the stamens and pistils (The flowers were completely closed before steaming and completely opened up after cooking).

Possible explanations for the low ratings in this study could be dual. Firstly, the flowers were picked at the end of the season, in February. Flowering only started in December and continued to January (Semuli, 2010). All vegetables do have an optimal harvesting ripeness where after suitability for human consumption and use in the production of products will diminish (Wills & Mahendra, 1989; Ronsivalli & Viera, 1992). Different chemical processes continue in the vegetables, like sugar-to-starch conversion, changes in pectic substances, etc. (Wills & Mahendra, 1989), which will definitely influence the flavour and taste profile of the vegetable. Therefore, it may be plausible that the same processes occurred in the agave flowers, which led to unpleasant flavours and tastes (Semuli, 2010).

A second reason for the poor performance of the agave flowers in this taste test may be the treatments used. In all the treatments the flowers were tasted on its own, only flavoured by salt, pepper or soaked in brine. Future applications may involve the inclusion of the flower as part of a complex dish, e.g. in a salad, cooked with potatoes and onions, like green beans, or dipped in batter and fried in oil (Semuli, 2010).

2.4 CONCLUSIONS

The recognition of wild and cultivated food plants is increasing worldwide and interest is aroused by the importance of these plants as sources of micronutrients. Traditional food plants are regarded as nutraceuticals or functional foods and are consumed mainly because of their health benefits. They are also eaten when recognized vegetables are not available, as a way of addressing food security in many parts of the world, especially in developing countries. Regardless of their importance, the availability of indigenous vegetables has declined hugely, due to massive cultivation of field crops. The scarcity of these valuable plants has impacted many rural communities negatively, as the incidence of nutritional disorders has increased in these areas.

Nowadays, flowers are incorporated in different dishes when preparing food, namely in desserts, stews, salads, drinks, soups and sauces. They are also used as garnishes and decorations for other dishes. In other areas flowers are not eaten as cooked vegetables, but rather as raw delicacies, while some are used as seasonings and herbs.

Cauliflower, broccoli and artichokes are the best known flowering vegetables and play an important role in the human diet, because of cancer preventing antioxidants and glucosinolates. On top of micro nutrients, these commonly used flowers also contain proteins and some essential amino acids, and cauliflower, broccoli and artichokes are included in diets mainly for their health benefits.

The agave plant is well known in the world for the production of tequila, agave syrup and inulin. However, not much is known about the nutritional composition and sensory profile of the *A. americana* flower for human consumption. In the preparation of other flowering vegetables, such as artichokes, broccoli and cauliflower, various cooking techniques can be used to enhance the flavour properties, e.g. steaming, stir frying and boiling. Commonly used preservation techniques, such as freezing, canning and brining, increase the shelf life of these vegetables and where applicable, prevent season ability from limiting the availability of these foodstuffs to the consumer.

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CHAPTER 3

NUTRITIONAL COMPOSITION OF FRESH *Agave americana* FLOWERS AND COMPARISON TO THE MOST COMMONLY EATEN FLOWER VEGETABLES

3.1 ABSTRACT

The agave flowers used in the present study, had the following nutritional composition: high in moisture (86.62%): low in energy (226 kJ/100 g), proteins (1.71 g/100 g) and fat (0.46 g/100 g); average dietary fibre (2.12 g/100 g); high in K (207.77 mg/100 g); average amounts of Mg (53.06 mg/100 g), Ca (48.33 mg/100 g), and P (32.12 mg/100 g); and low levels of Na (1.27 mg/100 g), Fe (1.03 mg/100 g), Zn (0.66 mg/100 g), Cu (0.04 mg/100 g) and Mn (0.15 mg/100 g). In agreement with many other vegetables, the flower samples contained sugars in the form of sucrose (0.52 g/100 g), glucose (0.77 g/100 g), fructose (1.06 g/100 g) and maltose (0.69 g/100 g). The vitamin C content was 1.03 mg /100 g, but no vitamin A was detected.

When compared to other flower vegetables, the agave flower had the lowest contents for protein, P, K, Mn, Na, Cu and vitamin C, but the highest value for fat. The agave flower and artichoke had similar values for energy, moisture and Mg, while the cauliflower and agave compared well in regard to Ca and Zn contents. Broccoli had similar contents for protein, fibre, P and Cu. The agave had higher values for energy, and fat than cauliflower, and higher fat and Ca, Fe, Mg, P and Zn values than broccoli. Artichokes had lower contents for moisture, fat, Ca and Zn than the agave flowers. Broccoli and cauliflower were moister than the agaves.

3.2 INTRODUCTION

More attractive and tasty food is nowadays being demanded on global scale. Quality of foodstuffs, as well as aesthetic aspects, contributes to the appearance of consumed meals, and this could be enhanced by edible flowers (Rop, Mlcek, Jurikova, Neugebauerova, & Vabkova, 2012). These have been an integral part of human nutrition for centuries and today, sales of fresh, top-quality flowers for human consumption are increasing world-wide. Continuous interest in edible flowers are due to globalization, which has contributed to a better awareness of consumers, as well as a comeback to earlier lifestyles, in which edible flowers played an important role. New food-processing technologies, logistic methods and quick distribution of cooled and well-preserved foodstuffs have enabled the consumer to return to earlier food resources (Mlcek & Rop, 2011).

The main sources of edible flowers are vegetables, fruit, medicinal and ornamental plants (Kelley, Behe, Biernbaum, & Poff, 2001). The contents of common components (proteins, fat, sugars, and vitamins) in flowers are not very different from those in other plant organs, e.g. in leaf vegetables. An example is where the crude protein of edible flowers are similar to that in fruit or vegetable (Aletor, Oshodi, & Ipinmoroti, 2002). However, it must be emphasized that the composition and nutritional value of each botanical species of edible flowers are quite unique (Purves, Sadava, Orians, & Heller, 2004). One of the most essential aspects that influence the use of edible flowers in human nutrition is the mineral contents (Rop *et al.,* 2012).

Edible flowers are an excellent source of minerals, especially of P and K (Rop *et al.*, 2012). Most of the minerals in the human body are salts containing Ca and P, as the building blocks of the human skeleton. Macroelements and microelements generally prevent many diseases and strengthen the human immune system (Campbell & Reece, 2006). For the macroelements, P has the following functions: part of nucleic acids, ATP and phospholipids; is important in bone formation; acts as a buffer; and plays a role in the metabolism of sugars. Potassium is important for nerve and muscle action, protein synthesis and is also the principal positive ion in cells. Calcium is found in bones and teeth, and plays a role in blood clotting, nerve and muscle action, as well as enzyme activation, while magnesium is required by many enzymes. Sodium is also important in nerve and muscle action, and water balance, and is the principal positive ion in tissue fluids.

Regarding microelements, Fe and Cu are found in the active sites of many redox enzymes and electron carriers, such as hemoglobin and myoglobin; Cu also plays a role in the production of hemoglobin and bone formation. Manganese and Mo activate many enzymes, while Co is found in vitamin B_{12} and is also of importance in the formation of red blood cells (Campbell & Reece, 2006).

Flowers which are unkown or toxic for humans may be dangerous. Beside toxic effects, it is also possible that even flowers which are clean and seem to be safe, may induce toxic and allergic reactions in people who are sensitive to some of their unidentified components. The amount of eaten flowers can also be a limiting factor (Rop *et al.*, 2012).

The aim of this study was therefore to determine the nutritional composition of *A. americana* flowers and to compare it to the most popular flower vegetables used for human consumption.

3.3 MATERIALS AND METHODS

3.3.1 Flowers

3.3.1.1 Identification of flowers

Identification of flowers was carried out in cooperation with volunteers from different areas in Lesotho. The local inhabitants of the chosen areas are well acquainted with this flower and were asked to look for flowers in full bloom.

3.3.1.2 Selection of flowers

Flowers were selected from three different areas in Lesotho: Sehlabeng (Maseru); Maliepetsane (Mafeteng); and Ha-Ramoshabe (Mafeteng). Flowers from all three areas were collected from as many different wild plants as possible. Flowers were pooled, since, in a preliminary study, no significant differences in chemical composition were found amongst flowers from the different areas.

3.3.1.3 Collection of flowers

The collection of flowers was conducted during the summer and autumn season. Some of the samples had either over-reached their seasonal maturity and/or not yet reached their optimal maturity stage. Harvesting was done with great care in order to maintain the quality, as well as to prevent the flower buds from falling on the ground. The plant is very high, so the harvester had to use a ladder in order to access the flower buds. The branch was cut from the main stem with a very sharp knife and the flowers removed from the main branch, by cutting or breaking, depending on the stage of maturity.

3.3.1.4 Flower preparation

All the flower samples were stored in plastic bags, from the collection site to the preparation area in Lesotho. The flowers were cut from the main stem and packed in freezer bags, where after they were frozen at -18°C for four months. Half of the flowers, from the three collection sites, were blanched before freezing. After four months, they were packed in a cooler bag for transportation from Lesotho to the University of the Free State, Bloemfontein, South Africa. At the Food Science Division they were put into freezers again, until analyses were performed.

3.3.2 Chemical analysis

3.3.2.1 Vitamin C

The ascorbic acid content of *agave* flowers was determined using 2, 6-di-chlorophenol-indophenol method ASM 057 (AOAC, 2000). Fifteen grams of meta-phosphoric acid was dissolved in 40 ml acetic acid and 200 ml distilled water, which was then diluted to 500 ml standard ascorbic acid (1 mg/ml). Approximately 30 g sample was subjected to extraction by pressing with a high speed blender (Salton Elite Stick Blender high speed model SSB40E 230-300 W); making a pulp and mixing with 50 ml extraction solution plus 50 ml sample. The samples were poured into centrifuge tubes and centrifuged in a Beckman J2-21centrifuge, at 5000 rpm for 20 min, using a Beckman JA-14 rotor. The pulp was separated from the juice and 7 ml of this juice was subjected to titration (Brubacher, Müller, & Southgate, 1985).

3.3.2.2 β-carotene

Samples were centrifuged for 15 min at 5800 rpm. About 30 g of flowers were extracted with 250 ml hexane, 125 ml acetone, 125 ml ethanol, where after 4.5 ml hexane plus 0.5 ml sample were mixed and stirred. Carotenoid extraction and determination was performed by filtering samples through a column of aluminium oxide, packed in a Pasteur pipette, plugged with glass fibre, and then washed with hexane until clear. Two milliliters of sample was diluted to 10 ml with hexane. Total carotenoid was determined with a Genesys 10 spectrophotometer, at 450nm (ASM 072) (Brubacher *et al*., 1985).

3.3.2.3 Free sugars

Free sugars, sucrose, glucose and fructose were determined by the method of Riaz and Bushway (1996) (ASM 017). Sugars were extracted by placing a 30 g flower sample in a 100 ml beaker, chopping it with a Salton Elite Stick Blender (model SSB40E 230-300W), and stirring after every 30 min with 50 ml 95% ethanol. Samples were shaken 20 times, kept at room temperature overnight, and then centrifuged for 15 min at 5800 rpm in a Beckman JA-14 rotor, before analysis by (HPLC). High performance liquid chromatography was carried out on a Waters System (501 pump) and Biorad Aminex column (7.8 mm X 300 mm), with a differential refractive index detector (R401) operated at 42ºC and a mobile phase of de-ionised water at a flow speed of 0.6 $ml.min^{-1}$ and temperature of 85ºC.

3.3.2.4 Fibre

Fibre was determined by the acid detergent fibre method (ASM 059) (Goering & Van Soest, 1970; Robertson & Van Soest, 1981; AOAC, 2005). Twenty grams acetyl tri-methyl bromide was dissolved in 28 ml 98% sulphuric acid and 1 ℓ of distilled water. The samples were air dried and milled to pass through a sieve with circular openings (1 mm in diameter). One gram of sample, in a small tube, was put overnight in the oven at 105ºC. Samples were put in a desiccator for 30 min, then placed in a hot extraction unit and cooled on the condenser cooling water. Hundred milliliters of acid detergent solution was added to each sample and heated on the heating element for 1 h. Samples were filtered with suction and washed three times with hot water and then rinsed twice with acetone. The samples were subsequently incinerated at 500ºC for 4 h and the mass of the remaining ash was determined.

3.3.2.5 Protein

Nitrogen was determined with the combustion method (ASM 056) (AOAC, 2005), using a Leco nitrogen analyzer. Protein content was calculated based on nitrogen content: % N x 6.25.

3.3.2.6 Moisture

Moisture was determined by oven drying (ASM 013) (AOAC, 2005) approximately 10 g of sample at 102^{o}C for 18 h and loss in weight was reported and moisture percentage was determined as follows:

% Moisture = loss in weight /sample weight x 100

3.3.2.7 Minerals

Mineral content was determined with a Varian Spectra 3000 atomic absorption spectrometer, according to the wet digestion method for plant analysis (FAO, 2008).

3.3.2.8 Ash

Ash was determined (AOAC 920.153, 2005) by burning the flowers in a muffle furnace at 525˚C for 18 h (ASM 048). To avoid samples boiling over and therefore sample loss, the furnace was started at 100˚C to dry the sample for two h and thereafter the temperature wais increased hourly, with 100˚C increments, until 525˚C was reached. The ash was then weighed and ash percentage was calculated as follows:

% Ash = weight of ash / weight of sample x 100

3.3.2.9 Fat and fat free dry matter (FFDM)

Extraction of total lipids from the flowers (± 5 g) was performed quantitatively, according to Folch, Lees and Sloane-Stanley (1957), using chloroform and methanol in a ratio of 2:1. Butylated hydroxytoluene (BHT) was added to the chloroform:methanol mixture as an antioxidant, at a concentration of 0.001%. The extracts were dried under vacuum in a rotary evaporator and further dried in a vacuum oven at 50ºC for 3 h, with phosphorus pentoxide as moisture adsorbent (ASM 048).

Total extractable fat content (EFC) was determined by weighing and expressed as % fat (w/w) per 100 g sample. The FFDM content was determined by weighing the residue on a pre-weighed filter paper, used for Folch extraction after drying. By determining the difference in weight, the FFDM could be expressed as % FFDM (w/w) per 100 g sample.

3.3.2.10 Energy

Energy was calculated following the guidelines described by Atwater and Bryant (1900), and Greenfield and Southgate (2003) (ASM 076):

$$ME = (GE_p - 7.9/6.25)D_p + GE_fD_f + GE_{cho}D_{cho}$$

Where, GE_p, GE_f and GE_{cho} = the gross energy of protein, fat and carbohydrate, respectively

D_p, D_f and D_{cho} = the digestibility coefficient of protein, fat and carbohydrate, respectively

3.3.3 Reagents

All reagents were of analytical grade and obtained from Merck, Halfway House, South Africa, unless indicated otherwise.

3.3.4 Statistical analysis of chemical data

Averages of three replications were determined, as well as the standard deviation, unless otherwise indicated.

3.4 RESULTS AND DISCUSSIONS

3.4.1 Chemical composition of *A. americana* flowers

The nutritional composition of the agave flower is given in Table 3.1. The results are expressed as average of the three research areas – Sehlabeng, Maliepetsane and Ramoshabe and represent the average of three repetitions, unless otherwise indicated.

Looking at the nutritional composition of other edible flower vegetables and agave flowers, there is a similar pattern on the nutrients contained by these vegetables (Aslam, Anwar, Nadeem, Rashid, Kazi, & Nadeem, 2005; Rop *et al.*, 2012), even though the contents differ in terms of quantity. For the agave flowers used in the present study, the nutritional composition was as follows: high in moisture (86.62 %): low in energy (226 kJ/100 g), proteins (1.71 g/100 g) and fat (0.46 g/100 g); average dietary fibre (2.12 g/100 g); high in K (207.77 mg/100 g); average amounts of Mg (53.06 mg/100 g), Ca (48.33 mg/100 g), and P (32.12 mg/100 g); and low levels of Na (1.27 mg/100 g), Fe (1.03 mg/100 g), Zn (0.66 mg/100 g), Cu (0.04 mg/100 g) and Mn (0.15 mg/100 g).The flower samples also contained sugars in the form of sucrose (0.52 g/100 g), glucose (0.77 g/100 g), fructose (1.06 g/100 g) and maltose (0.69 g/100 g). The vitamin C content was 1.03 mg /100 g and no vitamin A was detected (Table 3.1).

Table 3.1: Nutritional composition of wet *A. americana* flowers per 100 g edible portion

Nutrient	**Unit**	**Amount**
Moisture	(%)	86.62 ± 2.59
Energy (calculated)	kJ	226.09*
Protein	g	1.71 ± 0.13
Dietary fibre	g	2.21 ± 0.22
Fat	g	0.46 ± 0.02
Vitamin A	mg	nd
Vitamin C	mg	5.15*
Ca	mg	48.33 ± 24.73.
Fe	mg	1.03 ± 0.33
Mg	mg	53.06 ± 4.37
P	mg	32.12 ± 7.07
K	mg	207.77 ± 20.09
Na	mg	1.27± 0.75
Zn	mg	0.66 ± 0.10
Cu	mg	0.04 ± 0.02
Mn	mg	0.15 ± 0.09
Sucrose	g	0.52 ± 0.23
Glucose	g	0.77 ± 0.37
Fructose	g	1.05 ± 0.28
Maltose	g	0.69*

*single analysis
nd=not detected

When compared to the rest of the agave plant, the flower is less nutritious. In a study by Rivera *et al*. (2010) on this plant being a functional food, the roots, leaves and sap, combined, had a dietary fibre content of 6.42 g/100 g, compared to the 2.21 g/100 g found in the flowers (Table 3.1). Also, for the fructose (0.90 g/100 g) and glucose (1.10

g/100 g), contents were noticeable higher in the roots, sap and leaves, compared to the flowers, respectively, 0.52 g/100 g and 0.77 g/100 g (Table 3.1). The proteins were 2.80 g/100 g for the root, sap and leaves, which was substantially higher than the content found for the flowers (1.71 g/100 g). The vitamin C content was almost double for the root, sap and leaves (11.00 versus 5.15mg/100 g). The mineral content of the roots, sap and leaves were much higher than that of the flower, for the following contents: Fe (1.70 versus 0.78 mg/100 g), Ca (42.0 g/100 g versus 37.18 mg/100 g) and P (71.00 versus 25.00 mg/100 g) (Table 3.1) (Rivera *et al*., 2010).

Both broccoli (91.8%) and cauliflower (88.5) had higher moisture content than the agave flower (86.62), which had a moisture content much closer to that of artichokes (84.9%) (Table 3.2). The energy value of the agave flowers (226 kJ) was in the same range of the artichokes (242 kJ), but almost one third higher than broccoli (133 kJ) and cauliflower (181 kJ). The agave's protein content (1.71 g/100 g) was comparable to broccoli (1.80 g/ 100 g), but lower than cauliflower (3.80 g/100 g) and artichokes (3.3 g/100 g) (Tables 3.1 and 3.2). The agave's protein content compared well with, or was even higher than, vegetables such as beetroot (1.0 g/ 100 g), cabbage (1.2 g/100 g) or carrots (1.0 g/100 g). Fat content (0.46 g/ 100 g) was low, but double that of broccoli, artichokes and cauliflower, all with a value of 0.2 g/100 g. The fibre value for the agave flower (2.21 g/100 g) was the same as for broccoli (2.2 g/100 g), but only two thirds of that for cauliflower (3.3 g/100 g), but only about half of that for artichokes (5.4 g/100 g) (Wolmarans, 2010).

There is not much data about the nutritional composition of the agave flowers, yet it is known that they do contain very sweet nectar, which is sucked by children in Lesotho (Ramasike, 2013). The total sugar content of flowers amounted to 4.01 g/100g and included fructose (1.06 g/100 g), glucose (0.77 g/100 g), sucrose (0.52 g/100 g) and maltose (0.69 g/100 g). According to Wolmarans (2010), the common flower vegetables like cauliflower and broccoli contain about half of the total sugar content of the agave flower (Table 3.2). In a study by Nunes (2008), the main identifiable sugars in fresh cauliflower were fructose (0.76-1.29 g/100 g), glucose (0.6-1.02 g/100 g) and sucrose

(0.06-0.35 g/100 g). Leroy, Grongne, Mabeau, Corre, Batty-Julíen (2009) indicated that globe artichokes contain glucose, sucrose and fructose, and Lahoz, Juan, Migliaro, Macua and Egea-Gilabert (2011) detected sucrose and glucose in eight cultivars of globe artichokes *(Cyanara cardunculus* L.).

Table 3.2: Nutritional composition of well-known edible flowering vegetables per 100g edible portion (Wolmarans, 2010).

Nutrient per 100g edible portion	Unit	Flowering vegetable		
		Artichoke**	Broccoli*	Cauliflower*
Moisture	%	84.9	91.8	88.5
Energy	kJ	242	133	181
Protein	G	3.3	1.8	3.8
Dietary fibre	G	5.4	2.2	3.3
Fat	G	0.2	0.2	0.2
Vitamin A	RE	18	2	66
Vitamin C	Mg	12	70	94
Ca	Mg	44	17	49
Fe	Mg	1.3	0.5	1.2
Mg	Mg	60	19	33
P	Mg	90	45	87
K	Mg	370	304	384
Na	Mg	94	12	14
Zn	Mg	0.49	0.32	0.66
Cu	Mg	0.23	0.07	0.15
Mn	mg	0.26	0.33	0.29
Sucrose	g	0.2	0.1	0.3
Glucose	g	1.5	1.5	0.9
Fructose	g	0.8	1.2	1.4
Maltose	g	0.0	0.0	0.0

*raw
**cooked, globe and French varieties

The content of mineral elements is one of the most essential aspects that influence the use of edible flowers in human nutrition (Mlcek & Rop, 2011). The Ca- (48.33 g/100 g) and Fe-contents (1.03 mg/100 g) of the agave flowers were similar to that of artichokes (44 mg/100 g; 1.3 mg/100 g) and cauliflower (49 mg/100 g; 1.2 mg/100 g), but higher than broccoli (17 mg/100 g; 0.5 mg/100 g). Potassium was the most abundant of the minerals, with a value of 207 mg/100 g for the agave flowers, which was almost two thirds of what was found for artichokes (370 mg/100 g), broccoli (304 mg/100 g) and cauliflower (384 mg/100 g). Phosphorus content for the agave flowers (32.12 mg/100 g) was low and similar to broccoli (45 mg/100 g); in comparison, artichokes (90 mg/100 g) and cauliflower (87 mg/100 g) were three times higher. The Mg content of the agave flowers (53.06 mg/100 g) was almost the same as the content of artichokes (60 mg/100 g), but higher than broccoli (19 mg/100 g) and cauliflower (33 mg/100 g) (Tables 3.1 and 3.2). The lower mineral values of the agave flowers can be explained by the poor quality of the soil, since these flowers were harvested from plants growing in the fields (Liphoto, 2013), whereas the flowering vegetables are cultivated in soil that has been enriched with fertilizers (Yoldas, Ceylan, Yagmur, & Mordogan 2008). The availability of minerals for a plant depends on its speciation in the soil, where the minerals can be present in many different physicochemical forms, e.g. in a free ionic form it is totally available to the plant. Alternatively, the minerals may be present in solution as a chelate, be adsorbed onto mineral or organic surfaces, be present as precipitates or in lattice structures, or be part of live or dead soil biomass, in which case they would either be partly available or completely unavailable to the plants (Frossard *et al.,* 2000).

For the micro-elements, Na was twelve to almost hundred times lower in the agave flowers (1.27 mg/100 g), than in the artichokes (94 mg/100 g), broccoli (12 mg/100 g) and cauliflower (14 mg/100 g). For Zn (0.66 mg/100 g), the agave had the same value as cauliflower (0.66 mg/100 g), which were higher than the artichoke (0.49 mg/100 g) and broccoli (0.32 mg/100 g). Copper values for the agave flowers (0.04 mg/100 g) and broccoli (0.07 mg/100 g) were the same, while the values for the artichokes (0.23 mg/100 g) and cauliflower (0.15 mg/100 g) were four to five times higher. Artichokes (0.26 mg/100 g), broccoli (0.33 mg/100 g) and cauliflower (0.29 mg/100 g) had higher Mn values, than what was found in the flowers (0.15 mg/100 g) (Tables 3.1 and 3.2).

The yellow colour of flowers is usually associated with high vitamin A contents (Mlcek & Rop, 2011), which, in the case of the agave, was not detected at all in the agave flowers analysed (Table 3.1). The other flowering vegetables, namely cauliflower (66 RE/100 g), artichokes (18 RE/100 g) and especially broccoli (2 RE/100 g) do contain vitamin A (Table 3.2). Vitamin C content of the agave flowers (5.15 mg/100 g) was half of the content of artichokes (12 mg/100 g) and seven to nine times less than that of broccoli (70 mg/100 g) and cauliflower (94 mg/100g) (Table 3.2), with cauliflower being one of the richest vegetable sources of vitamin C (Sińgh, Updhyay, Bahadur, & Sińgh, 2008; Koh *et al.,* 2009).

3.5 CONCLUSIONS

The agave flowers had the following nutritional composition per 100 g edible portion: 86.62% moisture; 226 kJ; 1.71 g proteins; 0.46 g fat; 2.12 g fibre; 207.77 mg K; 53.06 mg Mg; 48.33 mg Ca; 32.12 mg P; 1.27 mg Na; 1.03 mg Fe; 0.66 mg Zn; 0.04 mg Cu; 0.15 mg Mn; 0.52 g sucrose; 0.77 g glucose; 1.06 g fructose; 0.69 g maltose; and 1.03 mg vitamin C. No vitamin A was detected.

When compared to other flower vegetables, the agave flower had the lowest contents for protein, P, K, Mn, Na, Cu and vitamin C, but the highest value for fat. The agave flower and artichoke had similar values for energy, moisture and Mg, while the cauliflower and agave compared well in regard to Ca and Zn contents. Broccoli had similar contents for protein, fibre, P and Cu. The agave had higher values for energy, and fat than cauliflower, and higher fat and Ca, Fe, Mg, P and Zn values than broccoli. Artichokes had lower contents for moisture, fat, Ca and Zn than the agave flowers. Broccoli and cauliflower were moister than the agaves.

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CHAPTER 4

DETEMINATION OF THE EFFECT OF DIFFERENT TREATMENTS ON THE SENSORY PROPERTIES OF *Agave americana* FLOWERS

4.1 ABSTRACT

Descriptive sensory analysis was used to investigate how various treatments would influence the sensory properties of *Agave americana* flowers. Blanched and unblanched flowers, subjected to three treatment methods (steaming, stir frying and pickling), were analyzed by ten trained panellists, in three replications. The data was analyzed using principle component analysis. A lexicon of 20 attributes was generated, including 11 for the steamed treatment, an additional six for the stir fried treatment and another four for the pickled treatment. Of these, three descriptors were for the attribute aroma, six for mouthfeel, five for appearance, four for taste and one for aftertaste. The unblanched pickled agave flowers were characterized by crunchy, fibrous and chewy mouthfeel, bitter taste, green pepper colour and cactus appearance, and a cucumber odour. For the blanched pickled agave flowers, taste descriptors were prominent, namely sweet, sour and sweet-sour, followed by a sweet aftertaste, combined with a moist appearance. For all the unblanched flowers, regardless of treatment, some of the descriptors had negative connections, like fibrous, bitter, cactus and rancid. Descriptors for the blanched flowers, again regardless of treatment, were more favourable and included sweet, sour and sweet-sour taste, and green bean and nutty odour. Blanching and pickling had significant ($p<0.0001$) effects on a*, b*, L*, chroma and hue angle values. Physical texture analysis supported the findings of the sensory panel that the unblanched samples had a significantly ($p<0.0001$) tougher mouthfeel than the blanched samples, for all treatments.

4.2 INTRODUCTION

Raw vegetables, like carrots, have sensory variables like sweet taste (Varming, Jensen, Møller, Brockhoff, Christiansen, Edelenbos, Bjørn, & Poll, 2004; Kreutzmann, Christensen, & Edelenbos, 2008; Araya, Smale, Zabaras, Winley, Forde, Stewart, &

Mawson, 2009), fruity aroma, carrot aroma, earthy odour, bitter taste, carrot odour, bitter aftertaste (Varming *et al.,* 2004), green flavour, green odour, crunchy texture and firm texture (Araya, *et al.,* 2009), while bitterness is considered an undesirable taste (Kreutzmann, Svensson, Thybo, Bro, & Peterson, 2008). Cauliflower and red cabbage extracts were found to be sweeter than broccoli and Brussels sprouts, while Brussels sprouts were found to be more bitter than cauliflower, red cabbage and broccoli (Zabaras, Roohani, Krishnamurthy, Cochet, & Delahunty, 2013). Sweetness, umami and saltiness were the main attributes across all *Brassica* samples (Zabaras *et al.,* 2013).

The important sensory attributes for fresh leafy vegetables are off-odour development, general appearance, wilting and browning of fresh-cut vegetable (Piagentini, Mendez, Guemes, & Pirovani, 2005). A trained sensory panel compiled a list of 32 sensory attributes to describe the flavour of fresh leafy greens. This lexicon included: five green attributes; mouthfeel characteristics such as pungent, bite, tooth-etch and heat burn; basic tastes such as bitter and umami; seven terms that described unique flavours related to specific vegetables such as cabbage, celery, lettuce, spinach, parsley, beet and radish leaves; and a group of other terms, including citrus, piney, woody, water-like, musty/earthy, floral, sulphur, metallic, soapy, petroleum and overall sweet (Talavera-Bianchi, Chambers, & Chambers, 2010).

In contrast to this, edible flowers taste differently, e.g. yucca from the agavaceae family tastes slightly bitter, lavender has a strong onion taste and calendula has a tangy peppery flavour. Nasturtium tastes like watercress and has a peppery flavour. Marjoram is spicy and sweet, and daylilies taste like cooked asparagus or zucchini, while dandelion flowers have a bitter taste (Maynard & Hochmuth, 2007).

For the more traditional flowering vegetables, sensory lexicons have also been compiled. The globe artichoke has a wide variety of odour descriptors, such as cauliflower, potato, artichoke and pungent, as well as nutty and fruity. Some attributes such as damp hay, musty, earthy, fresh grass and acid were exclusively quoted for odour, while others were used only to describe flavour, including green bean and buttery. Frankness and astringency were used persistently, along with the taste descriptors of bitterness, sweetness and acidity. Texture descriptors varied from fibrous and firm, to melt in the mouth, crunchy, pasty, gritty and watery (Batty-Julien & Hélias, 2011).

According to Baik *et al.* (2003) and Brückner *et al.* (2005), raw broccoli had the odour of and smelled like fresh newly cut green grass, the flavour of grass and sourness, and a chewing resistant texture (Jacobsson, Nielse, Sjöholm, & Wendin, 2004). It was also characterized by bitter, sulfurous or off-flavours (Baik *et al.,* 2003). Cauliflower and broccoli showed the following properties when tasted raw: brighter and intense colour; green grassy flavour, and sweet and bitter taste (Schonhof *et al.,* 2004; Brückner *et al.,* 2005). Other descriptors included broccoli-like, cauliflower-like, juicy and crispy mouthfeel, and pungent aftertaste (Brückner *et al.,* 2005).

Blanching is a type of pre-heat treatment and involves the immersing of vegetables in boiling water for a few minutes. Alternatively, vegetables can also be blanched by surrounding it with steam or by applying microwave heating. The shortest possible time is needed to inactivate enzymes and to avoid both actual cooking and the loss of water soluble nutrients (Benion & Scheule, 2004; Somsub, Kongkachuaichal, Sungpuag, & Charoensiri 2008; Lisiewska, Gębczyński, Bernaś, & Kmiecik, 2009; Volden *et al.,* 2009). This process involves exposing plant tissue to heat for a prescribed time at a specified temperature and is the primary pre-freezing means of inactivating undesirable enzymes present in the vegetable (Barrett & Theerakulkait as cited by Garrotte, Silva, & Bertone, 2001; Puupponen-Pimiä, Häkkienen, Aarni, Suortti, Lampi, Eurola, Piironen, Nuutila, & Oksman-Caldentey, 2003). The temperature and time combination used will generally be determined by the thermal stability of the enzymes involved in the quality deterioration of the processed product (Dekker, Dekkers, Jasper, Baár, & Verkerk, 2013). In a study by Guida, Ferrari, Pataro, Chmbery, DI Maro and Parente (2013), it was found that the colour of raw artichoke heads was well preserved after ohmic blanching, while after water blanching it changed significantly from yellow/green to a brownish/green colour. Also, when comparing the artichokes blanched by ohmic treatment to conventionally steamed ones, the latter samples appeared heterogeneously softened, showing a lower softening in the inner region, but excessive softening in the outer part. Volden *et al.* (2009) found that blanching for three min in boiling water led to a loss of 42% in the levels of glucosinolate, for five different varieties of cauliflower. This high loss of glucosinolate was ascribed to leaching or thermal destruction. In another cauliflower study by Tamer (2012), blanching reduced the total phenolic compounds by 7.12-14.78%. Boiling water blanching for eight min achieved complete chlorophyllase inactivation and 99% peroxidise inactivation, as well as good colour characteristics in globe artichokes (Ihl, Monsalves, & Bifani, 1998). In the same study it was found that using steam as method of blanching, complete inactivation of chlorophyllase was found after 6 min, resulting in lower values for lightness index, hue and chroma than water blanching.

Different methods can be applied to render vegetables suitable for human consumption. Steaming is a moist cooking method, where the food can have either direct or indirect contact with the steam. Direct contact steaming is done in a closed container, while indirect steaming may be done in the closed top of a double boiler (Ceserani, Kinton, & Fosket, 1995; Benion & Scheule, 2004; Volden, *et al.,* 2009). Stir frying is a dry cooking method and involves the brief stirring of vegetables in a small amount of oil in a frying pan or wok. As the vegetables are cooked in the oil and then steamed in the moisture from the vegetables, a desirable flavour develops. The pieces of vegetables should be thin to allow rapid heat penetration in the short cooking time (Benion & Scheule, 2004; Somsub *et al.,* 2008). Pickling is a preservation method where vegetables are marinated in seasoned brine. The vegetables are trimmed and/or chopped, sliced or left whole. In some cases the produce is blanched, e.g. asparagus, or cooked until tender, e.g. beets, and cooled. The produce is then packed into canning jars and a heated pickling liquid is poured over the contents. The liquid generally consists of vinegar and water, and it can include spices, herbs, sugar and salt. Sometimes, the vegetables are heated in the liquid before being packed into the jars (Lau & Tang, 2002; Lee, 2004).

Cooking alters the sensory attributes of vegetables, such as colour, texture and flavour and consumption of vegetables depends largely on their sensory appeal (Kala & Prakash, 2006; Poelman & Delahunty, 2011; Donadini, Fume, & Poretta 2012). According to Rennie and Wise (2009), microwave steamed and conventionally steamed broccoli rated high on sensory properties like appearance, texture, taste and overall acceptability. Fiore *et al.* (2013) found that steamed broccoli maintained a good texture, softened the stem, induced a strong cell wall destruction, reduced fibrousness of the stem, and was the best method to retain chlorophyll (Martínez-Hernàndez, Artès-Hernàndez, Gómez, & Artès, 2013). Steaming artichokes led to lower values for lightness index, hue and chroma, thus indicating the major loss of chlorophyllous pigments during this process (Ihl *et al.*, 1998). Volden *et al*. (2009) found that the least reduction in total glucosinolates was found when cauliflower was steamed, in comparison to boiling and blanching.

Stir-frying yields an interesting flavour, different from both that of raw and water cooked vegetables (Addler-Nissen, 2007). Stir fried vegetables, such as carrots, green spring onion, red pepper, snow pea, white spring onion and yellow pepper, retained more than 85% of their carotenoids content. More than 75% of consumer panellists reported positive indicators such as like extremely/like very much/like moderately for the appearance, colour, flavour, texture and overall acceptability of carrots, green spring onion, red pepper, snow pea and yellow pepper, after being stir fried (Rajagopal, Giraud, & Hamouz, 2007). According to Poelman and Delahunty (2011), the stir frying process imparted a more intense colour, browned flavour, shiny appearance, crunchy, firm texture, oily mouth coating, after taste and more mastication effort than vegetables treated differently.

In a study by Bakr and Gawish (1993), where they sprayed cucumber with K and Ca, panellists preferred pickled cucumbers which were firmer in texture, had an increase in chlorophyll content and tasted superior. Pickled cucumbers, blanched at 98°C, with bay leaves and different types of flavoured salts, showed a better texture than the ones with purified salt (Yoo, Hwang, Ji, & Moon, 2005). Visual colour, texture, sweetness and flavour of pickled paprika were the sensory attributes preferred by consumers (Park, Kim, & Moon, 2011). Pickled mustard tubers had different odours, depending on the treatment done and ranged from pucker, pungent, bitter, acid, spicy, light, fresh and fruity to spicy (Liu, Li, Deng, Wang, & Yang, 2009). In a study to determine the sensory quality of canned cauliflower pickles having different ingredients in their brines, acetic and citric acid containing samples were preferred for odour, while acetic and lactic acid containing samples were preferred for taste; the lactic acid containing samples was also preferred for hardness (Tamer, 2012).

Many descriptive analysis techniques, such as descriptive sensory analysis (DSA) (broccoli) (Baik *et al.,* 2003), quantitative descriptive analysis (QDA) (broccoli and cauliflower) (Schonhof *et al.,* 2004), QDA (broccoli and cauliflower) (Brückner, *et al.,* 2005), QDA (broccoli) (Gajewski, 2004), DSA (broccoli and cauliflower) (Zabaras, 2013) and DSA (globe artichokes) (Baty-Julien & Hélias, 2011) have been used for the sensory evaluation of flowering vegetables.

The aim of this study was to describe the sensory attributes of blanched and unblanched *A. americana* flowers, after being steamed, stir fried and pickled, by using DSA.

4.3 MATERIALS AND METHODS

4.3.1 *Agave americana* flowers

4.3.1.1 Flowers

Identification of flowers was carried out in three different areas in Lesotho: Sehlabeng (Maseru); Maliepetsane (Mafeteng); and Ha-Ramoshabe (Mafeteng). Flowers were collected during the summer and autumn season from wild plants and pooled, because a preliminary study showed no significant differences in chemical composition amongst flowers from the different areas.

The flowers were cut from the main stem and half of it was blanched before freezing at -18ºC, while the others were frozen unblanched.

4.3.2 Descriptive sensory analysis

A group of ten trained panellists, comprising of staff members and post graduate students of the University of the Free State, participated in the sensory study. Most of the panel members had never tasted agave flowers before. They were selected, based on their taste and smell acuity, interest, ability to discriminate between the four basic tastes and availability for the entire study. Furthermore, they were screened prior to participation for recognition of the basic taste (bitter, sweet, sour, salt and umami), a colour test and descriptive test.

The assessors were asked to taste two samples from a specific treatment and develop a lexicon, generating as many terms as possible to describe appearance, mouthfeel, aroma, taste, aftertaste and afterfeel. The remaining of the samples (i.e. four samples, two each from two different treatments) was assessed in a second and third session, allowing the addition of terms thought to have previously been omitted. Thus, the panellists received a whole flower per sample (total of six samples), and were then trained to increase their sensitivity and ability to discriminate between the samples and identify sensory attributes. Being a consensus technique, the panellists had to agree on a definition for each attribute and revision of the definitions, reference standards and reference intensities continued until the panellists were satisfied. A score sheet and the sequence of the descriptors were designed and agreed to by the panel through consensus. A structured line scale, with appropriate anchors, ranging from zero (0) denoting not (e.g. not fibrous) to ten (10) denoting extreme (e.g. extremely fibrous) was constructed and used to evaluate the different samples (Figure 4.1). Panellists were once again informed to avoid exposure to foods and fragrances at least 1 h before the evaluation sessions.

All samples were served and evaluated according to the sensory principles and methods described in the ASTM Manual on Sensory Evaluation (ASTM Manual Series: MNL 13, 1992). Panellists received one flower, approximately 5 cm in length, per treatment. This size, considerably larger than average bite size, was employed to ensure enough sample was available to evaluate all the necessary categories. Flowers were defrosted and stored at a temperature between 2-6°C. The flowers were rinsed and dried with paper towels before the different treatments were applied. For stir frying, blanched and unblanched flowers were lightly seasoned with salt, and fried in sun flower oil (Pick ‘n Pay Retailers (Pty) Ltd., Pick ‘n Pay Office Park, 2 Allum Road, Kensington, 2094, South Africa) at temperatures ranging between 260 and 288°C, for three min. Lightly salted blanched and unblanched flowers were also steamed in a VERIMARK S*team Supreme* steamer (Verimark Holdings (Pty) Ltd., P.O. Box 78260, Sandton, 2146, South Africa) for three min. Pickling brine, consisting of onions, vinegar, sugar, garlic and pickling spices (Table 4.1), were used to pickle the blanched and unblanched flowers for 7d, before testing. All samples were served: at room temperature, approximately 22°C; one at a time; in 50 mℓ clear plastic cups with clear lids (Freepak, 112 Nelson Mandela Avenue, Bloemfontein, 9301); on white polystyrene trays; at 22°C; under white fluorescent lights (*PHILIPS Tornado* 11 Watt warm white); and in individual sensory booths. All samples were served blinded, coded (three digit codes) and the serving order randomised to exclude any bias due to the position effect. Filtered water (Aquartz still mineral water, Clover SA (Pty) Ltd., Clover Park, 200 Constantia Drive, Constantia Kloof, Roodepoort, 1709, South Africa), at room temperature, was provided as palate cleansers before the start of evaluation and between samples. Three evaluation sessions were scheduled with a 60 min rest period between each session, amounting to a total of three evaluation sessions per product. During each session all six samples were evaluated once. Three replications (6 x 3) were considered the absolute minimum to ensure reliability and validity of results.

Table 4.1: Brine formulation for pickled *A. americana* flowers.

Ingredient	Inclusion (%)
Water	48.38
Vinegar	32.25
Sugar	12.90
Onion	3.22
Garlic	1.96
Pickling spice	1.29
Total	**100.00**

With reference to the aim of this study, DSA was used in order to describe the effect of different treatments on the characteristics of *A. americana* flowers. A general training programme was followed, consisting of five, two h sessions to develop a consensus list of appropriate descriptive terminology for the flower samples. Attributes were grouped together according to sensory characteristics such as appearance, texture/structure, aroma, mouthfeel, taste, aftertaste and afterfeel. Formal definitions, reference standards and reference intensities had to be agreed upon by all panel members through consensus. This was followed by compiling a score sheet and the sequence of the descriptors (Annexure 1). Samples were thus scored on structured line scales, using the consensus vocabularies, anchored at the ends by the terms "not present/none" and "extremely/very high" (Figure 4.1). Data were recorded on paper ballots and entered into worksheets for analysis.

4.3.3 Colour analysis of *A. americana* flowers after treatments

The colour (L^*, a^* and b^*) values of six blanched and six unblanched flower samples, from each treatment, were assessed on various parts of each flower, 30 min after preparation, using a Minolta chromometer. The flowers were cut open lengthwise, split open and pressed down, as to ensure a flat surface to take measurements on. Saturation index (SI), which is related to the colour intensity of the flower, was calculated according to the formula: $SI = (a^{*2} + b^{*2})^{0.5}$ (Lanari, Schaefer, & Scheller, 1995). Hue angle was calculated according to the formula $\tan^{-1}(b^*/a^*)$ (Ripoll, Joy, & Munoz, 2011).

4.3.4 Physical texture analysis of *A. americana* flowers after treatments

Physical texture analysis was performed with the Instron Universal Testing Machine (UTM Model 3344), to correlate the results with the findings of the taste panel. Six unblanched and six blanched flower samples from each treatment were cooled down to room temperature for at least 5 h, before shear force measurements. The part of the flowers with a core diameter of more or less 12.7 mm and a length of 30 mm, namely the ovary (Figure 4.1), was selected, as this was the part of the flower that best correlated with the prescribed method. The load cell size was 1 kN. A Warner Bratzler shear device, mounted on a Universal Instron apparatus was used and the reported value in kg represented the average of the peak force measurements of each sample. Sample compression data was generated by the Instron Bluehill software.

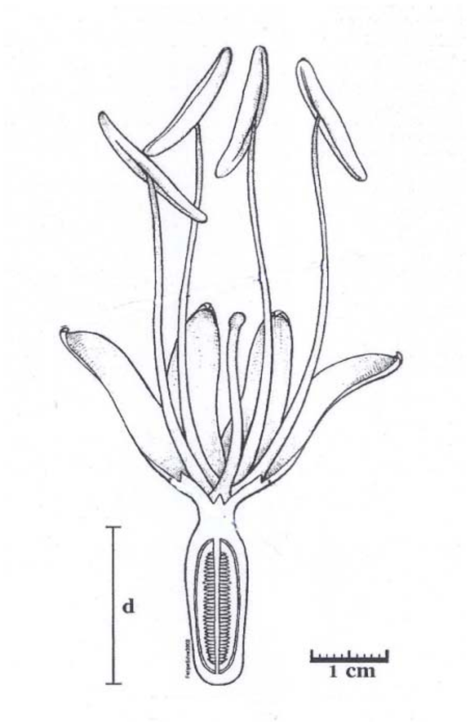

Figure 4.1: The ovary (d) of the agave flower used for physical texture analysis (Silva-Montellano & Eguiarte, 2003).

4.3.5 Statistical analysis

4.3.5.1 Statistical analysis of descriptive sensory analysis

The descriptive data obtained from the sensory panel were entered on to a spreadsheet, using Microsoft Excel (2000). Data were statistically analysed using the GenStat for Windows (2000) statistical computer program. The significance of all the sensory attributes, measured for each flower sample, was tested by means of an ANOVA, which tested the main effects of the sample at a 5% level of significance. If the sample main effect was significant, the Fisher protected Least Significant Difference (LSD) test was applied to separate the sample means. The multivariate analysis technique, principal component analysis (PCA), was performed to reduce the large set of variants into a smaller set, to explain most of the variations in the entire data set. Principal component analysis is a graphical presentation of the data and is used to better classify and group samples, using the sensory variables (Shaw, Moshonas, Busling, Barros, & Wildmer, 1999). A correlation matrix was constructed to show the correlation (positive or negative) between the sensory attributes measured.

4.3.5.2 Statistical analysis of colour and physical texture analysis

Differences between treatments were determined by using factorial analysis of variance (ANOVA) procedure for balanced data. The factorial design comprised of 2 pretreatments (blanched and unblanched) and 3 preparation techniques (steaming, stir frying and pickling)

4.4 RESULTS AND DISCUSSION

4.4.1 Sensory profile

The DSA technique generated 21 attributes for the six samples in the three treatment groups (Tables 4.2, 4.3 and 4.4). Firstly, Table 4.2 shows the attributes, definitions, reference standards and reference intensities for the unblanched and blanched steamed *A. americana* flowers (USAF, BSAF), with two attributes for aroma, three for taste, one for aftertaste, three for mouthfeel and one for appearance. Secondly, for the unblanched stir fried and blanched stir fried *A. americana* flowers (USFAF, BSFAF), there were one attribute each added for taste and aroma, three for mouthfeel and two for appearance (Table 4.3). Finally, the unblanched and blanched pickled flowers (UPAF, BPAF) attributed to one more attribute each for taste and aroma, and two for appearance (Table 4.4).

The attribute of aroma included four descriptors, including ‘nutty’ and ‘cooked green beans’ for the USAFs and BSAFs, while the USFAFs and UPAFs had a rancid and cucumber aroma, respectively. Stir frying has been found to impart a more intense odour and browned flavour on stir fried green beans (Poelman & Delahunty, 2011). The

Table 4.2: Descriptions, definitions, reference standards and reference intensities of attributes used by the trained sensory panel, to evaluate steamed blanched and unblanched *A.americana* flowers.

	DEFINITION	REFERENCE STANDARD	REFERENCE INTENSITIES
BLANCHED STEAMED AGAVE FLOWERS (BSAF)			
Aroma			
Nutty	aroma associated with raw peanuts/peas.	'sugar snap'*	6-7
Beans, green, cooked	aroma associated with cooked green beans.	canned green beans**	7
Taste			
Sweet	taste associated with the sweet taste.	2% sucrose solution	2
Bitter	taste associated with the bitter taste.	Lindt 85% cocoa	8-9
Aftertaste			
Sweet	lingering taste associated with sucrose, lingering in mouth after swallowing	2% sucrose solution	1-2
Mouthfeel			
Chewy	number of chews (at I chew/s) needed to masticate the sample to a consistency, suitable for swallowing	fresh Swiss chard (spinach)	7
Fibrous	degree to which a sample contains small or long fibres.	fresh stalk of celery	7-8
Appearance			
Flower	appearance associated with that of an open lily	open lily***	10
		half open lily	5
		closed lily	1
UNBLANCHED STEAMED AGAVE FLOWERS (USAF)			
Taste			
Sour	taste associated with the sour taste	0.07% citric acid solution	6-8
Mouthfeel			
Starchy	mouthfeel associated with starch	boiled potato	6-7

**Pisum sativum* var. *macrocarpon* (See Annexure 2 for picture)
**KOO French Cut Green Beans, Tiger Brands Ltd., 3010 William Nicol Drive, Bryanston, 2191, South Africa
****Lilium asiatic* (Annexure 2 for picture)

Table 4.3: Descriptions, definitions, reference standards and reference intensities of attributes used by members of the trained sensory panel, to evaluate stir fried blanched and unblanched *A.americana* flowers.

	DEFINITION	REFERENCE STANDARD	REFERENCE INTENSITIES
BLANCHED STIR FRIED AGAVE FLOWERS (BSFAF)			
Aftertaste			
Sweet	lingering taste associated with sucrose lingering in mouth after swallowing	2% sucrose solution	1-2
Mouthfeel			
Crunchy	force needed to crumble, crack or shatter sample	raw carrot	9
Appearance			
Cactus	appearance resembling a dessert plant	'*vygie*'*	8
UNBLANCHED STIR FRIED AGAVEFLOWERS (USFAF)			
Aroma			
Rancid	aroma associated with staleness	week old bread	5
Mouthfeel			
Rubbery	energy required to disintegrate a semi-solid food to a state ready for swallowing	grilled calamari	7-8
oily mouth coating	oily coating in the mouth alter mastication	peanut butter	6
Appearance			
Oily	amount of oil perceived on product's surface	commercial '*vetkoek*'**	5

* *Mesembryanthemum* (See Annexure 2 for picture)

** 'Vetkoek' literally means 'fat cake' and is dough that is deep-fried in cooking oil.

Table 4.4: Descriptions, definitions, reference standards and reference intensities of attributes used by members of the trained sensory panel, to evaluate pickled blanched and unblanched *A.americana* flowers.

	DEFINITION	REFERENCE STANDARD	REFERENCE INTENSITIES
BLANCHED PICKLED AGAVE FLOWERS (BPAF)			
Taste			
sweet and sour	taste associated with the combination of sweet and sour	sweet n sour sauce*	8-9
Appearance			
Moist	amount of moisture perceived on product's surface	pickled gherkins**	7-8
UNBLANCHED PICKLED AGAVE FLOWERS (UPAF)			
Aroma Cucumber	aroma associated with fresh cucumber	cucumber***	8
Appearance			
green pepper	appearance associated with chopped green pepper	fresh green pepper	9

*Hasty Tasty sweet and sour sauce with real pineapples, Hasty Tasty frozen foods (Pty) Ltd., 14 Slater Street, North End, 6056, South Africa
** Woolworths Sweet & Tangy Gherkins, Woolworths (Pty) Ltd. Regd. Head Office, 93 Longmarket Street, Cape Town, 8001, South Africa
***_Cucumis sativum_ (see Annexure 2 for picture)

type of oil used for frying the flowers was sunflower oil, which had a nutty toasted nuts and hay/grains flavour (Timm-Henrich, Xu, Nielsen, & Jacobsen, 2003; Bendini,Barbieri, Valli, Buchecker, Canavari, & Tschi, 2011). In another study, it was found that these attributes were considered positive by the panellists. They also noted the same negative sensory attribute of rancidity in some types of sunflower oil assessed (Timm-Henrich, *et al*., 2003; Bendini, *et al*., 2011).

The attribute of taste contributed four descriptors, namely sweet, sour, bitter and the combined taste property of sweet-sour, while only one descriptor was used for aftertaste, i.e. sweet. Bitter, sour and sweet are tastes that are commonly associated with vegetables (Corrigan, Irving, & Potter, 2000; Varming *et al*., 2004; Bingham, Hurling, & Stocks, 2005; Brückner *et al*., 2005; Dinehart, Hayes, Bartoshuk, Lanier, & Duffy, 2006; Tordoff & Sandell, 2009). Phenols, flavonoids, isoflavones, terpenes and glucosinolates are some of the compounds responsible for vegetable bitterness, pungency and/or astringency (Drewnowski & Gomez-Carneros, 2000). Vegetables having a high content of Ca are more bitter than vegetables with a low content (Tordoff & Sandell, 2009). Mono- or disaccharides, released by starch during processing, may impact sweetness. In cruciferous vegetables, sweetness has been shown to decline in proportion to an increase in bitter glucosinolates (Schonhof *et al*., 2004). In a vegetable, such as winter squash, sweetness was an important attribute to flavour, acceptability and perceived quality. In this case, glucose, fructose and sucrose contributed differently to the perceived sweetness of eight winter squash cultivars. Corrigan *et al.* (2000) found that starch was converted into maltose during the cooking of cultivars with high starch content.

For the attribute mouthfeel, six descriptors were used, while the appearance attribute included five descriptors, of which two also had to do with visual textural properties, such as ‘oily’ and ‘watery’. The other three had to do with the specific shape and colour of the flower after specific treatments and referred amongst others to specific plant forms, such as ‘lily’, ‘cactus’ and ‘green pepper’.

4.4.2 Influence of treatments on sensory properties of *A. americana* flowers

The results for the various treatments of the unblanched and blanched flowers, as obtained from the sensory panel, are summarized in Table 4.5. From this table it is clear that no significant differences were observed in two of the appearance descriptors, namely flower and cactus, as well as for the mouthfeel descriptor fibrous, between flowers from the different treatment groups.

All the odour descriptors, namely nutty, cucumber, cooked green beans and rancid, differed significantly ($p<0.01$) between the treatments (Table 4.5). The BPAFs had the lowest value for nutty (0.52), indicating that the aroma was present at a low concentration, (Table 4.5) and differed significantly ($p<0.001$) from the BSAFs, USAFs, BSFAFs and USFAFs (Table 4.5). The highest value for this descriptor was found for the BSFAFs (2.26) (Table 4.5) and this treatments also differed significantly ($p<0.001$) from the BPAFs and UPAFs. The panel defined nutty as the aroma associated with raw peanuts or peas (Table 4.2). In a lexicon for green odour or flavour, Hongsoongnern and Chambers (2008) characterized the sensory characteristic 'green' as peapod which, in turn, described the green character generally found in beans and some vegetables, including green beans, raw peanuts and broccoli. This research was followed up by Talavera-Bianchi *et al.* (2010), when they developed a lexicon to describe the flavour of fresh leafy vegetables, in which 'green-peapod' was defined as a green aromatic associated with green peapods and raw green beans. From this it can be concluded that the nuttiness that was identified by the panel in the present study was in fact a 'green odour'. The low nutty values obtained for the BPAFs and UPAFs could be attributed to the use of the brine mixture (Table 4.1), which masked the nutty or 'green' odour. In contrast, the high value scored for this descriptor by the BSFAFs could be the result of the sunflower oil that was used for the stir frying.

The cucumber odour descriptor was the highest in the UPAFs (3.96) (Table 4.5) and this treatment differed significantly ($p<0.001$) for this descriptor, from all the other treatments. The values for the other samples were very low, varying from 0.07 – 0.74, indicating that the odour was present at a low concentration. Cucumber is another

Table 4.5: Analysis of Variance (ANOVA) of DSA Results

Treatment	Blanched Steamed Agave Flowers	Unblanched Steamed Agave Flowers	Blanched Stir-Fried Agave Flowers	Unblanched Stir Fried Agave Flowers	Blanched Pickled Agave Flowers	Unblanched Pickled Agave Flowers	Sign. Level
Odour: nutty	2.07 + 1.41^{bc}	2.07 + 1.17^{bc}	2.26 + 1.35^{c}	1.78 + 1.05^{bc}	0.52 + 1.12^{a}	1.15 + 0.95^{ab}	$p < 0.001$
Odour: cucumber	0.07 + 0.27^{a}	0.63 + 1.18^{a}	0.56 + 1.22^{a}	0.52 + 1.09^{a}	0.74 + 1.02^{a}	3.96 + 1.91^{b}	$p < 0.001$
Odour: Beans, green, cooked	2.85 + 0.99^{c}	2.19 + 1.18^{bc}	2.22 + 1.15^{bc}	2.15 + 0.91^{bc}	0.52 + 1.01^{a}	1.44 + 1.19^{b}	$p < 0.001$
Odour: Rancid	0.63 + 1.21^{a}	0.59 + 1.22^{a}	1.00 + 1.24^{ab}	1.81 + 1.49^{b}	0.41 + 0.97^{a}	0.22 + 0.80^{a}	$p < 0.001$
Appearance: Flower	7.59 + 0.57	7.59 + 0.50	7.59 + 0.69	7.81 + 0.40	7.78 + 0.42	7.78 + 0.42	NS
Appearance: Cactus	3.89 + 1.63	4.04 + 1.83	4.15 + 1.68	4.15 + 1.90	4.26 + 1.58	4.56 + 2.08	NS
Appearance: Oily	0.22 + 0.51^{a}	0.26 + 0.59^{a}	1.48 + 1.40^{b}	1.26 + 1.20^{b}	0.41 + 0.84^{a}	0.30 + 0.78^{a}	$p < 0.001$
Appearance: Moist	2.07 + 1.49^{ab}	2.00 + 1.59^{a}	1.78 + 1.67^{a}	1.63 + 1.39^{a}	3.22 + 1.65^{b}	2.56 + 1.42^{ab}	$p < 0.01$
Appearance: Green pepper	0.93 + 1.07^{a}	1.00 + 1.21^{a}	1.48 + 1.60^{a}	1.11 + 1.40^{a}	0.63 + 0.74^{a}	3.96 + 2.12^{b}	$p < 0.001$
Mouthfeel: Chewy	3.26 + 0.98^{a}	4.15 + 1.35^{ab}	3.63 + 0.93^{ab}	4.04 + 1.45^{ab}	3.70 + 0.95^{ab}	4.41 + 1.50^{b}	$p < 0.05$
Mouthfeel: Fibrous	4.56 + 0.58	4.85 + 0.72	4.74 + 0.94	4.78 + 0.93	4.63 + 0.63	4.93 + 0.73	NS
Mouthfeel: Starchy	1.85 + 0.95^{b}	1.33 + 1.04^{b}	1.67 + 0.92^{b}	1.48 + 0.80^{b}	0.56 + 0.70^{a}	1.56 + 1.28^{b}	$p < 0.001$
Mouthfeel: Crunchy	1.63 + 1.11^{a}	2.59 + 1.19^{ab}	2.07 + 1.49^{a}	2.67 + 1.36^{ab}	2.59 + 1.25^{ab}	3.37 + 1.57^{f}	$p < 0.001$
Mouthfeel: Rubbery	0.89 + 1.09^{a}	1.22 + 0.89^{ab}	1.48 + 1.42^{ab}	2.11 + 1.25^{b}	1.00 + 1.00^{a}	1.15 + 1.29^{a}	$p < 0.01$
Mouthfeel: Oily mouth coating	0.30 + 0.61^{a}	0.11 + 0.42^{a}	1.78 + 1.40^{b}	1.37 + 1.33^{b}	0.15 + 0.53^{a}	0.44 + 1.01^{a}	$p < 0.001$
Taste: Sweet	1.81 + 0.48^{b}	1.30 + 0.72^{a}	1.63 + 0.63^{ab}	1.30 + 0.72^{a}	1.59 + 0.80^{ab}	1.44 + 0.75^{ab}	$p < 0.05$
Taste: Bitter	0.74 + 0.90^{ab}	1.59 + 1.08^{c}	0.89 + .97^{abc}	1.52 + 1.09^{bc}	0.70 + 1.03^{a}	1.52 + 1.01^{bc}	$p < 0.001$
Taste: Sour	0.40 + 0.19^{a}	0.41 + 0.64^{a}	0.30 + 0.67^{a}	0.41 + 0.84^{a}	1.74 + 1.10^{b}	0.30 + 0.47^{a}	$p < 0.001$
Taste: Sweet n sour	0.01 + 0.01^{a}	0.44 + 1.31^{a}	0.19 + 0.96^{a}	0.01 + 0.01^{a}	3.67 + 1.88^{b}	0.01 + 0.01^{a}	$p < 0.001$
Aftertaste: Sweet	0.96 + 0.59^{ab}	0.74 + 0.45^{a}	1.00 + 0.55^{ab}	0.93 + 0.38^{ab}	1.33 + 0.88^{b}	0.89 + 0.51^{ab}	$p < 0.05$

Means with different superscripts in the same row differed significantly
NS = Not Significantly

‘green’ odour, described under the collective name of ‘green-viney’ by Hongsoongnern and Chambers (2008), and was defined as a green aromatic associated with green vegetables and newly cut vines and stems. It was furthermore also characterized by an increased bitter and musty/earthy character. As reference in their test they used sliced fresh cucumber, with an intensity of 5 and 6, respectively, for the attributes of green-viney and musty/earthy. In an experiment to link certain chemicals to certain odours, Vara-Ubol, Chambers, & Chambers ,(2004) showed that some chemicals associated with a specific aroma were found to be characteristic of one odour at low concentration (1 -10 ppm), but that the odour characteristics changed completely at higher concentrations. Furthermore, harmful changes in flavour can be attributed to increases in enzymes such as peroxidise (Brewer *et al*. as cited by Collins, Biles, Warn, Perkins-Veazie, & Maness, 1996). In unblanched broccoli it was found that enzymes such as lipoxygenase, peroxidise and cystinelyase increased (Barette, Garcia, Russel, Ramirez, & Shirazi; 2000; Azcarate & Barringer, 2010), while cystinlyase was especially associated with off-aroma production in broccoli (Barette *et al*., 2000). It is thus postulated that the green-peapod odour discussed in the previous section was changed to a green-viney odour, associated with the odour of cucumber, due to the acid and sucrose used in the pickling brine.

The BPAFs had the lowest value (0.52) (Table 4.5) for cooked green bean odour and differed significantly ($p<0.001$) from the UPAFs, BSAFs, USAFs, BSFAFs and USFAFs. The UPAFs also differed significantly ($p<0.001$) from the BSAFs, which had the highest cooked green bean odour value of 2.85 (Table 4.5). The green bean odour, again, as explained earlier, is related to green odour. This descriptor had values ranging from 2.15 - 2.85 for the four heat treatments, i.e., steaming and stir frying (Table 4.5). The values decreased significantly ($p<0.001$) for the two pickled treatments, again confirming the influence of the acid on odour changes. When using acetic acid in the brine of blanched pickled cauliflower, these were preferred to other samples specifically, for odour (Tamer, 2012).

The panel defined rancid as the aroma associated with week old stale bread (Table 4.2) and this descriptor had the highest value (1.81) for the USFAFs (Table 4.5). This treatment differed significantly ($p<0.001$) for this attribute from the BSAFs (0.63), USAFs (0.59), BPAFs (0.41) and UPAFs (0.22), which again had values indicating low concentrations. Although there was no significant difference between the USFAFs and BSFAFs, the value for the latter was lower (1.00) (Table 4.5). One of the volatile compounds that has been used as a reference to green notes in vegetables, is hexanal, which has been characterized by Baldwin, Goodner, Plotto, Pritchett and Einstein (2004) as green, grassy, vine and stale. Thus, the rancidity picked up by the panel, appeared to be yet another green odour, which was formed by the intense heat used in the stir frying process.

Two of the appearance descriptors, oily and green pepper, differed significantly ($p<0.001$) between the treatments (Table 4.5). For the oily appearance (Figure 4.2), both the stir fried treatments, i.e., BSFAFs and USFAFs, differed significantly ($p<0.001$) from all the other treatments. Sunflower oil was used for the stir frying and customary stir fried products are covered with a thin film of oil (Poelman & Delahunty, 2011). The bright green colour (Figure 4.2) of green peppers were quite dominant in the UPAFs, which had the highest value (3.96) (Table 4.5) and also differed significantly ($p<0.001$) from all the other treatments. Mano-Francis and Badrie (2004) also found that carambola slices, treated with different acids, were the brightest and greenest after pickling. According to Bibek and Bhunia (2007), at low concentrations, such as those used in canned foods, sugar enhanced colour. This was in agreement with a study by Czaikoski, Leite, Mandarino, Carrão-Panizzi, da Silva and Ida (2013), where it was found that the addition of sucrose in the acidified brine of a vegetable-type soybean grains contributed to maintain the desirable colour. Therefore, it could be concluded that the presence of sugar and acid, along with active enzymes, attributed to the bright green colour of the UPAFs.

A moist appearance and rubbery mouthfeel, the last regarded as a negative attribute in most cooked foods, especially vegetables, differed significantly ($p<0.01$) between the groups (Table 4.5). Bennion and Scheule (2004) noted that enzymatic action in unblanched vegetables resulted in an undesirable texture during freezing of vegetables. The BPAFs had the highest value for moist appearance (3.22) (Table 4.5)

a b c

(l) (r) (l) (r) (l) (r)

Figure 4.2: a.USFAFs (l), BSFAFs (r); b.USAFs (l), BSAFs (r); c.UPAFs (l), BPAFs (r)

and differed significantly (p<0.01) from the USAFs (2.00), BSFAFs (1.78) and USFAFs (1.63). The last two samples had an oily appearance, due to being fried in oil. The brine solution and blanching kept the BPAFs moist, because the UPAFs (2.56) had a lower value. The USFAFs also had the highest value for rubbery mouthfeel (2.11) (Table 4.5) and differed significantly (p<0.01) from the BSAFs (0.89) (Table 4.5), BPAFs (1.00) (Table 4.5) and UPAFs (1.15) (Table 4.5). It is in confirmation with the fact that blanching helped improving the texture and ultimately the overall acceptability of a product (Manpreet, Shivhare, & Ahmed, 2000).

Chewy mouthfeel, being regarded as a positive attribute in vegetables (Brückner *et al.,* 2005; Talavera-Bianchi *et al.,* 2010), differed significantly (p<0.05) between the treatment groups. The BSAFs were significantly (p<0.05) less chewy than the UPAFs. Samples from the treatments groups with unblanched flowers, showed higher scores for chewiness, than flowers from the blanched treatment groups. The panel defined chewy as the number of chews (at one chew/sec) needed to masticate the sample to a consistency suitable for swallowing (Table 4.2). One of the minor functions of blanching is the softening of plant tissue (Guida *et al.*, 2013) and this could explain the lower scores for the blanched treatment groups regarding chewiness. In a study by Martínez-Hernàndez *et al.* (2013) it was found that steaming softened broccoli stems by 82.5-75.3%. The treatment method of steaming uses natural convection of heat that then migrates in air, steam or liquid. This method gives an exact even cooking temperature throughout the cooking period and makes food more tender, because foods are not exposed to intense dry heat. Steaming thus protects foods which are contained within sealed, perforated or slated tiers, wax paper or foil parcels or heat proof basins, and never come in contact with heat source or steam producing liquid (Tan, Tan, Tian, Liu, & Shen, 2009). When comparing artichokes blanched by ohmic treatment to artichokes blanched in boiling water, the latter appeared heterogeneously softened, showing a lower softening in the inner region, but excessive softening in the outer part (Guida *et al.*, 2013). Pre-treating broccoli by steam blanching at 50-80°C could increase the resistance towards softening in a subsequent steaming process (Dekker *et al.,* 2013).

The lowest score for the descriptor starchy was for BPAFs (0.56), which differed significantly ($p<0.001$) from all the other treatments (Table 4.4). The panel defined starchy as the mouthfeel associated with the pastiness of boiled potato (Table 4.2) and awarded the values ranging from 1.33 to 1.85 (Table 4.5) for all the other treatments, which did not differ significantly between each other. The starchy 'feel' is described in the research of Hongsoongnern and Chambers (2008), as being part of the 'beany' attribute, which was defined as aromatics characteristic of beans and bean products, and included a starchy, powdery feel and one or more of the following characteristics: green/peapod, nutty or browned'. The BPAFs also had the lowest score for the cooked green bean odour (0.52) (Table 4.5), which supported the finding in the present study that this treatment should also have the lowest score for the starchy descriptor.

According to the panel, the definition of crunchy is the mouthfeel associated with raw carrot (Table 4.2). The highest value for this descriptor was given to the UPAFs (3.37) (Table 4.5), which was significantly ($p<0.001$) higher than the values for all the other treatments. This could be explained by the fact that this treatment did not include any heat processing at all, i.e. no blanching or steaming or stir frying. Blanching did soften the fibres in the agave flowers significantly ($p<0.001$) in the present study, as could be deduced from the lower value of 2.59, which was scored by the BPAFs (Table 4.5). This, along with the action of enzymes, such as pectinesterase which was found to remove methyl groups from pectin when cucumbers were fermented or acidified (Bell & Etchells as cited by Breidt, McFeeters, Perez-Diaz, & Lee, 2013), added to the softening of the BPAFs. Furthermore, it was also found that polygalacturonase also affected the texture of pickled vegetables by degrading pectic substances in the structure of vegetable cell walls (Martínez-Garcia, Mujica-Paz, Valdez-Fragoso, Welti-Chanes, & Ortega-Rivas, 2007).

For the oily mouthfeel, both the stir fried samples differed significantly ($p<0.001$) from the other treatments, but not amongst each other. The oil that is used during the stir frying process forms a layer on the stir fried pieces, adding to the characteristic flavour of such cooked foods (Bennion & Scheule, 2004).

Blanching, as noted earlier, inactivates enzymes, thus improving the flavour and odour of vegetables (Lee, 1958; Begum & Brewer, 2001; Nielsen, Larsen, & Poll, 2004). Respiration, catalysed by many enzymes, continues in fruits and vegetables after they are severed from the growing plant. This reduces sugar content, which accounts for the loss of sweetness in vegetables. Blanching expels air, which is essential for respiration, thus inactivating the enzymes (Bennion & Scheule, 2004). Sweet taste and sweet aftertaste are both positive attributes in vegetables (Brückner *et al.,* 2005; Talavera-Biachi *et al.,* 2010). In the present study, the BSAFs had the highest value for sweetness and differed significantly ($p<0.05$) from the USAFs and USFAFs, but not from the UPAFSs (Table 4.5). Lin and Brewer (2005) reported that unblanched peas were more bitter than blanched ones. Blanching for one min in boiling water also reduced the phenolic content of cauliflower by 13-37% (Volden *et al.*, 2009). In a study on the effect of steaming on polyphenols and flavonoids in broccoli, Roy, Juneja, Isobe and Tsushida (2009) observed that steaming significantly increased the extractability of these components, due to thermal processing, disrupting the cell walls and releasing phytochemicals from the insoluble portion of the broccoli. This elevated release was a promising sign that antioxidant activity would be positively balanced, which would be beneficial to the sensory profile.

According to Batty-Julien and Hélias (2011), the bitter taste of artichokes is usually attributed to the presence of polyphenols, while the bitterness in cauliflower and broccoli is caused by a group of glucosinolates (Schonhof *et al*., 2004). Brückner *et al*. (2005) found that glucosinolate content also affected sweetness, as well as bitter and pungent notes. Lower intensities of bitter and pungent flavours were associated with glucosinolate content of 30-35 mg/100 g fresh weight or less (Nunes, 2008). It must also be pointed out that the agave flowers contained some sugar in the form of glucose, fructose, sucrose and lactose (Table 3.1). The USAFs were significantly ($p<0.001$) more bitter than the BSAFs (0.74) and BPAFs (0.70), and also had the highest score for this attribute of 1.59 (Table 4.5). The BPAFs were significantly ($p<0.001$) less bitter than the USTAFs (1.52) and UPAFs (1.52) and had the lowest value of 0.70 (Table 4.5). All the unblanched samples had almost double the score for this attribute, compared to the blanched treatment groups (Table 4.5), again stressing the importance of blanching to inactivate detrimental enzymes. Active enzymes might produce phytotoxic free radicals, which could react with a wide range of food constituents including ascorbic acid, carotenoids and fatty acids (Brewer, Begum, & Bozeman, 1995; Lim *et al*. as cited by Ramirez, & Whitaker, 1998; Barette *et al*., 2000; Martínez-Hernàndez *et al*., 2013). Other substances may also be present, such as polyphenols, glucosinolates and flavonoids, which also attributes to the bitter taste (Schonhof *et al*., 2004; Brückner *et al*., 2005). It has been reported that steam cooking did not change the level of glucosinolates in a major way (Rungapamestry *et al.* as cited by Volden *et al*., 2009). Furthermore, cystinelyase was determined to be the principal enzyme responsible for the off-aroma deterioration of unblanched broccoli (Lim *et al*. as cited by Ramirez, & Whitaker, 1998).

For the sour taste descriptor, the BPAFs differed significantly ($p<0.001$) from all the other treatments (Table 4.5). It is important to note the significant ($p<0.001$) difference between this sample and the UPAFs, which had a score of only 0.30 (Table 4.5). In a study by Talavera-Bianchi *et al.* (2010) a PCA of 32 attributes, used to describe the flavour of 30 fresh leafy vegetables, showed that sour taste was alone correlated with factor nine, indicating that it was present in all the vegetables at low intensities. In the present study, blanching definitely played a role to allow the acetic acid in the vinegar to intensify the sour taste in the BPAFs. It was found that blanching released volatile organic acids, which are trapped in the steam blanching treatment (Ihl *et al*., 1998). On the other hand, the UPAFs were significantly ($p<0.001$) less sour and significantly more bitter ($p<0.001$), as mentioned earlier. In addition, the UPAFs had a distinct cucumber odour, that was significantly ($p<0.001$) more pronounced than in the BPAFs (Table 4.5). This confirms the result previously discussed, that under influence of enzymes and in the presence of acetic acid and sucrose from the brine, a specific compound with a specific flavour character at a specific concentration, may, at higher concentrations, reveal a totally different flavour profile.

For the combined taste descriptor sweet and sour, again the BPAFs differed significantly ($p<0.001$) from all the other treatments (Table 4.5). The blanching pre-treatment inactivated all unwanted enzyme activity, while the brine mixture (Table 4.1), containing vinegar and sugar, infused the flowers, resulting in the sweet n sour taste. Again it is significant to note the huge difference between this sample and the UPAFs, and the effect of no blanching on the end product. The presence of enzymes completely counteracted the effect of the brine and this sample scored the same extremely low value of 0.01, which was awarded to samples that were not pickled at all, such as the BSAFs and USFAFs (Table 4.5).

The UPAFs tasted sweet, because of the sugar that was added to the brine (Table 4.1). For the sweet aftertaste, the BPAFs had the highest value (1.33) (Table 4.5) and differed significantly ($p<0.05$) from the USAFs. This can be explained by the presence of sugar in brine, in which the flowers were pickled for a week (Table 4.1). Again, the absence of blanching caused the presence of enzymes to influence the taste of the steamed flowers (Lin & Brewer, 2005). Unless the enzymes responsible for undesirable chemical changes are destroyed before foods are treated, like e.g. with a brine, various detrimental colour, flavour and texture changes can occur (Bennion & Scheule, 2004).

When looking at the effect of blanching on the individual treatments, only one descriptor differed significantly ($p<0.05$) between the two treatments for steaming. The BSAFs were significantly ($p<0.05$) sweeter than the USAFs (Table 4.5), due to inactivation of enzymes in BSAFs. For the stir fry treatment, there were no significant differences for any of the descriptors between the blanched and unblanched flowers (Table 4.5). This may be the result of frying in sunflower oil, which, due to a nutty odour, might have masked increased bitterness (1.52) due to action from enzymes in the USFAFs (Table 4.5). However, the most significant ($p<0.001$) differences between blanched and unblanched flowers were observed for the pickled treatment. The UPAFs had a significantly ($p<0.001$) cucumber and cooked green bean odour, green pepper colour, starchy and crunchy mouthfeel, and a bitter taste (Table 4.5). In contrast, the BPAFs were significantly ($p<0.001$) more sour and sweet n sour in taste (Table 4.5). Blanching protects antioxidant components from enzyme-mediated degradation, by inactivating enzymes such as polyphenol oxidase (Patras *et al.,* 2011). As mentioned previously, the acetic acid and sucrose in the brine mixture had an influence on the final odour and taste of both the BPAFs and UPAFs.

Figure 4.3 is the principal component biplot of F1 and F2, featuring the significant ($p<0.05$; $p<0.01$; $p<0.001$) sensory and physical attributes for the BSAFs, USAFs, USFAFs, BSFAFs, BPAFs and UPAFs. The first dimension explained 45.46%, and the second dimension, 28.77% of the variance in the data. The two dimensions accounted for 74.23% of the total variation in the data, making it sufficient to discuss only these two factors. The first dimension divided the six treatments into two groups, with the two pickled treatments on the left side of the plot, and the rest on the right side. This dimension explained the differences by means of descriptors amongst the three basic treatments, namely pickling on the left and steaming and stir frying on the right. The addition of an acid and sucrose to the flowers had a pronounced effect on the sensory quality of the flowers, as well as the absence of a second heat (BPAFs) or no heat

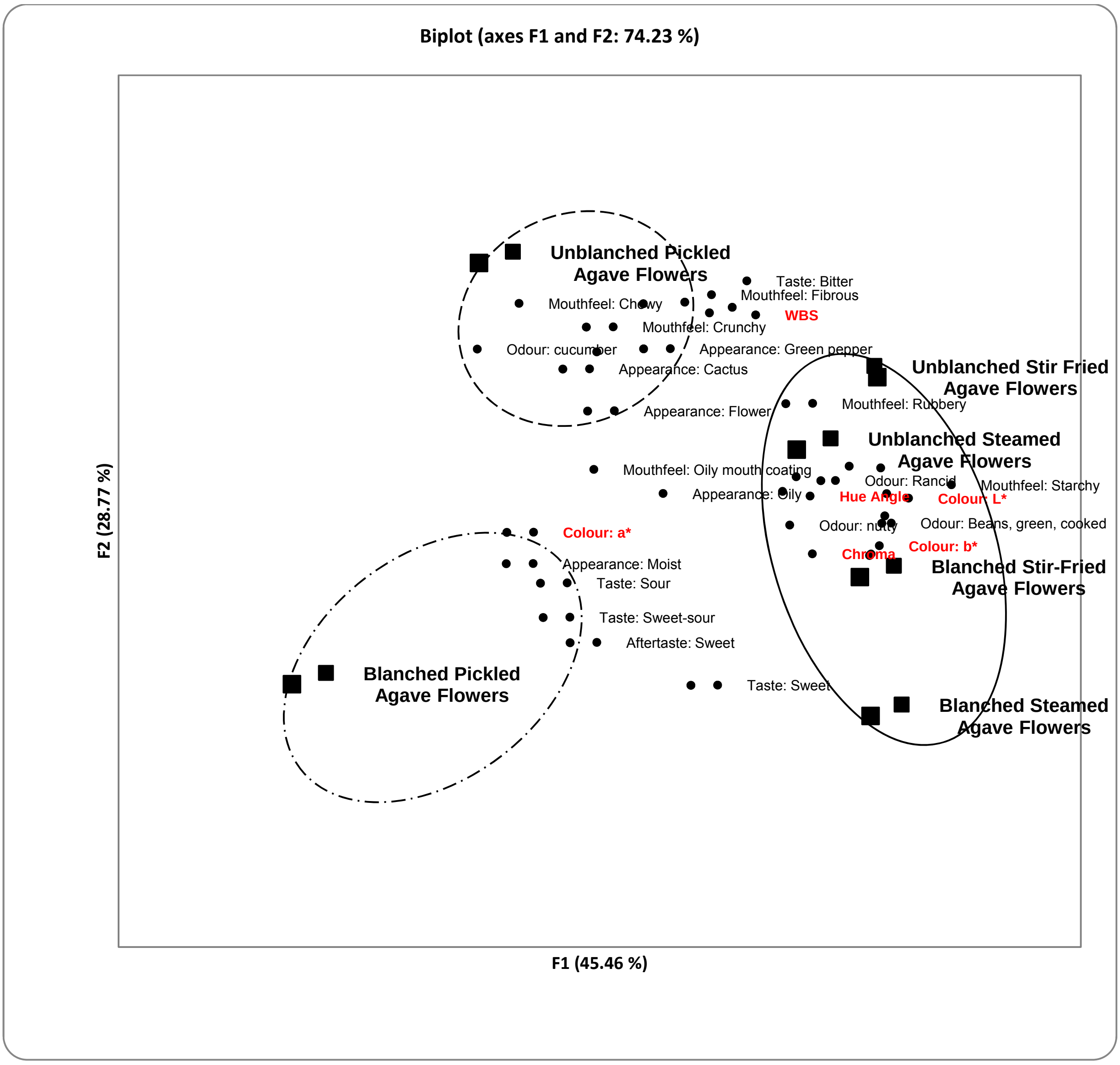

Figure 4.3: Principal component analysis biplot (F1 and F2) of significant sensory descriptors for differently treated blanched and unblanched *A. americana* flowers.

treatment at all (UPAFs). The second dimension, which adds to the explanation of differences among treatments, indicates differences between blanched and unblanched treatments, again by means of descriptors. All the unblanched treatments were clustered together in the top half of the biplot, while all the blanched treatments were found in the bottom half. Again, the absence or presence of blanching had serious implications for the sensory quality of the flowers, as was demonstrated in the discussion above. Some of the descriptors that were found in the top half of the biplot, could have negative associations, especially regarding vegetables, such as fibrous, bitter, cactus and rancid. Descriptors in the bottom half were generally more favourable and included mainly tastes (sweet, sour and sweet-sour) and odours (green bean and nutty) associated with vegetables (Figure 4.3).

These results clearly demonstrated the negative influence of no blanching of the agave flowers before treatments, whether or not heat is applied as part of the after treatment. It should be noted that the most prominent differences in the descriptors of the various treatments occurred due to the flowers being blanched or not. Panellists may possibly tolerate greater variation in descriptors due to different treatments, as opposed to variation in descriptors due to no blanching pre-treatment.

In the biplot in Figure 4.3 specific sensory attributes could be assigned to the BPAFs and UPAFs, while no clear distinction was possible between the USFAFs and BSFAFs in the right top corner of the biplot, and the USAFs and BSAFs in the bottom right corner. The BPAFs were described as having a sour and sweet-sour taste, a moist appearance and a sweet aftertaste. In contrast, the UPAFs were characterised by a crunchy, fibrous and chewy mouthfeel, cactus and flower-like appearance, along with green pepper colour and cucumber odour.

4.4.3 Colour and physical texture analysis of *Agave americana* flowers after treatments

4.4.3.1 Colour

Colour is a major quality attribute of vegetable products (Ihl *et al*., 1998). The most common alteration that occurs in green vegetables is the conversion of chlorophylls to pheophytins, causing a dramatic colour change from bright green to olive-brown. This conversion is enhanced by extended heat treatment and is dependent upon the amount of acids formed during processing and storage (Schwartz & Lorenzo, 1990). The enzyme chlorophyllase catalyses the cleavage of the phytol group from chlorophyll or from pheophytin and produces chlorophyllides or pheophorbides, respectively (Heaton

& Marangoni, 1996). Mild heat treatment, such as blanching, induces the formation of the C-13^2 epimers, producing chlorophylls a' and b'; which increase in quantity upon further heating (Schwartz & Lorenzo, 1990).

All three of the individual colour ordinates showed significant (p<0.001) differences between the six treatments, but not within the treatments (blanched versus unblanched) (Table 4.6). The L* or lightness index value for the BPAFs (45.33) was significantly (p<0.001) lower than the BSAFs (56.12), USAFs (55.37), BSFAFs (53.32) and USFAFs (55.94), but not the UPAFs (49.36). The UPAFs (49.36) was also significantly (p<0.001) lower than the BSAFs (56.12), and USFAFs (55.94) for lightness. The value of 56.12

Table 4.6: ANOVA of colour results of agave flowers from six different treatments.

Treatment	L*	a*	b*	Chroma	Hue Angle
BPAFs	45.33 ± 2.16^{a}	-0.28 ± 0.43^{d}	33.37 ± 6.42^{ab}	33.37 ± 6.42^{ab}	90.38 ± 0.75^{a}
UPAFs	49.36 ± 2.31^{ab}	-1.78 ± 0.31^{cd}	32.25 ± 4.92^{a}	32.30 ± 4.91^{a}	93.20 ± 0.68^{ab}
BSAFs	56.12 ± 3.36^{c}	-4.26 ± 0.67^{ab}	43.64 ± 4.74^{c}	43.85 ± 4.65^{c}	95.69 ± 1.43^{bcd}
USAFs	55.37 ± 5.79^{bc}	-3.29 ± 1.56^{bc}	45.80 ± 7.34^{c}	45.96 ± 7.20^{c}	94.44 ± 2.75^{bc}
BSFAFs	53.32 ± 2.35^{bc}	-4.60 ± 0.26^{ab}	41.17 ± 2.66^{abc}	41.43 ± 2.65^{abc}	96.39 ± 0.47^{cd}
USFAFS	55.94 ± 3.52^{c}	-5.56 ± 1.22^{a}	41.90 ± 5.28^{bc}	42.29 ± 5.16^{bc}	97.73 ± 2.23^{d}
Significance level	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$

Means with different superscripts in the same column differ significantly

(BSAFs) was the highest L* value, while the lowest L* value of 45.33 was measured for the BPAFs (Table 4.6). As mentioned earlier, the amount of acids present enhances the conversion of the bright green colour to olive brown and in the case of the BPAFs, the acetic acid in the brine contributed to this effect. The BSAFs were subjected to a hot water blanching process, followed by steaming. Boiling water blanching of artichokes, for 8 min, retained the total quality of chlorophyllous pigments, producing simultaneously good colour characteristics and achieving chlorophyllase inactivation (Ihl *et al*., 1998). The steaming that followed only softened the texture of the flowers and did not interfere with the colour of the flowers.

When looking at the effect within the specific treatments, the BPAFs (45.33) were significantly ($p<0.001$) lower in L* values (lightness) than the BSFAFs (53.32) and the BSAFs (56.12); the latter did not differ significantly from the BSFAFs. The pickling process had a significant ($p<0.001$) influence on the lightness of the agave flowers. The same trend was seen for the unblanched treatments. The UPAFs (49.36) did not differ significantly from the USAFs (55.37), and in turn, the USAFs also did not differ significantly from the USFAFs (55.94); however, the UPAFs had significantly ($p<0.001$) lower L* values than the USFAFs. The amount of acids present enhanced the conversion of the bright green colour to olive brown for both pickled treatment, despite the fact that there was no pre-heat treatment for the UPAFs. On the PCA (Figure 4.3), the colour L* values is positioned with the BSAFs and USAFs.

All a* values (redness) were negative, representing greenish colour (Tamer, 2012). Again, there were significant differences between the different treatments, but not within treatments (blanched versus unblanched). The lowest value was -5.56 and was measured for the USFAFs, which differed significantly ($p < 0.001$) from the USAFs (-3.29), UPAFs (-1.78) and BPAFs (-0.28) (Table 4.6), but not from the BSFAFs (-4.60) and BSAFs (-4.26). The USAFs (-3.29) were significantly ($p < 0.001$) lower in a* values than the BPAFs (-0.28), which had the highest measurement (Table 4.6). The two stir fried samples had the lowest a* values, followed by the two steamed samples, with the two pickled samples having the highest hue towards redness. This confirmed the results for the L* values, that the pickled flowers had a more olive brown colour than the other four treatments (Figure 4.3).

For the effect of treatment, the BPAFs (-0.28) were significantly ($p<0.001$) higher in a* value than the BSAFs (-4.26), as well as the BSFAFs (-4.60); the latter did not differ significantly from the BSAFs. This again is confirmation that the acids, combined with the sucrose in the brine had a significant influence on the colour of the flowers. A similar tendency was observed for the unblanched treatments, only here the UPAFs (-1.78) and USAFs (-3.29) differed significantly ($p<0.001$) from the USFAFs (-5.56); the UPAFs and USAFs did not differ significantly from one another (Table 4.6). On the PCA

(Figure 4.3), the colour a* value is positioned with the UPAFs, along with the sensory descriptor of green pepper appearance.

The colour b* values (yellowness) also differed significantly ($p < 0.001$) between the six treatments, but not within a specific treatment. The highest measurement for yellowness was found for the USAFs, with 45.80, and this treatment differed significantly ($p < 0.001$) only from the two pickled flowers, i.e., the BPAFs (33.37) and UPAFs (32.25); the last two mentioned treatments had the least yellowness in the flowers. The BSAFs (43.64) only differed ($p < 0.001$) significantly from the two pickled samples, while the USFAFs (41.90) only differed significantly ($p < 0.001$) from the UPAFs (32.25). Similar findings were reported by Fante, Scher, Noreña and Rios (2013), when steamed blanched yacon roots exhibited a light yellow colour along with red colour loss. From Table 4.6 it is evident that there was a numerical difference of about ten between the L* and b* values for the responding treatments, with the L* values being higher. For the effect of treatment, the BPAFs (33.37) had significantly ($p < 0.001$) lower values for yellowness than the BSAFs (43.64), while the UPAFs (32.25) were also significantly ($p < 0.001$) less yellow than the USAFs (45.80) and USFAFs (41.90). Thus, the same effect that was found with the L* values, was also seen with the b* values, i.e., significantly ($p < 0.001$) lower values for the two pickled treatments, compared to the other four treatments. This confirms the fact that the stability of the chlorophylls is affected by both temperature and pH (Ryan-Stoneham & Lorenzo, 2000). The central Mg atom is easily removed during thermal processing, particularly under acidic conditions, replacing it with hydrogen and forming the unappealing olive-brown pigments, pheophytins (Schwarts & Lorenzo, 1990), which is seen in Figure 4.2. According to Figure 4.3, the colour b* value is positioned with the USAFs and BSAFs in the present study.

For the present study, the chroma (saturation index/brightness) differed significantly ($p < 0.001$) between treatments, but not within treatments, meaning that the presence of blanching did not influence this calculated measurement (Table 4.6). The BPAFs and UPAFs had the lowest chroma /brightness values of 33.37 and 32.30, respectively and both differed significantly ($p < 0.001$) from both the BSAFs (43.85) the USAFs (45.96). The two pickled treatments had the lowest b* and highest a* values, in contrast to the two stir fried treatments, which showed the highest b* values and fairly low a*values. Finally, the UPAFs also differed significantly ($p < 0.001$) from the USFAFs (42.29), because of the low a* and high b* values of the USFAFs, compared to the low b* and high a* values of the UPAFs.

Conventional perceived colour is associated with the hue characteristic and is represented by yellow for an angle of 90°; objects with a higher hue angle are greener, while those with lower hue angles are more orange-red (Brewer, Klein, Rastogi, & Perry, 1994). For the present study, the hue angle also differed significantly ($p < 0.001$) between treatments, but not within treatments, meaning that the presence of blanching did not influence these two calculated measurements (Table 4.6). All values were higher than 90°, an indication of the green colour. The highest hue angle was calculated for the USFAFs (97.73) and lowest hue angle for the BPAFs (90.38). The BPAFs were also significantly ($p < 0.001$) lower for hue angle than the BSAFs (95.69), USAFs (94.44), BSFAFs (96.39) and USFAFs (97.73). These lower values for the blanched pickled treatment again confirmed the fact that the stability of the chlorophylls was affected by especially the pH, as were suggested by Ryan-Stoneham and Lorenzo (2000). The central magnesium atom is easily removed during thermal processing, particularly under acidic conditions, replacing it with hydrogen and forming the unappealing olive-brown pigments, pheophytins (Schwartz & Lorenzo, 1990). The UPAFs, which had low b* and high a* values, was also significantly ($p < 0.001$) lower in hue angle than the BSFAFs (96.39) and USFAFs (97.73), both of which had low b* and low a* values. The USAFs (94.44), with a hue angle of 94.44, low b* and low a* values, were significantly ($p < 0.001$) lower than the USFAFs' hue angle of 97.73, low a* and high b* values (Table 4.6).

4.4.3.2 Physical texture

Texture is an important product property that strongly affects the quality evaluation of processed vegetables by consumers (Dekker *et al.,* 2013). In pickled vegetables, texture has been identified as the most important factor determining consumer eating satisfactory (Fleming, McDonald, McFeeters, Thompson, & Humphries, 1995). Furthermore, it is also one of the quality indexes most affected by blanching (Olivera, Viña, Marani, Ferreyra, Maugridge, Chaves, & Mascheroni, 2008), since it leads to the softening of plant tissue (Guida *et al.*, 2013). Being a heat treatment, loss of turgor in cells is experienced due to destruction of membrane integrity and partial degradation of cell wall polymers (Bahçeci, Serpen, Gökmen, & Acar, 2005). Table 4.7 shows that there were in fact significant ($p < 0.001$) differences in the Warner Bratzler Shear measurements for all the treatments. This physical texture analysis was performed to correlate the results with the findings of the taste panel, in regard to mouthfeel. The reported value in kg represents the average of the peak force measurements of each sample.

The BPAFs (2.39) were significantly ($p < 0.001$) softer than the UPAFs (4.40), USFAFs (4.45) and the USAFs (3.90), while the BSFAFs were significantly softer than the USFAFs (4.45) and USAFs (3.90). On the other hand, the UPAFs were significantly ($p < 0.001$) tougher than the BSFAFs (2.13) and BSAFs (2.65), with the USFAFs (4.45) also significantly ($p < 0.001$) tougher than the BSAFs (2.65) and BSFAFs (2.13) (Table 4.7). It is significant to note that the blanched treatments did not differ amongst one another, a trend that was also followed by the unblanched samples. However, all the blanched samples were significantly ($p < 0.001$) softer in texture than the unblanched samples.

Table 4.7: Analysis of Variance (ANOVA) of Warner Bratzler Shear Data.

Product	WBS* (kg)
Blanched pickled agave flowers (BPAFs)	$2.39 + 0.61^{a}$
Unblanched pickled agave flowers (UPAFs)	$4.40 + 0.67^{c}$
Blanched stir fried agave flowers (BSFAFs)	$2.13 + 0.52^{a}$
Unblanched stir fried agave flowers (USFAFs)	$4.45 + 1.03^{c}$
Blanched steamed agave flowers (BSAFs)	$2.65 +0.48^{ab}$
Unblanched steamed agave flowers (USAFs)	$3.90 + 0.38^{bc}$
Significance level	$p < 0.001$

Means with different superscripts in the same column differ significantly

*Warner Bratzler Shear

This is in accordance with the findings of the sensory panel, who described the mouthfeel of the unblanched flowers as chewy, rubbery and crunchy. Blanching did soften the fibres in the agave flowers significantly ($p<0.001$) in the present study and confirmed the fact that blanching helps to improve the texture and ultimately the overall acceptability of a product.

4.5 CONCLUSION

Descriptive sensory analysis was used to describe the sensory properties of blanched and unblanched *A. americana* flowers, prepared by means of steaming, stir frying and pickling. Of the eleven attributes generated by the trained panel, three descriptors were for the attribute aroma, six for mouthfeel, five for appearance, four for taste and one for aftertaste. For the blanched pickled agave flowers, taste descriptors were prominent, namely sweet, sour and sweet n sour, followed by a sweet aftertaste, combined with a moist appearance. For all the unblanched flowers, regardless of treatment, some of the descriptors had negative connections, like fibrous, bitter, cactus and rancid. Descriptors for the blanched flowers, regardless of treatment, were more favourable and included sweet, sour and sweet n sour taste, and green bean and nutty odour.

Blanching and pickling significantly ($p<0.0001$) influenced the colour of the end product. Physical texture analysis supported the results of the trained panel regarding the significantly ($p<0.0001$) tougher texture of the unblanched samples, compared to the blanched samples, for all treatments.

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CHAPTER 5

DEVELOPMENT AND CONSUMER ACCEPTABILITY OF PRODUCTS DEVELOPED WITH WHOLE AND DRIED *Agave americana* FLOWERS

5.1 ABSTRACT

Blanched and unblanched agave flowers were dried and milled to a flour, to be used in the development of steamed bread and chocolate cake. Three panels of 50 members each participated in consumer acceptance tests, one each for the flour products (steamed breads and chocolate cakes) and one for the stews and deep fried flowers. Groups of five respondents convened every 15 min to taste the designated samples. Apart from acceptability, aroma, taste and texture were also evaluated for the two breads and two chocolate cakes. The breads, cakes and stews were defrosted at 4 ºC overnight and left at room temperature (22ºC) before serving. The steamed breads, fritters and stews were prepared with blanched flowers, while the agave flour cake was made with unblanched flowers. All the products were acceptable, but to different degrees. The scores were lower for aroma and final acceptability of the bread, due to unfamiliar texture experienced by the consumer panel. The agave cake scored lower on aroma and taste, but higher than the bread on texture. Compared to the other products, the blanched pickled agave flower stew and battered agave fritters, seasoned with chilli salt, were more acceptable than the other products, because of the good interaction between the chilli flavour and the sweet-sour taste of the pickled agave flowers.

5.2 INTRODUCTION

Agave americana is a very seasonal plant which flowers in different times, depending on the region. In Lesotho, flowering is determined by the weather. If it rains in spring (beginning of August), the plant will start flowering at the end of October, but if the rain falls in late spring (November), it will start flowering towards the end of December. Normally by the end of February, the flowers have reached maturity. These also differ based on the geographical regions of Lesotho (Liphoto, 2013).

Various methods of preservation are used to prolong the shelf life of flowers and new advanced preservation methods are created to retain nutrient content, similar to that found in fresh fruits and vegetables. Broccoli, cauliflower and artichokes can be canned, frozen, dried and pickled (Rickman, Barret, & Bruhn, 2002; Mrckí, Cocci, Rosa & Sacchetti, 2006; Jambrak, Mason, Paniwnyk, & Lelas, 2007; Kadam, Samuel, Chandra, & Sikarwar, 2008; Barrett & Lloyd, 2012), to transform these perishables into products that can be consumed year round and transported safely to consumers all over the world (Barrett & Lloyd, 2011).

Cauliflower that was blanched and treated with potassium bisulphite, dehydrated in a solar dryer and then packed in laminated aluminium foil, showed better results in terms of nutrients retention, moisture content and non-enzymatic browning (Kadam *et al*., 2008). High temperature short time processes maximised the antioxidant activity of broccoli, owing to the negative effect of drying time on antioxidant activity (Mrckí *et al.*, 2006). Ultrasound, as a pre-treatment method before drying cauliflower, shortened the drying time and showed good results on rehydration properties (Jambrak *et al.,* 2007). Artichoke hearts are processed simply by freezing, preserved in oil or vinegar, in brine water, marinated, freeze dried or dehydrated (Bianco, 2007).

Research on the drying and milling of vegetables, and in specific flowering vegetables, was found to be limited in literature. Flour was prepared from artichoke bracts by drying it at 80 °C in a ventilated oven, where after it was grounded in a Wiley mill with a 20 mesh. This flour was then used as an ingredient to enrich wheat flour when making bread (Khalil, 2002). In another study, cauliflower florets were also dried and milled as a way of making flour, and then incorporated into a range of model foods, such as minced beef burgers, sauces and delicatessen/bakery products (Femenia, Flefebvre, Thebaudin, Robertson, & Bourgeois, 2006). In a study using with artichoke flour, loaf volume of the control wheat bread was significantly higher than the volume of the wheat bread substituted with artichoke bracts, at different levels. There was, however, no significant difference in crust colour between wheat bread and wheat bread substituted with 5% and 10% artichoke bracts. There was also no significant difference in crumb colour, crumb texture, flavour, and overall quality between breads substituted with 5% and 10% artichoke bracts, before and after fortification with zinc sulphate at a level of 100 mg/100 g edible portion (Khalil, 2002).

Oliviero, Verkerk and Dekker (2013) used broccoli in a case study to explain how adsorption drying could be used to retain the health benefits of this vegetable. They described three products with different glucosinolate, myrosinase and isothiocyanate related health profiles, just by applying different drying scenarios with specific optimization targets.

In a study by Stojceska, Ainsworth, Plunkett, İbanoğlu, and İbanoğlu (2013), the incorporation of cauliflower trimmings into ready-to-eat extruded products and the effect on the textural and functional properties, were investigated. Dried and milled cauliflower was added at levels of 5-20% to the formulation mix. It was found that expansion indices, total cell area of the products and wall thickness showed negative correlations with the inclusion level of cauliflower. Sensory testing indicated that cauliflower could be incorporated into this type of product up to a level of 10%. In another study on cauliflower, drying characteristics was determined (Abhay, Thakur, & Jain, 2006), by thin-layer drying of fresh cauliflower 50, 60 and 70 °C air temperatures. Hot water blanching was done as pre-treatment. It was found that rehydration of the cauliflower dried at 50°C showed best reconstitution characteristics than at the higher temperatures. Sensory evaluation indicated that drying florets at 60°C could yield a relatively satisfactory dried product. Low temperature drying maintained the good colour of the dried cauliflower, although scores for taste and flavour were lower.

The aim of this study was therefore to develop products with whole and dried *A. americana* flowers and to test the consumers' acceptability of these products.

5.3 MATERIALS AND METHODS

5.3.1 *Agave americana* flowers

5.3.1.1 Flower preparation

Identification of flowers was carried out in three different areas in Lesotho: Sehlabeng (Maseru); Maliepetsane (Mafeteng); and Ha-Ramoshabe (Mafeteng). Flowers were collected during the summer and autumn season from wild plants and pooled, because a preliminary study showed no significant differences in chemical composition amongst flowers from the different areas.

The flowers were cut from the main stem and half of it was blanched before freezing at -18ºC, while the others were frozen unblanched.

5.3.1.2 Drying and milling of flowers

Two types of fresh flowers, namely blanched and unblanched, were placed on stainless steel trays and dried in ovens at 50°C for 48 - 72 h, so as not to destroy any nutrients (AOAC, 2005). Thereafter the dried samples were milled by using a 2 mm mesh. The agave flour was stored in 300 ml plastic jars with screw tops (Freepak, 112 Nelson Mandela Avenue, Bloemfontein, 9301) until used.

5.3.2 Development of products with dried flowers, i.e. agave flour

It was decided to use the blanched agave flour in the traditional Zulu steamed bread (TZSB) (*Ujeqe*), because of the absence of the bitter taste which was prevalent in the unblanched flour, as noted in Chapter 4. The unblanched agave flour was used in a modern recipe, namely flourless chocolate cake (FCC), because the use of dark chocolate, being already bitter in taste, would mask/enhance the bitter taste of the unblanched flour. The FCC also used ground almonds to replace wheat cake flour, so that the absence of gluten in the agave flour would not have an influence on the texture of the cake.

The formulation of the original and adapted traditional steamed bread can be seen in Table 5.1. The inclusion level of the agave flour was very low - ± 2% - due to the intense brown colour that was formed upon the addition of water to the agave flower. All the ingredients were mixed together and steamed in double boilers, cooled down, packaged and frozen at -18ºC until the sensory acceptability could be tested.

The formulation for the FCC and the agave chocolate cake (ACC) are given in Table 5.2. Here all the ground almonds were replaced by the bitter unblanched agave flour. The intense brown colour, formed after the agave flour was mixed with water, was in this

Table 5.1: Formulation of original and adapted traditional steamed bread.

Ingredient	% in TZSB (Kwakhehle, 2012)	% in agave flour steamed bread (AFSB)
white bread flour	46.15	45.19
salt	0.19	0.19
sugar	4.81	4.81
yeast	0.77	0.77
water, luke warm	48.08	48.08
agave flour	-	0.96

case not a problem, because of the dark brown colour of the dark chocolate used in this cake. After melting the chocolate, butter and sugar over low heat, the brandy, coffee and ground almonds/agave flour were added. This was followed by the addition of the beaten egg yolks and finally the beaten egg whites. The cakes were baked in Defy *Thermofan* ovens at 180 ºC for 45 min, cooled down, packaged and frozen at -18ºC until sensory testing.

Table 5.2: Formulation of original and adapted flourless chocolate cake.

Ingredient	% in FCC (Nataniël, 2002)	% in agave flour chocolate cake (AFCC)
eggs	30.49	30.49
dark chocolate	24.39	24.39
butter	18.28	18.28
castor sugar	12.20	12.20
brandy	1.22	1.22
black coffee	1.22	1.22
ground almonds	12.20	-
agave flour	-	12.20

5.3.3 Development of products with whole flowers

From Chapter 4 it was clear that the best eating quality was obtained by pickling the blanched agave flowers in brine (Table 4.1). It was therefore decided to use BPAFs to replace pond weed, or better known as w*aterblommetjie* (*Aponogeton distachyos*), in the stew with the same name. *Waterblommetjie* literally means water flower (Pemberton, 2000). Traditionally the flowers are used instead of green beans in Dutch green bean stew (Pemberton, 2000), and cooked with mutton, onions, potatoes, a large quantity of sorrel, white wine, salt, pepper and pondweed (Robbin as cited by Pemberton, 2000). Some recipes also include apples, tomatoes and chilli (Food and Cookery, 1991). Other applications include salads, soufflés, casseroles, fritters, sweet cakes and on toast (Louw as cited by Pemberton, 2000).

In the formulation for the agave flower stew (AFS), the pondweed flowers were simply replaced with the BPAFs, with no other changes to the basic recipe (Table 5.3). Since a

Table 5.3: Formulation of blanched pickled agave flower stew and blanched steamed agave flower stew.

Ingredient	% in BPAF stew (adapted *waterblommetjie* stew) (Foods and Cookery, 1991)	% in BSAF stew (adapted green bean stew) (Foods and Cookery, 1991)
mutton	25	25
cake flour	0.75	0.75
fat	0.25	0.25
onions	2.5	2.5
tomatoes	8	8
chilli	0.2	-
salt	0.2	0.2
pepper	0.1	0.1
sugar	0.5	0.7
wine	5	5
apple, Granny Smith	2.5	-
potato	5	7.5
BPAFs	50	
BSAFs		50

distinct cooked green bean flavour was detected in the BSAFs (Table 4.2), it was furthermore decided to include another agave stew, based on the traditional green bean stew (TGBS). Again, the BSAFs replaced the green beans in this formulation (Table 5.3). After frying the flour-coated meat and onions in fat, the tomatoes, chilli, BPAFs, chilli, potato, apple, wine, salt and pepper was added. The stew was covered and left to simmer for two to three h. Fifteen min before serving, the sugar was added (Foods and Cookery, 1991). For the green bean stew, the same procedure was followed, with the replacement of the green beans with BSAFs and the omittance of the apple and chilli (Foods and Cookery, 1991).

For the deep fat fried fritters, the BPAFs was drained and dipped into tempura batter, seasoned with one of two flavourings. For the batter all the ingredients were mixed together to a fairly stiff consistency. The flowers were dipped into this batter and special attention was paid not to remove excess batter, as to completely cover the flowers. It was then deep fried in sunflower oil (Pick ‘n Pay Retailers (Pty) Ltd., Pick ‘n Pay Office Park, 2 Allum Road, Kensington, 2094, South Africa), in a Kenwood deep fryer at 170 ºC, until golden brown.

Table 5.4: Formulation of tempura batter of deep fried blanched pickled agave flowers.

Ingredient	% in batter 1	% in batter 2
self raising flour	16	16
corn flour	16	16
soda water	55	55
onion salt	1	-
chilli salt	-	1
eggs	10	10

5.3.4 Consumer sensory tests

Three panels of 50 members each participated in the three consumer acceptance tests, one each for the two flour products (steamed breads and chocolate cakes) and one for the stews and deep fried battered flowers. Groups of five respondents convened every 15 min to taste the designated samples. Apart from acceptability, degree of liking of aroma, degree of liking of taste and degree of liking of texture were also evaluated for the two breads and two chocolate cakes. All samples were served and evaluated according to the sensory principles and methods described in the ASTM Manual on Sensory Evaluation (ASTM Manual Series: MNL 13, 1992).

The breads, cakes and stews were defrosted at 4 ºC overnight and left at room temperature (22ºC) before serving. Bread and cake cubes of 1 x 1 x 1 cm were served on white polystyrene trays; the bread samples were spread with Flora margarine, due to its neutral flavour (Unilever South Africa (Pty) Ltd, 15 Nollsworth Crescent, la Lucia, 4051, South Africa). The stews were heated in the microwave oven for 3 min on 100% power setting and 15 ml samples were spooned into individual miniature glass bowls. These bowls were covered with aluminum foil squares and placed in a *bain marie* until serving. Whole battered flowers were fried and drained, and served immediately to panelists.

Before starting and in between sampling, panelists' cleansed their palettes with a sip of mineral water (Aquartz still mineral water, Clover SA (Pty) Ltd., Clover Park, 200 Constantia Drive, Constantia Kloof, Roodepoort, 1709, South Africa). Respondents were asked to respond to the question "how much do you like or dislike the sample?" on a nine-point hedonic scale (Figure 5.1). All samples were coded with randomized, three-digit codes and rotated to prevent bias. Tasting were done in individual booths and under red lights as to prevent bias, at the Sensory Laboratory of the Food Science Division, Department of Microbial, Biochemical and Food Biotechnology, University of the Free State.

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

Figure 5.1: Nine point hedonic scale (Stone & Sidel, 2004).

5.3.5 Colour and physical texture analysis of products made with agave flour

The colour (L^*, a^* and b^*) values of six samples from the two different steamed breads and two chocolate cakes were assessed on cooled down slices (to ensure a flat surface to take measurements), using a Minolta chromometer. Saturation index (SI), which is related to the colour intensity of the samples, was calculated according to the formula: $SI = (a^{*2} + b^{*2})^{0.5}$ (Lanari *et al.,* 1995). Hue angle was calculated according to the formula $\tan^{-1}(b^*/a^*)$ (Rippoll *et al.,* 2011).

Physical texture analysis was performed with the Instron UTM (UTM model 3344), to correlate the results with the findings of the consumer panel. Again six samples from the two different types of steamed bread and two types of chocolate cake were cooled down to room temperature for at least 5 h, before shear force measurements. Cores, measuring a diameter of more or less 12.7 mm and a length of 30 mm, were prepared as prescribed by the method. The load cell size was 1 kN. A Warner Bratzler shear device, mounted on a Universal Instron apparatus was used and the reported value in kg represented the average of the peak force measurements of each sample. Sample compression data was generated by the Instron Bluehill software.

5.3.6 Statistical analysis

5.3.6.1 Statistical analysis of consumer panel

All the data were collected in spread sheets, using Microsoft Excel 2007 and all the statistical analyses were done using XLSTAT 2007 (NCSS, 2007). The significance of the overall acceptance measured for each sample was tested by means of analysis of variance (ANOVA). The different samples were used as the main effects at a significance level of $P < 0.001$. If the main effect was significant, Fisher's LSD-test was applied to determine the direction of the differences between mean values (Heymann, 1995).

After the data was calculated, the results were represented as a spider plot, where a specific spoke denotes a specific attribute. The distances of attribute mean from the center of the plot along each spoke directly corresponds to attribute intensity. The plot provides a visual presentation of product similarities and differences. For each attribute, the relative intensity increases as it moves farther away from the center point (Heymann, 1995).

5.3.6.2 Statistical analysis of colour and physical texture analysis

Differences between treatments were determined by using factorial analysis of variance (ANOVA) procedure for balanced data.

5.4 RESULTS AND DISCUSSION

5.4.1 Traditional Zulu steamed bread versus agave steamed bread

The demographic composition of the TZSB consumer panel is given in Table 5.5. Eighty two percent of the panel members were female, while 18% were male. For the age split, 16 % came from the age group 40-59, while 84% were in the age group 18-39. Figure 5.2 is the spider plot representing the sensory results, clearly showing the overwhelming acceptability of the TZSB to the AFB. From Table 5.6 it is evident that there were significant ($p < 0.001$) differences between the two steamed breads for all the attributes evaluated by the consumer panel. The TZSB had the highest values for all the attributes, ranging from 5.92 (taste) to 6.18 (texture). This range represented 'neither like nor dislike' to 'like slightly' on the hedonic scale Figure 5.1. The AFSB with

Table 5.5: Demographic profile of 50 member sensory panel for traditional steamed bread.

Gender:	% Of Total	Age	% Of Total
Female	82	< 20	4
Male	18	20 – 29	72
		30 – 39	8
		40 – 49	10
		50 – 59	4
		> 60	2

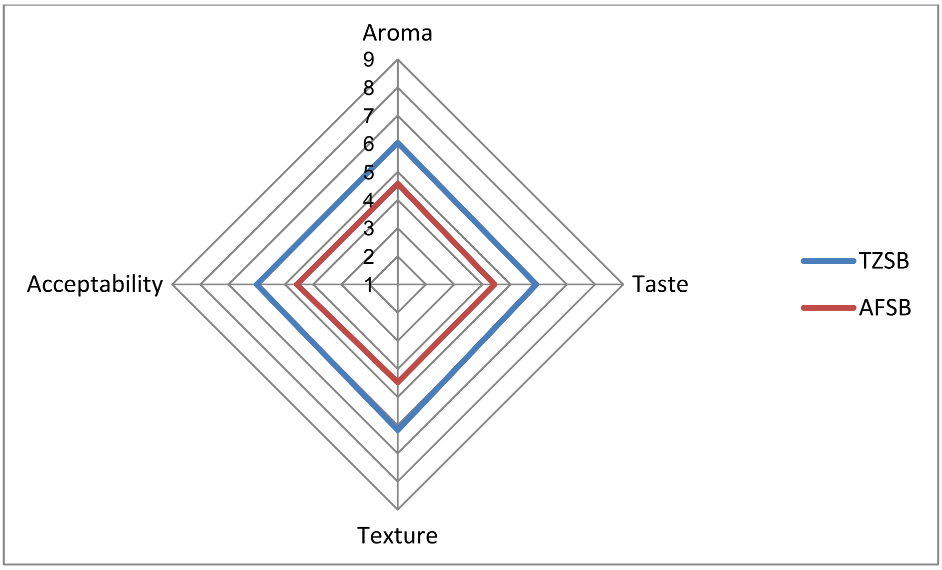

Figure 5.2: Spider plot of degree of liking of sensory properties for steamed breads

the 2% agave flour substitution scored significantly ($p < 0.001$) lower, from 4.44 (degree of liking of taste) to 4.58 (degree of liking of aroma and overall acceptability) (Table 5.6), representing 'dislike slightly' on the hedonic scale. From the low scores for the degree of liking of aroma and taste it is clear that the oven drying of the flowers also had a negative effect on the odour, and subsequently, also the taste and final acceptability of the bread. In a study on the drying of dasheen leaves, Maharaj and Sankat (1996) found that natural convection drying at 40 - 70 °C caused chlorophyll degradation and concomitant increase in the brown pigment, pheophytin. These changes accompanied a significant increase in acid formation, as well as increased susceptibility of chlorophyll to acid action. They also found the absence of blanching, as pre-drying treatment, also led to a significant decline in the pH of the dehydrated vegetables, which, as mentioned before, directly influenced colour and hence pigment (chlorophyll and pheophytin) concentrations.

Table 5.6: ANOVA of liking of sensory properties for steamed breads.

Sample	Aroma (n = 50)	Taste (n = 50)	Texture (n = 50)	Acceptability (n = 50)
TZSB	6.04 ± 1.80	5.92 ± 1.89	6.18 ±1.97	6.00 ± 1.87
AFSB	4.58 ± 2.06	4.44 ± 2.05	4.48 ± 2.31	4.58 ± 2.14
Significance Level	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$

Steamed bread usually has a larger volume and softer crumb (Nkhabutlane, du Rand & de Kock, 2013), while oven baked bread has a soft elastic crumb texture (Carr, Rodas, Torre, & Tandini, 2006). Although the dense, moist texture is not unacceptable as such, the panel communicated that this texture was totally unfamiliar to them in regard to bread (Bothma, 2013). Also, in traditional Zulu culture this type of bread is eaten with stews and curries (Kwakhehla, 2012), and not with spread, as was the case in this sensory test. When reviewing the measurements of the Warner Bratzler Shear (Table 5.7), there was no difference between the two bread samples, indicating that the agave flour did not change the texture of the bread. It can be speculated that the unfamiliar texture, unpleasant taste and odour of the AFB influenced the panel in such a way that they gave a low score for acceptability. When observing the two breads in Figure 5.3, the difference in colour is clearly visible, with the AFB having the darker colour of the two.

Table 5.7: ANOVA of colour and shear force data of breads and chocolate cakes.

Product	**L***	**a***	**b***	**Chroma**	**Hue Angle**	**WBS (kg)**
TZSB	64.93 ± 3.36^c	-0.29 ± 0.24^a	16.83 ± 0.37^a	16.83 ± 0.37^a	90.99 ± 0.84^d	0.13 ± 0.03^{ab}
AFSB	58.48 ± 3.04^b	1.81 ± 0.43^b	24.18 ± 0.87^b	24.25 ± 0.89^c	85.73 ± 0.90^c	0.13 ± 0.04^{ab}
FCC	30.46 ± 1.67^a	10.11 ± 0.39^d	16.03 ± 0.60^a	18.96 ± 0.71^b	57.76 ± 0.27^a	0.11 ± 0.04^a
AFCC	30.83 ± 1.30^a	7.00 ± 0.42^c	15.63 ± 1.12^a	17.12 ± 1.18^a	65.85 ± 0.60^b	0.15 ± 0.02^b
Sign. level	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.05$

Means with different superscripts in the same column differ significantly
WBS = Warner Bratzler Shear

All the colour measurements differed significantly ($p < 0.001$) between the two breads (Table 5.7). The L* (lightness) value for the TZSB (64.93) was significantly ($p < 0.001$) higher than that of the AFSB (58.48), confirming that the TZSB was lighter in colour. Furthermore, the negative a* value of -0.29 for the TZSB indicated a slight greenish colour (Martínez, Ros, Periago, López, Ortuño, & Rincón, 1995; Ihl *et al*., 1998), whereas the positive a* value for the AFSB showed a reddish colour, which was a significant ($p < 0.001$) difference between the two breads. The b* value, indicating yellowness, was significantly ($p < 0.001$) higher for the AFSB (24.18), than the TZSB (16.83).

a

b

Figure 5.3: a) traditional steamed Zulu bread (TZSB)
b) steamed agave flour bread (AFSB)

As mentioned earlier, conventional perceived colour is represented by yellow for an angle of 90°, while a higher hue angle indicates a greener colour and a lower hue angle, more orange-red (Brewer *et al.,* 1994). For the present study, the hue angle also differed significantly ($p < 0.001$) between the two breads (Table 5.7). The TZSB (90.99) was the only product with a hue angle > 90° and being so close to 90° it confirmed the yellowness of the bread; this was also the highest value for hue angle for the four baked products. The AFSB (86.73) was significantly ($p < 0.001$) lower for hue angle than the TZSB, indicating a shift towards the orange-red hue. Chroma or saturation index (SI) is related to the colour intensity of the samples and these calculated values also differed significantly ($p < 0.001$) between the two bread samples. The TZSB had the lowest values for redness and yellowness, thus resulting in the lowest chroma value of 16.83. The chroma of the AFSB was significantly ($p < 0.001$) higher, at 24.25, as a result of its relatively low a* value of 1.81 (Table 5.7).

5.4.2 Flourless chocolate cake versus agave chocolate cake

Table 5.8 shows the demographic composition of the panel used for the chocolate cakes. Seventy four percent of the panel members were female in this case, with 26% males. For the age split, 12 % came from the age group 40-59, while 88% were in the age group 18-39. The spider plot in Figure 5.4 represents the sensory data, showing a preference for the taste, aroma and acceptability of the FCC. According to Table 5.9, the preference for taste, aroma and acceptability differed significantly ($p < 0.001$) between the two samples. Again the FCC scored significantly ($p < 0.001$) higher values for aroma (7.22 = 'like moderately'), taste (7.12 = 'like moderately') and acceptability (6.92 = 'like slightly'). The scores for the agave cake were significantly ($p < 0.001$) lower and ranged from 5.68 for aroma ('neither like nor dislike') to 5.46 for taste ('neither like nor dislike') to 5.78 for acceptability ('neither like nor dislike'). There was no significant difference for texture between the two samples, with the ACC, in fact, scoring the numerically higher value than the FCC, because of the more cake-like texture of the ACC. However, the Warner Bratzler Shear measurements for the two samples showed a significantly ($p < 0.05$) higher shear force value for the ACC (0.15) than the FCC (0.11), indicating that the texture of this cake was softer than that of the ACC (Table 5.7). In Figure 5.5 it can clearly be seen that the FCCs had a hollow top, while the ACCs' tops were rounded, although cracked. Because of the almond flour, the FCC had a moist, dense texture; in contrast, the texture of the ACC showed a clear crumbliness, which is characteristic of cake flour-containing cakes (Karaoglu, Konttancilar & Gercękaslan, 2008; Psimouli & Oreopoulou, 2012). Both textures were acceptable to the consumer panel, as the scores of 6.30-6.38 (Table 5.9) represented 'like slightly' on the hedonic scale (Figure 5.1). Again, as was the case for the AFSB, the taste and aroma, and subsequently the overall acceptability of the agave bread were adversely affected by the drying process of the raw unblanched agave flowers.

The USFAFs had a rancid odour (Table 4.3) and it was noted during the development of the products, that the unblanched agave flour had an intense bitter taste, which might

Table 5.8: Demographic profile of 50 member sensory panel for chocolate cakes.

Gender:	% Of Total	Age:	% Of Total:
Female	74	< 20	2
Male	26	20 – 29	80
		30 – 39	6
		40 – 49	6
		50 – 59	4
		>60	2

Table 5.9: ANOVA of liking of sensory properties for chocolate cakes.

Sample	Aroma (n = 50)	Taste (n = 50)	Texture (n = 50)	Acceptability (n = 50)
FCC	7.22 ± 1.31	7.12 ±1.33	6.30 ± 2.12	6.92 ± 1.58
ACC	5.68 ± 1.71	5.46 ± 1.96	6.38 ± 1.46	5.78 ± 1.79
Significance Level	p < 0.001	p < 0.001	NS	p < 0.01

NS = Not significant

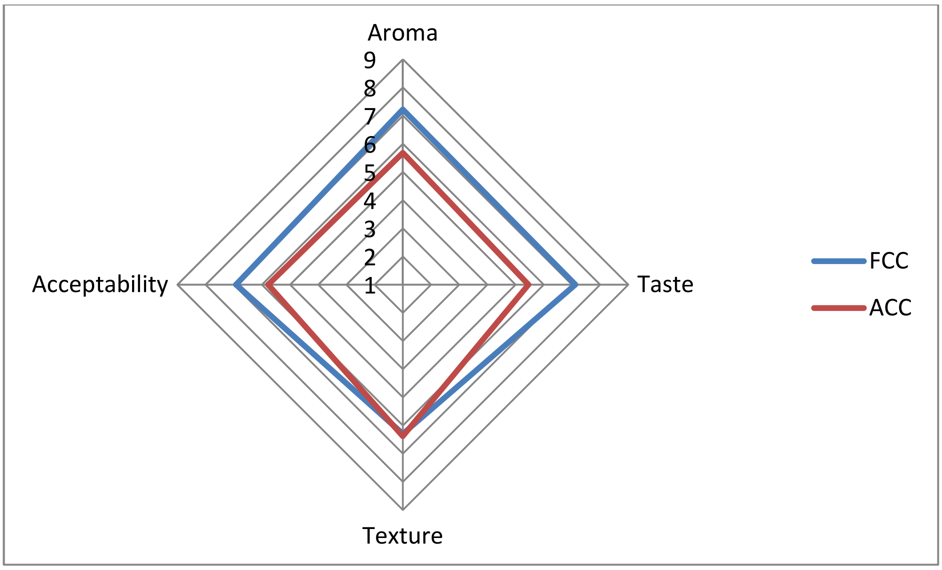

Figure 5.4: Spider plot of degree of liking of sensory properties of chocolate cakes

a b

Figure 5.5: a) flourless chocolate cake b) chocolate cake with agave flour

have been due to active enzymes in the plant material, which was elevated by the drying process. It was concluded in Chapter 4, that the dry heat treatment should not be used in the preparation of agave flowers, because of all the negative effects it had on the quality characteristics of the final product.

When looking at Figure 5.4, it can be seen by the naked eye that there is a difference in the colour of the two types of chocolate cakes. The L* values did not differ significantly, but was low (30.46 – 30.83), indicating that the cakes were rather dark in colour (Table 5.7). Furthermore, there was also no difference between the low b* values (15.65 – 16.03), indicating once more low amounts of yellowness. The only significant ($p < 0.001$) difference was for the a* values, where the FCC (10.11) was more red than the ACC (7.00), confirming that the ACC was more red in colour than the FCC. As the a* values became smaller and tend to become negative, it moved towards the green colour (Lin, Hwang, & Yeh, 2003).

The lowest hue angle was calculated for the FCC, with 57.76, which was significantly ($p < 0.001$) lower than the value for the ACC (65.85). The FCC had the highest value for redness (a* = 10.11), which was also significantly ($p < 0.001$) lower than the a* value for the ACC (7.00) (Table 5.7).

5.4.3 Blanched pickled agave flower stew versus blanched steamed agave flower stew

The demographic composition of the agave stew and fritter panel is shown in Table 5.10. Seventy eight percent of the panellists were females, while 22% were males, with the age group ranging between 20 and 59. Seventy four percent of the panellists were between the ages of 18 to 39, and 26% in the age group 40-59.

Table 5.11 shows the values for the sensory acceptability of the stews, with the BPAF stew scoring 7.10 and the BSAF stew 6.96. Both scores indicated that the panel 'liked' the stews 'moderately', as represented on the nine-point hedonic scale. There was no significant difference between the two types of stew in terms of preference. As noted in Chapter 4, the preference for the stew might have been influenced by the blanching pre-treatment, which generally improved the flavour of other vegetables due to inactivation of enzymes (Nielsen, Larsen, & Poll, 2004). Also, the stews contained other vegetables like potatoes, tomatoes, onions etc. (Table 5.3), which could have contributed to the preferred taste.

Table 5.10: Demographic profile of 50 member sensory panel for agave stews and fritters.

Gender:	% of Total	Age:	% of Total:
Female	78	< 20	2
Male	22	20 – 29	62
		30 – 39	10
		40 – 49	16
		50 – 59	10

Table 5.11: ANOVA of liking for agave stews.

Product	BPAF stew	BSAF stew	Sign. Level
Sensory Score	7.10 ± 1.62	6.96 ± 1.70	p = 0.6304

Means with different superscripts in the same row differ significantly

5.4.4 Blanched pickled agave fritters

The demographic profile of agave fritters is similar to the one for the agave stews (78% females, 22% males). The sensory scores for the fritters ranged between 7.02 - 7.26,

(Table 5.12), which represented “like moderately” on the hedonic scale. Similarly, there was no significant difference for the preference of the agave fritters. The fritters containing onion salt scored 7.02 and the fritters with the chilli salt, 7.26. The fritters followed the same tendency as the stew, where the BPAF stew, containing fresh chilli in combination with the sweet-sour taste of the pickled agave flowers, scored the highest value for preference (Table 5.11).

Table 5.12: ANOVA of liking for agave fritters.

Product	Onion flavoured BPAF fritters	Chilli flavoured BPAF fritters	Sign. Level
Sensory Score	7.02 ± 1.45	7.26 ± 1.29	p = 0.3841

Means with different superscripts in the same row differ significantly

5.5 CONCLUSION

Consumer panels were used to determine the acceptability of products developed with whole and dried agave flowers. Flour milled from blanched agave flowers was used to make TZSB, while unblanched agave flour replaced almond flour in chocolate cake. Two stews were prepared, one with BPAFs and the other with BSAFs; BPAFs were also dipped in onion- and chilli-seasoned tempura batter and deep fried in oil. For the breads and cake, overall acceptability, taste, aroma and texture were evaluated by 50-member consumer panels, while colour and physical measurements were also done. The stews and fritters were scored by a 50-member consumer panel for acceptability. The scores were lower for aroma and final acceptability of the bread, due to the unfamiliar texture experienced by the consumer panel. The ACC scored lower on aroma and taste, but higher than the bread on texture. Products made with BPAFs were most acceptable, regardless of the cooking method and included the BPAF stew and BPAFs dipped in seasoned batter and deep fried.

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CHAPTER 6

GENERAL DISCUSSION AND CONCLUSIONS

Flowers have been used in various ways in cookery. Nasturtium blossoms, stuffed with crab meat, make a colourful dish when served on a bed of deep green nasturtium leaves (Bennion & Scheule, 2004). Generally, flower usage was confined to decorations for desserts and drinks, or garnishes for salads. Other culinary uses for edible flowers include using flowers in baking, and the flavouring of sauces, jellies, syrups, vinegar, honey, oils, teas, flower-scented sugars, candied flowers, wine and flavoured liquers (Mlcek & Rop, 2011). About three authors have reported on the use of flowers as food in Southern Africa (Fox, 1982; FAO, 1988; Roberts, 2000). On top of that, Mildred (2009) highlighted the good features and nutritional importance of flowers, as well as preparation of different dishes using flowers.

In many African countries, including Lesotho, there is the ever increasing problem of food insecurity. However, hardy plants, like *Agave americana*, are abundantly available in Lesotho and can be used as a food crop (CSIR News, 2008). According to Felger and Moser (1970), the Seri people from Cerén (El Salvador) used eight species of agave flowers as a major source of food, especially sugar. Furthermore, the agavaceae is among the 62 species of flowers which are eaten raw in salads, and among the 55 species which are fried for preparing side-dishes, vegetarian stuffed balls and omelettes in Sicily (Lentini & Francis, 2007).

Indigenous African leafy vegetables have recently been attracting research attention, not only in terms of their inherent nutritional quality, but also for the healing power of some of these plants. Diversification of diets through increased utilization and consumption of these vegetables would go a long way in alleviating hunger and malnutrition (Kimiywe *et al.,* 2007).

Flowers are good sources of important nutrients. Broccoli, being greener, rates higher in nutritive value than cauliflower and is a good source of F, P, vitamins A and C, and riboflavin (Bennion & Scheule, 2004). Cauliflower is also a good source of Vitamin C. Artichoke is a good source of minerals, particularly K, Ca, P and dietary fibre (Lintas, 1992).

Agave flowers contain fructans, which function as prebiotics in the body (Boguslavsky *et al.,* 2007). The leaves and sap of *A. americana* contain saponins, inulin, fructans and steroidal glucosides. They also contain dietary fibre, fructose, glucose, proteins, essential amino acids like lysine, tryptophan, histidine, phenylalanine, and vitamins B and C. The main mineral contents of *A. americana* leaves are Fe, Ca and P (Islas-Lopez *et al*. 2005; Pard as cited by Rivera *et al.,* 2010). Inulin, derived from agave flowers, has a potential prebiotic effect, as it increases the growth of bifidobacteria and lactobacilli (Gomez *et al*., 2009).

In Chapter 2 of this thesis an attempt was made to provide an adequate and orderly overview of the literature available, explaining the malnutrition problem experienced in certain parts of the world. The importance of vegetables in the human diet was investigated, as well as the use and nutritional content of the most important flowering vegetables, namely artichokes, broccoli and cauliflower. Other well-known edible flowers of the world, Southern Africa and Lesotho were classified in tables, along with pictures and usages. The agave plant and specifically the flower were discussed, highlighting the most important characteristics for future human consumption. Research into the sensory analyses of edible flowers was found to be limited; however, there appeared to be an increased interest in the nutraceutical benefits of horticultural flowering plants. The author believes that this literature review has made a contribution in that it has highlighted the positive effects of flower consumption by humans.

The first experimental part of this study determined the nutritional composition of the *A. americana* flowers and compared it to the nutritional composition of the most commonly eaten flower vegetables. The nutritional composition of agave flowers compared well to that of artichokes, broccoli and cauliflowers, showing a similar trend for nutrients contained by these flowers, albeit differences in quantities. The agave flowers were high in moisture (86.62%) and K (207.77 mg/100 g), had an average content of dietary fibre (2.12 g/100 g), Mg (53.06 mg/100 g), Ca (48.33 mg/100 g) and P (32.12 mg/100 g), and were low in energy (226 kJ/100 g), protein (1.71 g/100 g), fat (0.46 g/100 g), Na (1.27 mg/100 g), Fe (1.03 mg/100 g), Zn (0.66 mg/100 g), Cu (0.04 mg /100 g), Mn (0.52 mg/100 g) and vitamin C (1.03 mg/100 g) contents. Vitamin A was not detected in the agave flowers.

Broccoli (91.8%) and cauliflower (98.5%) were higher in moisture than the agave flowers (86.62%); however, the agave flowers' moisture content was closer to that of artichokes (84.9%). The flowers also had a similar energy value (226 kJ) to that of artichokes (242 kJ), which was quite higher that of broccoli (133 kJ) and cauliflower (181 kJ). The protein (1.7 g/100 g) content was close to that of broccoli (1.8 g/100 g), but lower than cauliflower (3.8 g/100 g) and artichokes (3.3 g/100 g). Despite the low fat content in the agave flower (0.40 g/100 g), it was double that of artichokes, broccoli and cauliflower, all having 0.20 g/100 g. The fibre value for the agave flower (2.21 g/100 g) was the same as for broccoli (2.2 g/100 g), but only about a third of cauliflower (3.3 g/100 g) and half of artichokes (5.4 g/100 g).

The total sugar content of agave flowers amounted to 4.01 g/100 g and included fructose (1.06 g/100 g), glucose (0.77 g/100 g), sucrose (0.52 g/100 g) and maltose (0.69 g/100 g). According to Wolmarans (2010), the common flower vegetables artichokes (2.5 g/100 g), broccoli (2.8 g/100 g) and cauliflower (2.6 g/100 g) contain about half of that amount.

In the second part of the study, the effect of blanching, or not, was studied on the sensory, colour and physical texture of agave flowers prepared in three different ways. Blanching is a heat treatment done in vegetables before freezing, in order to inactivate enzymes. The shortest possible time is needed to avoid actual cooking and loss of water soluble nutrients. One of the advantages of blanching is the preservation of colour; however there is no agreement in literature on whether this is true. In 1998, Ihl *et al*. found that steam blanching of artichokes led to lower values for lightness index, hue and chroma, which indicated major loss of chlorophylous pigment. This was contradicted by Martínez-Hernàndez *et al*. (2013), who stated that steaming was indeed the best method to retain chlorophyll. Blanching also resulted in good texture, softened stem and induced a strong cell wall structure in vegetables.

Descriptive sensory analysis of the various agave flower treatments indicated that blanching was of the utmost importance for panellist satisfaction. The treatment that was significantly ($p<0.001$) superior in taste, aroma, texture, aftertaste and appearance, was the agave flowers that were blanched and pickled in a brine. Taste descriptors for this treatment included sweet, sour and sweet-sour, combined with a moist appearance. For the unblanched flowers, regardless of the treatment, some of the descriptors had negative connections like fibrous, bitter and rancid. Descriptors for blanched flowers were more favourable regardless of the treatment, and included sweet, sour and sweet-sour taste, green bean and nutty odours. Blanching and pickling influenced the colour of the end product significantly ($p<0.001$) and this was supported by the physical texture analysis; unblanched samples had a tougher texture compared to the blanched samples for all treatments.

For the first time agave flowers were dried and milled into a flour to be used in the development and enrichment of baked products. This was a deliberate way to add variation to the applications of the flowers, as well as the diet of local people and health conscious consumers. More agave flower products would be made available to the consumers from all over the world.

Blanched agave flour was used to make the traditional Zulu steamed bread, while unblanched agave flour was used for the flourless chocolate cake. Aroma, taste and acceptability of the breads were evaluated by a 50-member consumer panel. Oven drying of the flowers had a negative effect on the odour, taste and final acceptability of the bread. Steamed agave bread had a moist texture, which was not acceptable as the panel indicated that the texture was totally unfamiliar to them. There was no difference between the two bread samples, based on the measurements of the Warner Bratzer Shear, indicating that the agave flour did not change the texture of the bread. The difference in colour was visible, with the agave bread having the darker colour of the two. The traditional steamed bread was lighter (L*-value) in colour, whereas the agave bread showed a reddish colour, as indicated by negative a*-values. The value indicating yellowness (b* -value) was significantly ($p < 0.001$) higher for the agave bread, than the traditional steamed bread.

The original chocolate cake contained ground almonds to replace wheat cake flour, so that the absence of gluten in the agave flour would not influence the texture of the agave cake. The agave cake scored lower on aroma and taste, but higher than the bread in texture. There was no significant difference for physical texture between the two samples, with the agave cake scoring a higher value than the flourless cake, because of the more cake-like texture of the agave cake. The agave cake again was darker in colour than the almond chocolate cake.

In the final part of the study flowers from the best treatment (Chapter 4) were used to develop agave stews and deep fried agave flowers, the latter coated in a seasoned tempura batter. A *waterblommetjie*-type stew was developed by replacing the pondweed with BPAFs. In the second stew, BSAFs were used to replace green beans, because of their characteristic green bean odour. There was no significant difference between the two stews in terms of likeness, scoring between 6.96 (‘like slightly’) for the BSAF stew and 7.10 (‘like moderately’) for the BPAF stew. For the deep fried agave flowers in seasoned batter, BPAFs were dipped in tempura batter flavoured with either chili seasoning or onion salt. This product group scored the highest values with the 50-member consumer panel, namely 7.02 (onion salt) and 7.26 (chili seasoning), both representing ‘like moderately’ on the nine-point hedonic scale.

This study has revealed the important nutrients contained in the flowers of a plant that is available in many parts of the world, and has been used for other valuable purposes. The products made with *Agave americana* flowers can be enjoyed by different people, even those who are health conscious, because the type of nutrients it contains are similar to those of well-known flowers, even though they differ in quantity. Rural people can make use of agave flowers to add variety to their diets. All the products were acceptable to the consumer panel, but the blanched pickled products were the most preferred.

A future study can be done to assess the complete nutritional composition of the flower. Further investigation can be done to find a suitable drying method, which will not impart any undesirable characteristics and lessen nutrient composition.

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CHAPTER 7

SUMMARY

The nutritional composition of agave flowers was determined and the following nutrients were analysed: moisture (86.62%); energy (226 kJ/100 g); proteins (1.71 g/100 g); fat (0.46 g/100 g); dietary fibre (2.12 g/100 g); K (207.77 mg/100 g); Mg (53.06 mg/100 g); Ca (48.33 mg/100 g); P (32.12 mg/100 g); Na (1.27 mg/100 g); Fe (1.03 mg/100 g); Zn (0.66 mg/100 g); Cu (0.04 mg/100 g); and Mn (0.15 mg/100 g). In contrast to many vegetables, the flower samples contained sugars in the form of sucrose (0.52 g/100 g), glucose (0.77 g/100 g), fructose (1.06 g/100 g) and maltose (0.69 g/100 g). The vitamin C content was 1.03 mg /100 g, but no vitamin A was detected.

When compared to other flower vegetables, the agave flower had the lowest contents for protein, P, K, Mn, Na, Cu and vitamin C, but the highest value for fat. The agave flower and artichoke had similar values for energy, moisture and Mg, while the cauliflower and agave compared well in regard to Ca and Zn contents. Broccoli had similar contents for protein, fibre, P and Cu. The agave had higher values for energy, and fat than cauliflower, and higher fat and Ca, Fe, Mg, P and Zn values than broccoli. Artichokes had lower contents for moisture, fat, Ca and Zn than the agave flowers. Broccoli and cauliflower were moister than the agaves.

Descriptive sensory analysis was used to investigate how various treatments would influence the sensory properties of *Agave americana* flowers. Blanched and unblanched flowers, subjected to three treatment methods (steaming, stir frying and pickling), were analyzed by ten trained panelists, in three replications. The data was analyzed using principle component analysis. A lexicon of 20 attributes was generated, including 11 for the steamed treatment, an additional six for the stir fried treatment and another four for the pickled treatment. Of these, three descriptors were for the attribute aroma, six for mouthfeel, five for appearance, four for taste and one for aftertaste. The unblanched pickled agave flowers were characterized by crunchy, fibrous and chewy mouthfeel, bitter taste, green pepper colour and cactus appearance, and a cucumber odour. For the blanched pickled agave flowers, taste descriptors were prominent, namely sweet, sour and sweet-sour, followed by a sweet aftertaste, combined with a moist appearance. For all the unblanched flowers, regardless of treatment, some of the descriptors had negative connections, like fibrous, bitter, cactus and rancid. Descriptors for the blanched flowers, again regardless of treatment, were more favourable and included sweet, sour and sweet-sour taste, and green bean and nutty odour.

Three panels of 50 members each participated in the consumer acceptance tests, one each for the steamed breads and chocolate cakes, and one for the stew and deep fried flowers. Apart from acceptability, aroma, taste and texture were also evaluated for the baked products. The breads, cakes and stews were defrosted at 4 ºC overnight. The breads and cakes were left at room temperature (22ºC) before serving, while the stews were served heated. The breads, fritters and stews were prepared with blanched flowers, while the cake was made with unblanched flour. All the products were acceptable, but in different degrees. The scores were lower for aroma and final acceptability of the bread, due to unfamiliar texture experienced by the consumer panel. The agave cake scored lower for aroma and taste, but higher than the bread on texture. The stews and battered agave fritters were liked by the consumer panels and scored between 6.92 and 7.26 on the hedonic scale.

Keywords: agave flower; nutrient; blanching; descriptive sensory; pickled; product development; consumer

OPSOMMING

Die nutrientsamestelling van die agaweblomme is bepaal en die volgende voedingstowwe is ontleed: vog (86.62%); energie (226 kJ/100 g); proteïene (1.71 g/100 g); vet (0.46 g/100 g); vesel (2.12 g/100 g); K (207.77 mg/100 g); Mg (53.06 mg/100 g); Ca (48.33 mg/100 g); P (32.12 mg/100 g); Na (1.27 mg/100 g); Fe (1.03 mg/100 g); Zn (0.66 mg/100 g); Cu (0.04 mg/100 g); en Mn (0.15 mg/100 g). In teenstelling met baie groentes, bevat die agaweblomme suiker in die vorm van sukrose (0.52 g/100 g), glukose (0.77 g/100 g), fruktose (1.06 g/100 g) and maltose (0.69 g/100 g). Die vitamien C-inhoud was 1.03 mg /100 g, maar geen vitamien A is bepaal nie.

In vergelyking met ander blomgroentes het agaweblomme die laagste proteïen- P-, K-, Mn-, Na-, Cu- en vitamien C-inhoud, maar die hoogste waarde vir vet. Die agaweblom en artisjok het eenderse waardes vir energie, vog en Mg, terwyl blomkool en die agave goed met mekaar vegelyk ten opsigte van Ca- en Zn-inhoud. Brokkoli het dieselfde inhoud as die agaweblom vir proteïene, vesel, P en Cu. Die agawe het hoër energie- en vetinhoud as blomkool, en hoër vet- en Ca-, Fe-, Mg-, P- and Zn-inhoud as brokkoli. Artisjokke het laer vog-, vet-, Ca- en Zn-inhoud as die agaweblomme. Brokkoli en blomkool het ‘n hoër voginhoud as die agawes.

Beskrywende sensoriese analise is gebruik om te wys hoe verskillende behandelings die sensoriese eienskappe van *Agave americana* blomme kan beïnvloed. Geblansjeerde en ongeblansjeerde blomme, voorberei met behulp van drie behandelings (stoom, roerbraai en pekeling), is beskryf deur tien opgeleide paneellede. Die data is ontleed met behulp van ‘principle component analysis’. ‘n Woordeskat van 20 kenmerke is opgestel, insluitend 11 beskrywende woorde vir die stoom-behandling, nog ses vir die roerbraai-behandeling en ‘n verdere vier vir die pekelbehandeling. Van hierdie beskrywende woorde was drie vir aroma, ses vir mondgevoel, vyf vir voorkoms, vier vir smaak en een vir nasmaak. Die ongeblansjeerde gepekelde agaweblomme is gekenmerk deur bros, veselagtige en taai mondgevoel, bitter smaak, groensoetrissie-kleur, kakatusvoorkoms en ‘n komkommergeur. Vir die geblansjeerde gepekelde agaweblomme was smaak-beskrywers prominent, naamlik soet en soetsuur, gevolg deur ‘n soet nasmaak, gekombineer met ‘n nat voorkoms. Beskrywende woorde vir al die ongeblansjeerde blomme, ongeag behandeling, het negatiewe verbintenisse gehad, soos veselagtig, bitter, kaktus en galsterig. Die beskrywende woorde vir die geblansjeerde blomme was, ongeag van die behandeling, meer gunstig en het soet, suur en soetsuur smaak, en groenboontjie- en neuterige geur ingesluit.

Drie panele, van 50 lede elk, het deelgeneem aan die verbruikersaanvaardingtoetse, een elk vir die gestoomde brode en sjokoladekoeke, en een vir die bredies en diepvetgebraaide blomme. Naas aanvaarding, is geur, smaak en tekstuur ook geëvalueer vir die gebakte produkte. Die brode, koeke en bredies is oornag ontdooi by 4 ºC. Die brode en koeke is by kamertemperatuur gehou tot bediening, tewyl die bredies warm bedien en die poffers vars gebraai was. Die brode, poffers en bredies is gemaak van geblansjeerde, meel/blomme, terwyl die koek gemaak is van ongeblansjeerde agawemeel. Al die produkte was aanvaarbaar, maar in verskillende grade. Die waardes vir die geur en finale aanvaarbaarheid van die gestoomde brood was laer as gevolg van die tekstuur wat ongewoon was vir die paneel. Die agawekoek het laer waardes gekry vir aroma en smaak, maar hoër waardes vir tekstuur as die brood. Die verbruikerspaneel het gehou van die bredies en gebraaide agawepoffers, soos duidelik sigbaar uit die tellings van 6.92 en 7.26 op die hedoniese skaal.

Sleutelwoorde: agaweblom; nutrient; blansjering; beskrywend sensories; gepekel; produkontwikkeling; verbruiker

ANNEXURE 1

Panel member name: **Sample code:** **Replication:**

Date:
Product
ODOUR:
Open container and smell immediately.

1. nutty

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

2. Cucumber

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

3. Beans, green, cooked

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

4. Rancid

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

APPEARANCE/TEXTURE:
Look at sample from the top and rate the similarity to:

5. flower

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

6. fibrous

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

7. Cactus-like

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

8. oily

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

9. moist

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

10. Green pepper

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

<u>MOUTHFEEL:</u>

Roll between palate and tongue – then chew, – then swallow.

11. Chewy

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

12. fibrous

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

13. starchy

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

14. crunchy

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

15. rubbery

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

16. Oily mouth coating

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

<u>TASTE:</u>

17. Sweet

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

18. Bitter

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

19. Sour

0	1	2	3	4	5	6	7	8	9	10

None **Very high**

20. Sweet-sour

0	1	2	3	4	5	6	7	8	9	10

None **Very High**

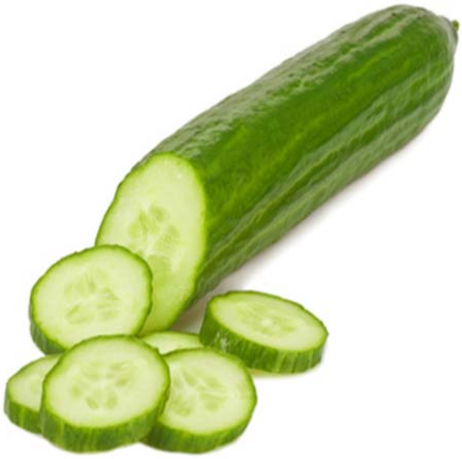
AFTERTASTE:

21. sweet

0	1	2	3	4	5	6	7	8	9	10

None **Very High**

ANNEXURE 2



Mesembryanthemum *Cucumis sativum*

'vygie' cucumber

Pisum sativum var. *macrocarpon* *Lilium asiatic* ‘sugar snap’

ANNEXURE 3

CONSUMER TEST: Agave steamed traditional bread

Gender		Date	16 October 2012
Age			

INSTRUCTIONS

Please indicate with an X how much you like or dislike the product OVERALL. Open the container and smell sample before tasting.

Sample code:

Aroma

1	2	3	4	5	6	7	8	9
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

Taste

1	2	3	4	5	6	7	8	9
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

Texture

1	2	3	4	5	6	7	8	9
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

General acceptability

1	2	3	4	5	6	7	8	9
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

CONSUMER TEST: Agave Flourless Chocolate Cake

Gender ______ **Date** 10 October 2012

Age ______

INSTRUCTIONS
Please indicate with an X how much you like or dislike the product OVERALL. Open the container and smell sample before tasting.

Sample code:

Aroma

1	2	3	4	5	6	7	8	9
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

Taste

1	2	3	4	5	6	7	8	9
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

Texture

1	2	3	4	5	6	7	8	9
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

General acceptability

1	2	3	4	5	6	7	8	9
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

ANNEXURE 4

CONSUMER TEST: Agave flower fritters

Gender		**Date**	01August 2013
Age			

INSTRUCTIONS
Please indicate with an X how much you like or dislike the product OVERALL. Open the container and smell sample before tasting.

Sample code:

1	2	3	4	5	6	7	8	9
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

Sample code:

1	2	3	4	5	6	7	8	9
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

CONSUMER TEST: Agave flower stew

Gender ______ **Date** 01August 2013

Age ______

INSTRUCTIONS

Please indicate with an X how much you like or dislike the product OVERALL. Open the container and smell sample before tasting.

Sample code:

1	2	3	4	5	6	7	8	9
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely

Sample code:

1	2	3	4	5	6	7	8	9
Dislike extremely	Dislike very much	Dislike moderately	Dislike slightly	Neither like nor dislike	Like slightly	Like moderately	Like very much	Like extremely