

**Relating consumer preferences to sensory and physicochemical properties  
of dry beans (*Phaseolus vulgaris* L.)**

**by**

**Alice Veronica Mkanda**

**submitted in partial fulfilment of the requirements for the degree**

**MSc (Agric) Food Science and Technology**

**Department of Food Science  
Faculty of Natural and Agricultural Sciences  
University of Pretoria  
Pretoria, 0002  
South Africa**

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## **DECLARATION**

**I hereby declare that this dissertation herewith submitted for the degree of MSc (Agric) Food Science and Technology at the University of Pretoria, has not previously been submitted by me for a degree at any other University or institution of higher education.**

**Alice Veronica Mkanda**

## **DEDICATION**

In loving memory of my late mother, Lucia Nankhoma Mtsiro, who believed in educating a woman and invested all she had for my education.

To my dear husband and friend (Eric) and our daughters (Hope and Lucia) for their daily support.

To Him who has promised never to leave nor forsake us.

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## ABSTRACT

Relating consumer preferences to sensory and physicochemical properties of dry beans  
(*Phaseolus vulgaris* L.)

By

Alice Veronica Mkanda

Supervisor: Dr H L de Kock

Co-supervisor: Prof A Minnaar

Department: Food Science

Degree: MSc (Agric) Food Science and Technology

The dry bean (*Phaseolus vulgaris* L.) is an important grain legume that is used for human consumption worldwide. In Africa and other parts of the World, legume diets contribute tremendously to protein and energy requirements of consumers. Dry beans provide about 16-33% protein, dietary fibre (between 14 and 19%), starch, minerals and vitamins. Dry beans have a long storage life and can be cooked as whole grains, fried or dehulled and splitted for production of dhal and salads.

There is a tremendous variability in the dry bean varieties. It is believed that consumer preferences for dry beans are influenced by factors such as seed size, seed colour, cooking time and flavour. Although, substantial research has been done on physicochemical properties, description of sensory properties that differentiate bean varieties specifically in terms of liked or disliked flavours was lacking. Sensory evaluation is one of the methods used for evaluating product quality and it can be used to describe the sensory properties of a product (i.e. descriptive sensory evaluation) and determines its acceptability by consumers (i.e. consumer acceptability or preferences).

Physicochemical properties and descriptive sensory evaluation of six dry bean varieties (Jenny, Kranskop, PAN 148, AC Calmont, PAN 150 and Mkuzi) from Mpumalanga (MP) and Free State (FS) locations of South Africa were determined. Significant ( $p < 0.05$ ) variety, location as well as location x variety interaction effects were found for both physicochemical and sensory properties of beans.

Of the six bean varieties, Jenny (FS), Mkuzi and PAN 148 (MP) beans had relatively long cooking times (>60 min) using a Mattson Bean Cooker. PAN 150 beans from both locations were described as bitter, soapy and metallic with a raw bean flavour. Mkuzi beans were mostly described as having a soapy mouthfeel. Jenny (MP), Kranskop (MP & FS) were sweet, soft and with a cooked bean flavour.

Consumer sensory evaluation revealed that beans with sweet, soft and cooked bean flavours were the most preferred. Beans that took long to cook and those that were described as bitter, soapy and metallic in the mouth, received low consumer ratings on a 9-point hedonic scale.

The total polyphenol content of PAN 150 (MP), along with Jenny and AC Calmont from MP was determined to find out whether the bitterness was associated with its polyphenol concentration. PAN 150 beans had the lowest concentration of total polyphenols compared to the two other varieties, suggesting that factors other than total polyphenol content caused the bitterness of these beans.

A follow up investigation of mineral profiles in whole bean flour of all six bean varieties from the two locations was done to find out whether differences in mineral content e.g. iron (Fe) contributed to bitterness and metallic mouthfeel of certain beans. Results showed significant ( $p < 0.05$ ) variety differences for phosphorous (P) and significant ( $p < 0.05$ ) location differences for magnesium (Mn) only. Fe and copper (Cu) contents did not contribute to bitterness or metallic mouthfeel of PAN 150 beans.

For maximum consumer acceptability, farmers should concentrate on the production of beans that have characteristics similar to Kranskop (MP & FS), PAN 148 (FS) and Jenny (MP) beans. As bean hardening was suspected in Jenny (FS), PAN 148 (MP) and Mkuzi (MP), the importance of storing beans at proper temperatures (e.g. less than 35°C) and relative humidity (e.g. < 75 %) should be emphasized to minimize the development of the hard-to-cook defect over long storage periods.

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## 1. INTRODUCTION

The dry bean (*Phaseolus vulgaris* L.) is a grain legume that belongs to the family of *Leguminosae* and is used for human consumption worldwide (Kutoš, Golob, Kač & Plestenjak, 2002). Dry beans can either be grown as a sole crop especially by commercial farmers or intercropped with maize, a common practice among most subsistent farmers in Africa. The Great Lakes region has the highest per capita consumption of dry beans in the world (AGSI/FAO, 2004). In general, legume diets contribute tremendously to protein and energy requirements of consumers (Elmaki, AbdelRahaman, Idris, Hassan, Babiker, & El Tinay, 2007). In Africa, dry beans are a major source of dietary protein in Kenya, Tanzania, Malawi, Uganda and Zambia (AGSI/FAO, 2004). They provide 16-33% protein, almost two to three times that of cereals. The protein content is important especially in developing countries where protein energy malnutrition (PEM) is prevalent (Van Heerden & Schönfeldt, 2004). Dry beans also provide a rich source of dietary fibre (between 14 and 19%), starch (Perla, Luis, Sonia, Maria, Juscelino, & Octavio, 2003; Reyes-Moreno & Paredes-Lopes, 1993), minerals and vitamins (Kutoš *et. al.*, 2002).

Inclusion of legumes in the diet has been reported to have many beneficial physiological effects such as control and prevention of different metabolic diseases (e.g. diabetes mellitus, coronary heart disease and colon cancer) (Tharanathan & Mahadevamma, 2003). For example, dietary fibre is reported to reduce colon cancer by increasing the transit time in the digestive system. The reduced transit time affects the digestion of lipids by absorbing the biliary salts that emulsify fat globules.

Primarily, beans are grown for their green leaves, green pods and dry seeds. The ultimate economic part of the whole bean plant being the dry seeds. Dry beans have a long storage life and are easily prepared in different ways for food (AGSI/FAO, 2004). There are many ways in which legumes are prepared for utilization in the human diet viz: cooked whole grains, fried, dehusked and split for production of dhal, salads and soups (Sathe & Deshpande 2003; Tharanathan & Mahadevamma, 2003). In South Africa, beans are also liked as a composite with samp (dehulled maize grains) popularly known as *Umngqusho* among the South African black communities.

Beans are also used to enhance cereal-based diets, to improve their nutritional quality (Iqbal, Khalil, Ateeq & Khan, 2006). In Uganda, beans are eaten as a composite with cassava providing a good source of both energy and protein in one meal (David, 1999).

There is tremendous variability of dry bean varieties (more than 40,000) worldwide (AGSI/FAO, 2004). However, there are some limitations to dry bean utilization of which long cooking times is one of them. Long cooking times lead to high energy expenses especially in low income communities. Scott and Maiden (1998) reported that rural farmers in Malawi considered good flavour and fast cooking as the most important characteristics in selecting dry bean varieties for production and consumption. Other researchers have reported visual appearance and textural properties of the cooked product as contributing factors to acceptability by consumers (Sanzi Calvo & Attienza del Rey, 1999). Variability in dry bean varieties is due to differences in physicochemical and sensory properties and these influence consumer preferences (the degree of liking or disliking) of those attributes. Flavour, seed size, colour and soft textures of the cooked product are some of the factors that influence dry bean users (Tharanathan & Mahadevamma, 2003; Shimelis & Rakshit, 2005; Vargas-Torres, Osorio-díaz, Islas-Hernández, Tovar, Paredes-López & Bello-Pérez, 2004). Although dry beans are considered as the poor man's meat (Tharanathan & Mahadevamma, 2003); nutritionally, they provide an affordable source of protein (Van Heerden & Schönfeldt, 2004).

Dry and/or cooked bean quality is one of the important factors that influence consumer preferences. One of the methods of evaluating product quality is the use of sensory evaluation. Sensory evaluation is a tool that is used to describe sensory properties of a product (i.e. descriptive sensory evaluation) and determine its acceptability by consumers (i.e. consumer evaluation). To incorporate sensory properties in breeding programs is a challenge as breeding of new dry bean varieties has been focused on the agronomic characteristics such as resistance to diseases, yield, rate of maturing (Scott and Maiden, 1998), and nutritional value (Graham & Ranalli, 1997).

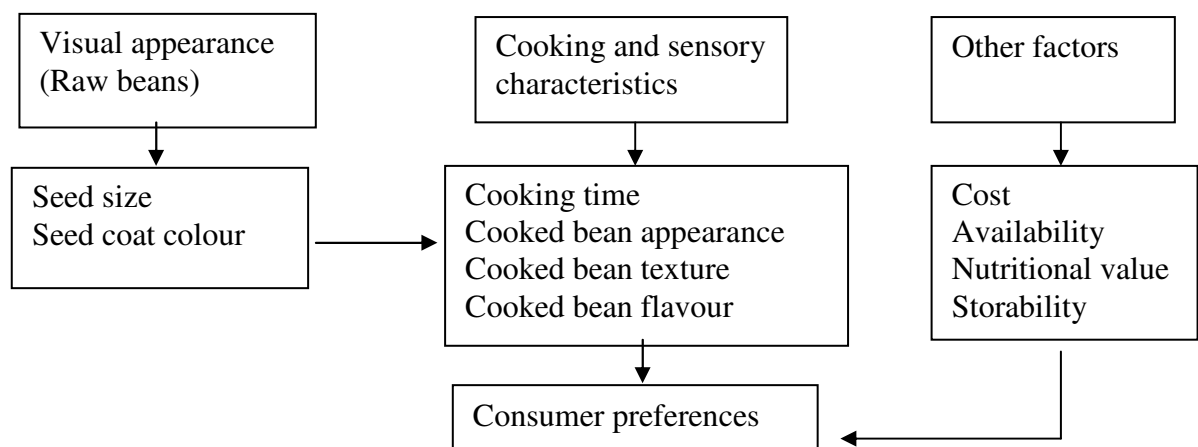
Substantial research has been done on determination of cooking time, cooked texture and underlying physicochemical properties of dry beans (Berrios, Swanson & Cheong, 1999; Shimelis & Rakshit, 2005; Sanzi Calvo & Attienza del Rey, 1999). However, there is limited systematic information on the description of the sensory properties that differentiate bean varieties in terms of liked or disliked flavours and textures. Therefore, this study relates consumer preferences to sensory and physicochemical properties of six dry bean varieties grown in two locations of South Africa. It is intended to identify some of the critical sensory properties of cooked beans for optimal consumer acceptance. In addition, it is also necessary to determine the reasons why certain beans may have attributes that may or may not be acceptable to consumers.

Bean samples from two locations were used to find out if differences in location would contribute to different physicochemical and sensory properties of beans.

## 2. LITERATURE REVIEW

### 2.1 Factors that influence dry bean utilization in Africa and other parts of the world

There are several factors that influence consumers regarding the choices they make for dry bean inclusion in their diets. Some of these factors include: physicochemical, structural, sensorial and other general factors (Figure 2.1)



**Figure 2.1 Factors influencing consumer preferences for dry and cooked beans**

In terms of visual appearance, beans are found in different sizes namely: small, medium and large sizes. Mukoko, Galwey & Allen (1995) referred to large seeds as those weighing more than 300 mg per seed. AGSI/FAO (2004) reported that beans could be classified as small if there are more than 900 seeds per kg, medium seeds - between 600 to 900 seeds per kg and large seeds - less than 600 seeds per kg. Seed size could also be measured in terms of number of seeds in a 100 g of bean seeds (Liebenberg, Heenop, and Fourie, 2003). Table 2.1 illustrates that the smaller the number of bean seeds per 100 g the larger the seeds are. Preference is normally given to medium and large sized beans probably because they have been reported to hydrate and cook well (Berrios *et al.*, 1999).

The colour of beans ranges from white all the way through the colour spectrum to black; they may have a plain colour or may be speckled. Consumers normally prefer light coloured seeds to dark coloured seeds possibly because of good taste as dark



coloured beans (black, red and bronze seed coats) have been reported to contain considerable amounts of polyphenols (Bressani & Elias, 1980), and have thus been associated with astringent and bitter tastes.

**Table 2.1 Seed size and colour of selected bean varieties grown in South Africa**  
**Adapted from (Liebenberg *et al.*, 2003)**

Bean Variety	Seed size	Seeds100 g <sup>-1</sup>	Appearance
Jenny	large	184	red speckled
AC Calmont	large	201	dark red kidney
Kranskop	large	208	red speckled
PAN 148	medium	241	red speckled
PAN 150	small	412	grayish speckled
Mkuzi	small	489	grayish speckled

Cooking time has been defined as the time required for beans to reach the cooked texture that is considered acceptable to consumers (Moscoso, Bourne & Hood, 1984). Although cooking time varies regionally it can be used as a criterion for consumer acceptance. Consumers prefer beans that cook fast (e.g. less than 1h) to those that are long cooking because it saves them on energy costs and time for preparation of meals. Well-cooked beans have a soft texture and most consumers prefer such beans because they are easy to chew. The dry bean quality and its final product are greatly influenced by storage temperature and relative humidity (AGSI/FAO 2004). Beans stored at high temperatures and low relative humidity, develop a tough seed coat and may fail to absorb water during soaking. Such beans are referred to as “hard shell” beans (AGSI/FAO, 2004). During soaking and cooking, hard shell beans resist water absorption because of chemical modification of the cotyledon cell walls (Del Valle, Stanley & Bourne, 1992). As a result, the cooked beans portray a hard texture, which may be associated with the failure of the middle lamella of the cotyledons to soften enough or dissolve and separate during cooking (Jones & Boulter, 1983). In contrast, AGSI/FAO (2004) reported that beans that absorb enough water but do not soften

enough during a reasonable cooking time are referred to as “hard-to-cook” beans. This is a defect that comes about due to storage of beans under high temperatures and high relative humidity (AGSI/FAO, 2004). Unlike hard shell beans, fresh beans give rise to soft textures which are normally desired by consumers (Scott and Maiden, 1998). In addition, well cooked beans develop good flavour, which is also a driving factor for preference to most bean users.

As reported for cooked cowpeas (Taiwo, Akanbi & Ajibola, 1997), splitting is considered as one characteristic that may be undesirable to consumers. Cowpeas may split as a sign of being cooked but some split because of vapour pressure build up in the interior of the seed without being fully cooked (Taiwo *et al.*, 1997). The seed coat may split either transversely below the hilum or longitudinally leading to separation of the two cotyledons. Mwangwela, Waniska & Minnaar (2006) suggested that differences in variety, pre-treatment and final water uptake could contribute to splitting of cowpeas during cooking (although they did not provide a hypothesis). Extended cooking times of cowpeas increase splitting and split cowpeas are associated with thick broths (Taiwo, Akanbi & Ajibola, 1998) due to leaching of nutrients during cooking. Split cowpeas leave some seed coat shells empty of all its contents. However preferences may differ between consumers, as some may prefer split and mushy beans while others may prefer non-split beans.

In terms of cost, dry beans are a cheaper source of protein compared to animal sources, and are more affordable to consumers from the low-income communities (Perla *et al.*, 2003). When stored properly, dry beans have a longer shelf life than most protein sources and animal products (Sathe & Deshpande 2003). Consumers, who cannot afford refrigeration systems, can use dry beans as their main source of protein because of easy storability.

There is a need to understand the structure of the bean seed, and its composition and the effect of cooking/processing steps on the bean physicochemical properties. This knowledge is important to understand consumer behaviour when it comes to bean consumption. This includes the whole bean seed structure (in terms of the seed coat and

the cotyledons), its chemical composition, hydration, cooking and sensory characteristics.

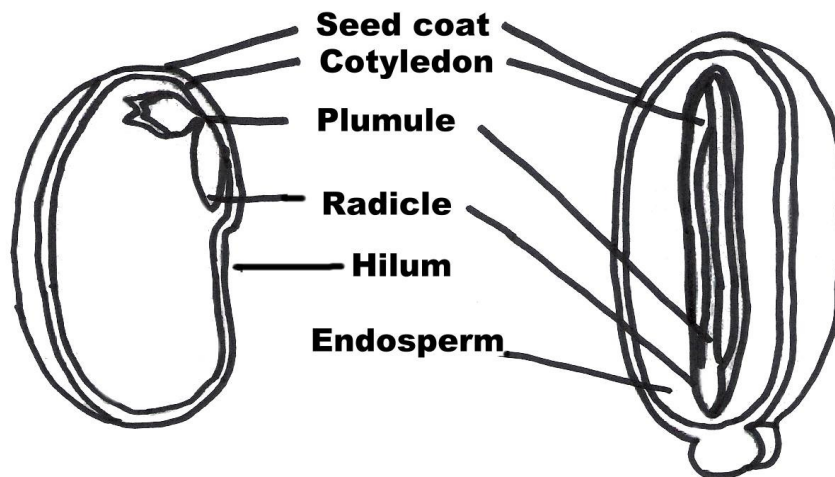
## **2.2 Bean seed structure and physicochemical composition**

There are two main components of a mature bean seed, namely: the seed coat, and the cotyledon (Figure 2.2). The seed coat comprises 8 to 20 % and the cotyledons, 80 to 90 % of the seed weight (Sathe & Deshpande, 2003). The structure of the bean seed and its composition contribute significantly to hydration and cooking properties of beans. These factors include the general seed size, seed coat colour and thickness, seed coat and cotyledon chemical composition, size of micropyle and hilum, storage conditions, soaking solutions, soaking temperature and soaking time.

### **2.2.1 Bean seed coat**

The seed coat acts as a protective layer between the cotyledons and the external environment of a bean seed (Reyes Moreno & Paredes-Lopes, 1993). The hilum and the micropyle are part of the external structure of the bean seed and have an influence on water absorption (Sathe & Deshpande, 2003). The micropyle (not shown in Figure 2.2) is a small pore on the seed coat through which water enters the seed to begin germination. For example, Agbo, Hosfield, Uebersax & Klomparens (1987) reported that beans with open and heart shaped micropyle and prominent seed coat pores favour rapid water uptake compared to beans with occluded micropyle and no seed coat pores. At room temperature, water seems to enter the seed largely through the micropyle rather than the seed coat. In addition, for some varieties, water entry seems to be through the hilum.

Depending on variety, the seed coat microstructure may have organized palisade cells as observed in adzuki beans or may be amorphous as observed in black eye peas (Sefa-Dedeh & Stanley, 1979a). Organized palisade cells may be associated with relatively thick seed coats (45.75 $\mu$ m - 53.33  $\mu$ m) that could be due to seed maturity (Sathe & Deshpande, 2003) and amorphous palisade cells may be associated with thin seed coats comprised of loosely packed palisade cells (Sefa-Dedeh & Stanley, 1979a).



**Figure 2.2 A transverse section of a bean seed showing primarily the seed coat and the cotyledon (Mc Leod, 2003)**

The seed coat may be thin or thick due to cell arrangement and composition. The seed coat has been reported to contain major amounts of phenolic compounds especially in black, red and bronze beans (Bressani & Elias, 1980), and some minerals such as calcium (Ca) and iron (Fe) (Sathe & Deshpande, 2003). During soaking of bean seeds, soaking water may or may not be discarded before cooking (Bressani & Elias, 1980). Discarding soaking and cooking water from beans eliminates relatively large amounts of phenolic compounds. However, the bean matrix (cotyledons) retains large quantities of these compounds because of apparent migration (e.g. of tannins) from the seed coat under adverse storage conditions.

Cell wall fractions of dry bean seed coats contain appreciable amounts of cellulose (59.4 to 60.7%), hemi cellulose (17.4 to 25.8%), pectin substances (11.1 to 15.9%) and lignin (1.4 to 1.9%). High lipid content has been reported to be associated with bean varieties that have thick seed coats (Sathe & Deshpande, 2003). Thick seed coats may also create a barrier to rapid water absorption during the first six hours of soaking. Agbo *et al.* (1987) suggested that the thickness of the seed coat palisade layer might have resulted in slow hydration rates, due to the barrier created by the sheet of cells, appearing like bundles, to the fast movement of water through the cotyledon cells.

### **2.2.2 Bean cotyledon**

The bean seed is composed of two cotyledons wrapped around by a seed coat. The cotyledons contain parenchyma cells (70 to 100 $\mu$ m) (Sathe & Deshpande, 2003) and act as storage sites for most nutrients e.g. starch granules and protein bodies (Sefa-Dedeh & Stanley, 1979b). Cotyledon cell walls mainly contain 15 to 25% proteins, 50 to 75% carbohydrates with 0.4 to 0.6 % lignin (Sathe & Deshpande, 2003). Each cell of the cotyledon is bound by a cell wall and middle lamella. Reyes Moreno & Paredes-Lopes, (1993) reported that the cotyledon cell walls also contain considerable amounts of non-starchy polysaccharides such as cellulose (25.9 to 30.9%) and pectic substances (28.5 to 41.2%) especially in the middle lamella. Lignin in the cell walls and pectic substances in the middle lamella have been related to cooking quality of dry beans (Reyes Moreno & Paredes-Lopes, 1993).

The total proteins in dry beans consist of water-soluble albumins (10 to 30 %) and salt soluble globulins (45 to 70 %). Globulins are globular in shape, as such; they require some ionic strength for their solubilization in aqueous media (Sathe & Deshpande, 2002) although certain globular proteins may be partly soluble in water.

Protein is the major component for water absorption in the parenchyma cells of the cotyledons, but may not immediately come into contact with water if the seed coat causes a barrier to water entry (Sefah-Dedeh & Stanley 1979b). However, parenchyma cells may also have different packing densities depending on variety and storage conditions (Jones & Boutler, 1983), which may result in different initial hydration rates. The void space between the two cotyledons, its size and the intercellular spaces within the cotyledon cells may dictate the amount of water absorbed during soaking and cooking (Del Valle *et al.*, 1992). A well-hydrated bean seed coat admits water freely to the cotyledon cells resulting in softening of the whole seed during cooking.

### **2.3 Hydration and cooking properties of beans**

Hydration is a step that is done before cooking beans. It consists of soaking of the seeds in water until maximum mass is reached (Prodanov, Sierra, & Vidal-Valverde, 2003). Previous studies (Wang, Daun, & Malcomson, 2003; Taiwo *et al.*, 1998) have

shown that soaking of beans or cowpeas and discarding soaking water could reduce the levels of total sugars,  $\alpha$ -galactosides, minerals, phytic acid and proteolytic enzyme inhibitors. This is so because of partial or total solubilization of these constituents into the soaking solution. Wang *et al.* (2003) also reported that the rate of hydration of beans determines their cookability and that the hydration and swelling capacities of the soaked beans would be related to the required cooking time. Prodavon *et al.* (2003) reported that the faster the legume hydration, the faster the mass transfer of the bean constituents such as vitamins from the seed to the soaking medium. The general seed size, varietal differences in terms of external and internal composition, length and temperature of storage, bring about different water absorption and cooking characteristics of dry beans (Bishnoi & Khetarpaul, 1993).

Beans could be soaked in water or other solutions prior to cooking in order to reduce cooking time (Bressani & Elias 1980; De Leon, Elias & Bressani, 1992). Soaking of beans is a common practice in Latin America and many other parts of the world where there is limited energy sources for cooking. The amount of water absorbed during soaking is dependent on the flexibility or resistance of the seed coat to transfer water to the cotyledon cells (Del Valle *et al.*, 1992). If the cell walls of the beans are rigid, swelling and dispersion of starch is inhibited. An increase in hydration capacity may result from water being held in void spaces between the seed coat and the cotyledons' intercellular spaces within cotyledon cells or the volume of the cavity between the two cotyledons. Yet this water may not necessarily show appreciable changes in swelling (Del Valle *et al.*, 1992). It is the amount of water that is effectively absorbed by the seeds that influences the length of cooking time.

Soaking temperature and time also contribute greatly to hydration capacity of beans. At high temperature (e.g. 50 °C) rapid initial water absorption may be experienced due to increased diffusion rate of the bean constituents (Abdel Kader, 1995). For example, when faba beans were soaked at 20 °C for 10h, a 90% total absorption was achieved. The same absorption capacity was achieved when beans were soaked at 50 °C for 2.5 h. Water absorption rates seem to reduce with short soaking time. In their study of regression relationships for the soaking and cooking properties of two cowpea varieties,

Taiwo *et al.* (1998) found that the amount of water absorbed per unit mass increased with soaking time. This could probably be due to inter-chemical changes of salts such as calcium and magnesium within the bean that would inhibit water uptake within the early hours of hydration.

### **2.3.1 Bean seed size**

In terms of the general seed size, there is insufficient evidence that correlates seed size to hydration rate as there have been different findings in this regard. For example, Berrios *et al.* (1999) reported that small seeds neither hydrated at all during a 24 h-soaking period, nor did they soften after boiling for a long time. Sefah-Dedeh & Stanley (1979a) also reported a slow water absorption rate in adzuki beans that were regarded as the smallest seeds (height  $5.1 \pm 0.2$ , length  $5.2 \pm 0.75$ , width  $5.25 \pm 0.35$  mm) of the five legumes studied. It was suggested that the slow water absorption rate was due to its thick seed coat that was hindering rapid water absorption. On the contrary, Del Valle *et al.* (1992) found that small seeds hydrated even more than large seeds during soaking. A negative correlation was reported between seed size and hydration rate and the authors attributed it to the effect of a large surface area per unit mass of small seeds (Abdel Kader, 1995). However there were some correlations in terms of density and hydration rate where smaller seeds were also associated with high density.

### **2.3.2 Bean seed colour**

In some places like Latin America, seed coat colour is of paramount importance such that local producers grow beans with a particular colour that is preferred in a particular area (AGSI/FAO, 2004). Satisfying consumer preferences help farmers to sell their beans at high prices. However, in Africa, it is reported that colour of beans is less important compared to fast cooking and good flavour (Scott and Maiden, 1998).

### **2.3.3 Cooking time**

Cooking time is regarded as one of the main considerations used in evaluating the cooking quality of pulses. Differences in dry bean varieties have resulted in different ranges of cooking times. For example, Vargas-Torres *et al.* (2004) reported cooking

time of beans ranging from 2.55 to 5.92 h. For soaked South African varieties cooked in an ordinary saucepan, cooking time ranges from 1h for small white beans to 4h for speckled beans (Liebenberg *et al.*, 2003). Cooking times of dry beans may vary due to a wide range in hydration capacity during soaking (Shimelis & Rakshit, 2005). In addition, cooking methods (Rehinan, Rashid & Shah, 2004) and maturation of seeds (Hsieh, Pomeranz & Swanson, 1992) also contribute to variations in cooking time. Beans that require long cooking time are less preferred by consumers than fast cooking beans because these beans are usually hard in texture. In addition, long cooking times also reduce the nutritive value of protein (Wang *et al.*, 2003). Jackson & Varriano-Marston (1981) reported a cooking time reduction of 38 % for decorticated beans (cooked with a Mattson cooker), showing a tremendous contribution of the seed coat to cooking time. As mentioned earlier on, soaking beans before the cooking step reduces cooking time (Abbu-Ghannam, 1998), which comes about due to the onset of the structural degradation of the seed coat. Water absorption continues during cooking due to the added effect of cooking temperature and starch solubilization (Abbu-Ghannam, 1998).

Apart from the degradation of the seed coat during the cooking process, another significant change that takes place in the cotyledons is the breakdown of the middle lamella causing cell separation (Varriano-Marston & Omana, 1979). Cell separation leads to the softening of the beans due to starch gelatinization. Differences in starch gelatinization and softening of other cell constituents such as the protein matrix also contribute to the overall softening of the beans (Sefa-Dedeh & Stanley 1979b). Apart from water absorption capacity and seed microstructure, water uptake during cooking may also be affected by rate of starch gelatinization, nature and amount of non-starch constituents (such as cellulose and pectic substances) that may cause a barrier to swelling of starch granules (Deshpande & Cheryan, 1986). During cooking, soluble hemicellulose and the amorphous fraction of the cellulose influences breakdown of the seed coat structure and the extent of hydration determines the final texture of the cooked product (Casañas, Pojula, Bosch, Sanchez & Nuez, 2002).



#### 2.3.4 Storage conditions

If stored properly, beans maintain their quality and result in soft cooked textures as a result of free water movement from the seed coat to the cotyledons during soaking and cooking (Aguilera & Stanley, 1985). Poor storage conditions e.g. high temperatures (30 to 40°C) and high relative humidity (more than 75%) bring about the Hard-To-Cook (HTC) defect as mentioned earlier on, leading to bean hardening. HTC and hard shell beans may mean one and the same thing (personal opinion) due to similar characteristics of the hard cooked textures of the final product. Long storage periods of beans under unfavourable conditions may also lead to an increase in pectin loss (Jones & Boulter, 1983). This may further lead to reduced pectin solubility as a result of ageing, which may partly contribute to the HTC defect. For cowpeas, Liu, Phillips, Hung, Shewfelt & McWatters (1992) associated the HTC condition with unfavourable storage temperature, relative humidity and time.

The hardened beans fail to absorb water efficiently within a reasonable soaking time because of the hard shell condition of the seed microstructure. For beans that contain polyphenols, these conditions (hard shell) promote high water activity within the bean seed that allows the migration of condensed tannins from the seed coat to the cotyledons (Stanley, 1992). These tannins bind with the macromolecules such as protein and pectin of the middle lamella forming complexes that strengthen the cell walls and reduce water penetration. The reduced hydration and swelling inhibit cell separation and softening during cooking.

Apart from changes in water activity during poor storage conditions of beans, enzymatic activities, macro components (protein, carbohydrates and lipids) and micro components (e.g. phytic acid, tannins) have also been related to bean hardening (Reyes-Moreno & Paredes-Lopes, 1993). Hentges, Weaver & Nielson (1991) suggested that the HTC defect could occur due to the action of phytic acid located in the protein bodies of the cotyledons that chelate divalent cations e.g.  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  during storage. The extent of pectin solubility in the middle lamella determines how cells separate from one another during cooking (Casañas *et al.*, 2002). During phytase activation, phytin is

hydrolyzed when the bound divalent cations are released. These cations diffuse to the middle lamella forming insoluble pectic salts (Jones & Boulter, 1983).

### **2.3.5 Soaking solution**

As mentioned earlier on, soaking solution also contributes to the rate of hydration as some researchers have previously soaked beans in either distilled water or salt solution in trying to reduce cooking time. Del Valle *et al.* (1992) reported an increase in water absorption rate, diffusion coefficients and equilibrium water absorption for beans soaked in distilled water compared to soaking them in 5 % sodium bicarbonate. In the salt solution, a reduction in the driving force of water uptake due to decreased osmotic pressure gradients across the cotyledon cell membranes was reported. In line with these findings, Abdel Kader (1995) found that at higher salt concentrations, low water absorption was pronounced probably due to higher viscosities and low water activity associated with increased salt concentration. For dehulled beans, ions in the salt soaking solution may react with the storage proteins in the bean cotyledons. These reactions may influence solubilization and denaturation properties in the beans.

For hardened beans, salt solutions such as sodium bicarbonate, has been reported to reduce cooking times of beans (Onwuka & Okala, 2003). Salt solutions reduce cooking time in that calcium ions decrease pectin gelation. Calcium ( $\text{Ca}^{2+}$ ) replaces the monovalent sodium and potassium ( $\text{Na}^+$  and  $\text{K}^+$ ) and reduces pectin solubility, bringing about the softening effect. De Leon *et al.* (1992), also evaluated the effect of using different ratios of monovalent ( $\text{Na}^+$  and  $\text{K}^+$ ) to divalent ( $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ) ions to reduce the cooking time of beans. The ratios of 8:30 of monovalent (0.5%  $\text{NaHCO}_3$ ) to divalent ions (2.5%  $\text{K}_2\text{CO}_3$ ) (w/v) were found to be cost effective in energy saving of US \$0.19 per kg of beans. Salt solutions have also been reported to improve heat transfer properties from the beans to its surroundings, increase water absorption capacity and water holding capacity. Sodium tends to migrate into the beans whereas  $\text{Mg}^{2+}$  and  $\text{K}^+$  tend to leave the beans.

## **2.4 Sensory quality attributes of dry beans**

Descriptive Sensory Evaluation identifies, describes and quantifies the sensory attributes of a food material or product using human subjects (Einstein, 1991). These human subjects are trained to describe the complete profile of food products in all sensory parameters such as appearance, flavour (taste and smell or odour)/and texture/mouthfeel characteristics. A descriptive sensory panel comprises of 8 to 12 people trained to consistently and reliably identify and quantify individual sensory characteristics of a particular product.

Consumer sensory evaluation is a process for evaluating personal opinions (of current or potential customers) of a particular product in terms of e.g. specific sensory attributes or overall liking (Resureccion, 1998). Sensory attributes that influence acceptance of cooked beans are general visual appearance, texture and flavour (taste and aroma) (Sanzi Calvo & Attienza del Rey, 1999).

### **2.4.1 Appearance of cooked beans**

Beans change colour during cooking due to solubilization of the colour pigments. For example, speckled beans do not appear speckled after cooking. Legumes treated with salt solutions (e.g. sodium bicarbonate), also brings about a change in colour. Onwuka & Okala (2003) reported that use of *akanwa* and sodium bicarbonate ( $\text{Na HCO}_3$ ) on African yam beans and cowpeas made them significantly darker in appearance. *Akanwa* is reported to contain the hydride of sodium hydrogen carbonate along with some impurities. Beans soaked in sodium chloride had better sensory attributes than those soaked in sodium bicarbonate. Onwuka & Okala (2003) explained that physical and chemical properties of denatured proteins change in the presence of salt solution e.g. fibrillar proteins may change their elasticity, flexibility and length whereas globular proteins may change their solubility, viscosity and osmotic properties. These changes may bring about a darkened appearance of cooked beans. In addition, splitting is also experienced as one aspect of visual appearance. Taiwo *et al.* (1998) reported that during cooking, the seed coat (of cowpeas) may crack, allowing the cotyledons to open up.

### 2.4.2 Texture of cooked beans

The panel of judges used by Sanzi Calvo & Attienza del Rey (1999) described surface textural characteristics of cooked beans based on visual appearance (complete or broken), surface characteristics, as a sensation produced by the seed coat on contact with the tongue and palate (rough, smooth or wrinkled). Other textural characteristics were described based on deformation of the seed in the mouth (hard, soft or tender). Fast cooking beans tend to have a softer texture preferred by most consumers. Hard texture of cooked beans normally occurs due to the failure of the middle lamella to break down thus inhibiting cell separation and subsequent softening of the beans (Varriano-Marston & De Omana, 1979). Partial starch gelatinization may also lead to a grainy texture which could be associated with differences in protein content and denaturation temperatures (Yousif, Batey, Larroque, Curtin, Bekes & Deeth, 2003). For example a lower denaturation temperature may result in protein gelation that may limit expansion of the starch molecule. The latter has been reported for HTC-beans.

### 2.4.3 Flavour of cooked beans

Flavour has been defined as *a perceived attribute resulting from our intergrated responses to a complex mixture of stimuli on several senses including smell, taste, touch, sight and even hearing* (Lawless & Lee, 1993). Aroma is one aspect of flavour that is perceived when the nose sniffs volatile molecules directly or when these molecules flow through the backward pathway from the mouth to the nose during eating. When food is in the mouth, taste is perceived when water-soluble chemicals within the food dissolve in saliva and interact with the taste receptors of the tongue and the mouth. During flavour profile analysis of seven varieties of cooked dry beans, Mctigue, Koehler & Silbernagel (1989) reported that after 20 h of training the profile score sheet developed by the panel for aroma, were: fragrant (spicy), green vegetable, browned (nutty and brothy), musty (earthy, rubbery, medicinal), and flavour profile by mouth were identified as: sweet, acid (bitter), browned (nutty and brothy) and musty (rubbery and earthy).

Some of the factors that affect flavour in cooked beans are: carbohydrates, proteins, phenolic acids and lipids as reported for red kidney beans (Van Ruth, Dings, Buhr &

Posthumus, 2004). Enzymatic factors (e.g. lipoxygenase activity), and non-enzymatic factors (e.g. Maillard reactions) also may contribute to flavour differences (Martins, Jongen & Van Boekel, 2001). Other factors include soaking solutions (De Leon *et al.*, 1992) and mastication rates (Buettner & Schieberle, 2000; Van Ruth *et al.*, 2004).

#### **2.4.3.1 Carbohydrates and flavour of beans**

Dry bean carbohydrates consist of 70 to 80% starch, which is mainly composed of amylose and amylopectin (Tharanathan & Mahadevamma, 2003). Amylose is a linear polymer of  $\alpha$  - (1-4) linkages of glucose units and amylopectin is a highly branched molecule consisting of the main chain of (1-4)-linked  $\alpha$ -D-glucose with short chains of (1-6) -  $\alpha$ -D-glucose linked branches (Tharanathan & Mahadevamma, 2003). Thermal heat treatment influences starch gelatinization and complex sugars break down to simple sugars such as glucose and fructose bringing about desirable flavours such as the sweet taste of cooked beans. However, partial starch gelatinization may affect flavour development especially in hardened beans whose cells fail to separate during cooking, restricting the development of volatile flavour compounds due to incomplete breakdown of polysaccharides.

#### **2.4.3.2 Proteins and flavour of beans**

Dry bean proteins have been classified broadly into metabolic and storage proteins (Sathe & Deshpande 2002). Metabolic proteins are both enzymatic and non-enzymatic. The major storage proteins are legumin and vicilin. Legumin (11S globulin) is less soluble in water and less coagulable by heat in dilute salt solution than vicilin (Sathe & Deshpande, 2002). Although there is no clear information on the influence of proteins on flavour of beans, proteins play an important role in influencing flavour of food in terms of its interaction with other flavour components. For example, saponins are nonvolatile flavour compounds that may contribute to the taste perception of food and also interact with proteins when present in the food (Heng, Van Koningsveld, Gruppen, Van Boekel, Vincken, Roozen & Voragen, 2004). Saponins are known to contribute to bitterness in peas probably because pea proteins (11S legumin and 7S vicillin) bind to aldehydes and ketones at different pH levels. These flavour compounds are then

released during mastication. For instance vicillin was reported to bind to both aldehydes and ketones at pH 7.6 and pH 3.8 whereas legumin showed binding to aldehydes only at pH 7.6 (Heng *et al.*, 2004). It was reported that heating showed a decrease in the binding of aldehydes and ketones to vicillin and those saponins may also occupy available binding sites on proteins leading to less flavour molecules to be bound to proteins. Heat denaturation of proteins increases absorption of flavour compounds and reduces the headspace concentration in food due to increased hydrophobic binding sites (Fischer & Widder, 1997). Semenova, Antipova, Misharina & Golovnya (2001) however, reported that during heating of broad bean protein (legumin) at 90°C, pH 7.2 for 30 min, no change in the capacity of legumin for binding aroma compounds was found.

#### **2.4.3.3 Phenolic acids and flavour of beans**

In dark coloured bean varieties where polyphenols are reported to be prevalent, there might be binding of the phenolic compounds with protein bodies interfering with protein utilization (Sathe & Deshpande, 2002). The presence of these tannins in beans may result in astringent taste, which may be undesirable to consumers. Tannins also decrease protein solubility due to protein-tannin interaction. Previous studies have indicated that phenolic compounds affect nutritional quality of a product such as beans (Bressani & Elias, 1980). Greater amounts of polyphenols are reported to be located in the seed coat. During processing of beans, cooking water alone contains 4-10% solids and discarding soaking and cooking water eliminates relatively large amounts of polyphenols. However, the bean matrix (cotyledons) retains large quantities of these compounds because of apparent migration of tannins from the seed coat. There are somehow conflicting views on the effect of polyphenols on the acceptability of beans. Previous studies have shown that polyphenols seem to be abundant in beans with dark coloured seed coats (Bressani & Elias, 1980), and that most people have a strong colour preference and regard these as flavourful beans. However some studies (Guzmán-Madondo, Castellana, González de Mejía, 1996) have shown that the beany flavours in dry beans have been due to the presence of phenolic compounds, but if the soak-water is

discarded before cooking, flavour of cooked beans may improve. This is because some of the soluble compounds would have been discarded together with the soaking water.

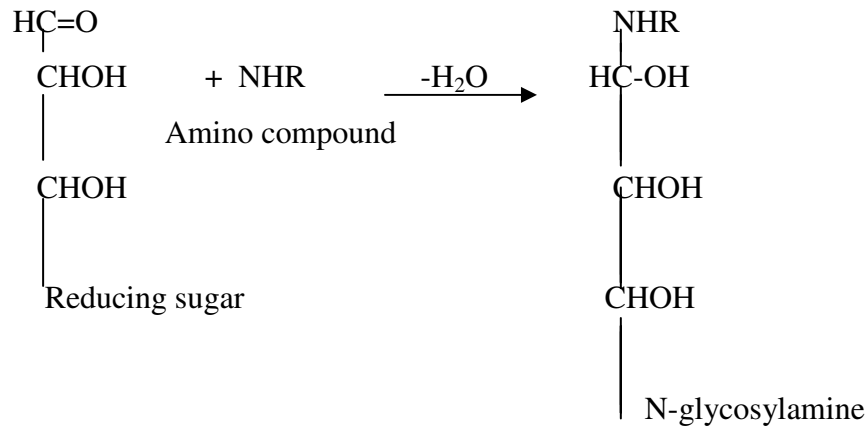
#### **2.4.3.4 Lipids and flavour of beans**

Dry beans contain between 1 to 3 % lipids, and their influence on flavour development is limited (Sathe & Deshpande, 2002). However previous studies have shown some relationship between storage and loss of quality in dry beans in terms of off-flavour development and odours, which could be due to lipid oxidation. With unfavourable storage conditions, the amount of saturated fatty acids increases while that of unsaturated fatty acids decreases. Mtebe & Gordon (1986) reported that beany flavours in legumes (such as winged beans) come about mainly due to lipoxigenase-catalysed oxidation of linoleic acids, producing hydroperoxides. Whitaker (1985) reported that most legumes such as peas, beans and peanuts contain lipoxigenase enzymes that may react with essential fatty acids such as linoleic, linolenic, and arachidonic acids resulting into the production of hydrocarbons e.g. aldehydes. Further oxidation produces carboxylic acids and alcohols (Whitaker, 1985). Mtebe & Gordon (1986) found that at moisture levels of less than 10% in beans, lipoxigenase activity was inhibited. However volatile compounds (hexanal, 2-heptanone, 2-pentyl furan, undane and tridecane) were identified in the headspace of winged bean flour after storage when treated with lipoxigenase. Esters with different odours may be formed non-enzymatically. For beans, the characteristic flavours have been reported to be hay-like in green beans and beany flavours in soybeans and their products. Hsieh (1994) also reported that in soybeans, degradation of unsaturated fatty acids by lipoxigenase produces hydroperoxides e.g. n-hexanal, cis-3-hexanal, which have been associated with grassy, beany and rancid off-flavours.

#### **2.4.3.5 Maillard reactions and flavour of beans**

Non-enzymatic factors such as the Maillard reaction take place during cooking of many kinds of food. These reactions are related to aroma, taste and colour (e.g. in roasting of coffee and cocoa beans, baking of bread and cakes or even toasting of cereals) (Martins

*et al.*, 2001). The Maillard reaction involves condensation of a reducing sugar with a free amino group such as lysine forming an N-substituted glycosylamine (Figure 2.3).



**Figure 2.3 A reaction between a reducing sugar and an amino group forming an N- substituted glycosylamine (Martins *et al.*, 2001)**

These reactions begin at low temperatures e.g. 50 °C, but increase with temperature and time of heating. N-glycosylamine is unstable and because of instability, it undergoes the amadori rearrangement forming ketosamines (Martins *et al.*, 2001). Further reactions with the amino acid forms brown nitrogenous polymers and copolymers called melanoidins that may give either off-flavours (e.g. bitterness) off-aromas (e.g. burnt, rancid or sweaty) or desirable flavours (e.g. malty, caramel, roasted).

Apart from temperature, other factors such as composition of a product, water activity and pH of the system may also influence Maillard reactions. For example, in terms of product composition, beans are a good source of lysine and more lysine present may result in darker colour during the Maillard reaction.

## 2.5 Gaps in knowledge

The wide range in dry bean varieties (AGSI/FAO, 2004) brings about variations in the physicochemical and sensory properties. As a cheaper source of protein compared to meat (Van Heerden & Schönfeldt, 2004), there is need to know the extent of these differences to maximize dry bean utilization, which has been limited due to long cooking times and differences in taste and colour preferences. Although these differences could



be genetic, poor storage conditions could also contribute to the low perception of beans. Extensive research has been conducted on dry beans in terms of the cooking times, nutritional status, and other underlying physicochemical properties (Berrios *et al.* 1999; Shimelis & Rakshit, 2005; Sanzi Calvo & Attienza del Rey, 1999). The question is: apart from long cooking times, what else makes consumers prefer certain bean varieties more than others?

With regard to previous sensory evaluation work on beans by Sanzi Calvo & Atienza del Rey (1999), some terms were developed to describe differences among bean varieties. However, little explanation exists as to how those characteristics may influence consumer acceptability of beans. Mctigue *et al.* (1989) also described the profile of aroma and flavour by mouth of seven varieties of cooked dry beans. However, little information exists on the causes of variation in the profiles and how they affect consumer choices. For beans, it is assumed that consumers are driven by the culinary quality in terms of seed size, colour, cooking quality and flavour. The underlying factors behind these drivers of choice are scanty. If consumers prefer fast cooking and good flavoured beans as pointed out by Scott and Maiden (1998), then what is it that brings about such characteristics in cooked beans? Therefore this study was conducted in order to describe and compare different dry bean varieties to be able to understand consumer choices of those beans and why. It was also aimed at finding out if any differences in aroma and taste influenced consumer acceptability of beans.

## **CHAPTER 3**

### **Hypotheses**

Differences in seed size, variety and growing location of the six dry bean varieties in this study will bring about differences in hydration capacity, swelling capacity and cooking time. Beans with lower hydration capacity will require a longer cooking time, and will also be described as less tender and less flavoured than those with high hydration capacity.

When cooked, different bean varieties will have different cooked appearance, texture, flavour and mouthfeel due to variations in water absorption capacity during hydration and cooking. This will bring about variations in the descriptive characteristics of the beans as measured by a descriptive sensory panel. These variations will further explain why consumers like or dislike some bean varieties.

Differences in the presence of phenolic compounds and/or mineral content of some beans will contribute to differences in taste (i.e. bitter, sweet). Beans with higher contents of phenolic compounds and/or mineral content such as iron (Fe) will be perceived as bitterer than those with low concentrations.

### **Objectives**

The main objective of this study was to compare the influence of physicochemical properties and sensory quality attributes on consumer preferences of six selected dry bean varieties grown in two locations (Mpumalanga and Free State) in South Africa (Figure 2.4).

#### **The specific objectives were:**

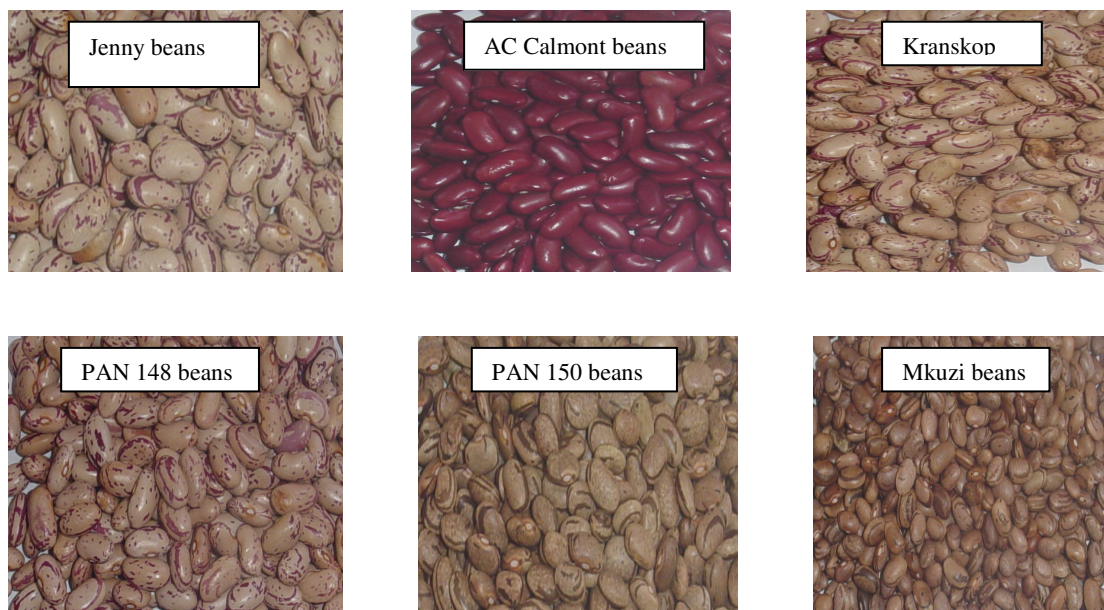
To determine the physicochemical properties (seed size, hydration capacity, swelling capacity, bulk density and cooking time) of dry bean varieties grown in these two locations.

To describe the sensory attributes in terms of overall appearance, texture and flavour of the cooked bean varieties using a descriptive sensory panel.

To determine the relationship between physicochemical properties, sensory attributes and consumer acceptance of the cooked beans.

To determine the mineral profile of the dry beans grown in the two locations.

To determine the total phenol content of bean varieties that were bitter and/or astringent.



**Figure 2.4** The six dry beans varieties grown in South Africa selected for the study

#### **4. RESEARCH**

The research chapter is divided into three sections:

**4.1** The effect of physicochemical and sensory properties of beans (*Phaseolus vulgaris* L.) on consumer preferences.

This chapter was published as a paper in the Journal of the Science of Food and Agriculture (Mkanda, Minnaar & de Kock, 2007).

**4.2** Consumer acceptance of designated bean varieties grown in Mpumalanga and Free State in South Africa

**4.3** The total polyphenol content and mineral profiles of some dry bean varieties grown in Mpumalanga and Free State in South Africa.

**4.1 The effect of physicochemical and sensory properties of beans**

**(*Phaseolus vulgaris* L.) on consumer preferences**

**Abstract**

Dry beans (*Phaseolus vulgaris* L.) have a range of varieties, colours and sizes. Differences in physicochemical and sensory properties influence consumer choices for beans. This study related consumer preferences to sensory and physicochemical properties of selected bean varieties; Jenny, Kranskop, PAN 148, AC Calmont, PAN 150 and Mkuzi, grown in Mpumalanga (MP) and Free State (FS) in South Africa.

Significant ( $p < 0.05$ ) variety, location as well as location x variety interaction effects were found for both physicochemical and sensory properties of beans. Jenny (FS), Mkuzi and PAN 148 (MP) beans had relatively long cooking times ( $>60$  min). Some beans (e.g. PAN 150 and Mkuzi beans) were described as bitter, soapy and metallic with a raw bean flavour whereas more preferred beans (e.g. Jenny MP, Kranskop MP) were sweet, soft and with a cooked bean flavour.

Apart from small seed size, sensory characteristics such as bitter taste, soapy and metallic mouthfeel and hard texture contributed to consumers' dislike of certain bean varieties. The sweet taste, cooked bean flavours, soft and mushy textures of the most accepted varieties seemed to be related to beans with good hydration capacities that facilitated softening during cooking.

#### 4.1.1 Introduction

Dry beans (*Phaseolus vulgaris* L.) are grain legumes that belong to the family of *Leguminosae* and are used for human consumption worldwide (Kutoš *et al.*, 2002). They provide an affordable source of protein (16-33%, almost two to three times that of cereals) especially in developing countries where Protein Energy Malnutrition (PEM) is prevalent (Van Heerden & Schönfeldt, 2004). In addition, dry beans provide a rich source of dietary fibre, starch (Osorio-Díaz, Bello-Pérez, Sáyago-Ayerdi, Del Pilar Benítez-Reyes, Tovar & Paredes-López, 2003), minerals and vitamins (Kutoš *et al.*, 2002). There is a wide range of dry bean varieties with different physicochemical and sensory properties satisfying varying consumer preferences. The physical properties such as seed size, colour and textural properties influence consumer acceptability of cooked dry beans (Sanzi Calvo & Attienza del Rey, 1999). Preference is normally given to medium and large sized beans probably because they have been reported to hydrate and cook well (Berrios *et al.*, 1999). Beans with amorphous and thin seed coats seem to promote higher rates of seed hydration during soaking than the lower rates evidenced in beans with thicker seed coats, which have organized palisade cells (Sefaddeh & Stanley, 1979b). Some of the most important characteristics considered in selecting dry bean varieties for production and consumption are fast cooking and good flavour (Scott & Maiden, 1998).

Before the cooking step, beans are hydrated in water until maximum weight is reached (Prodanov *et al.*, 2003). Hydration capacity is dependent on the ease of water absorption through the seed coat to the cotyledon (Del Valle *et al.*, 1992). If the cell walls of the beans are rigid, swelling and dispersion of starch during cooking is inhibited rendering the cooked product hard in texture (Wang *et al.*, 2003). It was reported for peas that the rate of hydration determines their cookability and cooking time.

It is a challenge to incorporate sensory properties in breeding programs as breeding of new dry bean varieties usually focuses on the agronomic characteristics such as resistance to diseases, yield, rate of maturing (Scott & Maiden, 1998) and nutritional content (Graham

& Ranalli, 1997). Substantial research has been done on determination of cooking time (Shimelis & Rakshit, 2005), cooked texture (Sanzi Calvo & Attienza del Rey, 1999) and underlying physicochemical properties of dry beans (Berrios *et al.*, 1999). However, there is limited information (Sanzi Calvo & Attienza del Rey, 1999; McTigue *et al.*, 1989) on the description of the sensory properties of beans that consumers refer to as having good flavour or good taste. This study relates consumer preferences to sensory and physicochemical properties of some of the dry bean varieties grown and stored in two locations in South Africa. The aim was to identify the sensory properties that should be considered for consumer acceptability.

#### **4.1.2 Materials and methods**

Six dry bean varieties were obtained from the South African Dry Bean Producers Organization (DPO). These bean varieties were chosen based on availability of the quantities (5 kg of each) required for the study. They were grown in two locations: Mpumalanga (MP) and Free State (FS), South Africa. The beans were planted between November and December 2003 and harvested between March and April 2004. After harvest, the beans were stored in farm grain stores in 50 kg polypropylene bags on pallets. Upon sample acquisition between August and October 2004, the bean seeds were sorted to remove foreign matter, shrivelled and broken seeds. The cleaned seeds were packed in polypropylene bags and stored at 4°C. The selected varieties were: three red speckled beans: Jenny, Kranskop and PAN 148; a dark red kidney bean: AC Calmont and two carioca beans: PAN 150 and Mkuzi.

##### **4.1.2.1 Physicochemical measurements**

###### ***Seed size***

Duplicate samples of 100 seeds were physically counted from each variety and weighed (Shimelis & Rakshit, 2005).

###### ***Hydration and swelling capacity***

Duplicate 20 g samples from each variety were soaked in 60 ml deionised water for 24 h at 22 °C using a 100 ml measuring cylinder (Shimelis & Rakshit, 2005). After soaking,

the water was drained and the beans were towelled dry with absorbent paper. The hydrated beans were weighed again to determine the increase in mass. The hydration capacity was calculated as the weight of water absorbed per kilogram of seeds (g of water per kg of seeds (Wang *et al.*, 2003). Swelling capacity was measured by calculating the difference in volume of deionised water displaced by beans before and after soaking (ml of water per kg of seeds) (Shimelis & Rakshit, 2005).

### ***Bulk density determination***

Bulk density was measured according to the method of Fasina, Tyler, Pickard & Zheng (1999) which was slightly modified due to the limited amount of sample available. Bean seeds were placed in a metal funnel and allowed to flow from 15.5 cm height into a 60 ml metal cup. Without pressing, the beans were leveled with a metal scraper and weighed. Bulk density was then calculated as the ratio of the weight of the sample in the metal cup to the volume of the cup and expressed as g per ml.

### ***Cooking time***

Cooking time was determined using the Mattson bean cooking device (custom made – University of Pretoria, South Africa) and the modified method of Jackson and Varriano-Marston (1981). For each variety, a 50 g bean sample was soaked for 24 h in 60 ml deionised water at 22°C (Shimelis & Rakshit, 2005). For each treatment, 25 bean seeds were positioned in the perforated saddles of the bean cooker. The piercing tip of each 90 g rod (25 rods in total) was placed in contact with the surface of the bean. The rack was then placed into a cooking pot filled with 1.5 l of deionised boiling water (96°C) and cooked. It is reported that when a bean is sufficiently tender, the plunger penetrates through the cooked bean and drops a short distance of about 4 cm from the top through the hole in the saddle (Jackson and Varriano-Marston, 1981). Cooking time was recorded when the 23<sup>rd</sup> rod (92% of the rods) had dropped (Proctor & Watts, 1987b).

## **4.1.2.2 Descriptive sensory evaluation**

### ***Preparation of bean samples***



Bean samples (150 g per variety) stored at 4 °C were soaked in 700 ml deionised water for 16 h (Wang *et al.*, 2003) in BB4L 300 mm x 450 mm plastic bags (O<sub>2</sub> permeability <20 ml/24 h 75 % RH) (Cryovac, South Africa). The beans were cooked in these bags, in boiling water (96 °C) using 6 l cooking pots (three samples per cooking pot) on a two-plate industrial stove (Anvil –South Africa, 220-240 V ~ 50 Hz and 3200 W). The bags were pierced at the top with steel rods (about 30 cm long), allowing them to hang in the cooking pot. Salt (2 g) was added to each sample (10 min before end of cooking time) for taste and also to present the beans in the same way they would be presented to consumers. Cooked beans (20 g portions) were served in preheated (50 °C) glass ramekins covered with aluminium foil. The sensory evaluation of beans was conducted in a sensory evaluation laboratory with individual booths equipped with computers for direct data entry using Compusense Five® release 4.6 (Compusense Inc., Guelph, ON, Canada). Panellists evaluated all samples in triplicate during 4 days with one session per day. Each panellist received 6 samples of beans on a white tray, with 6 stainless steel teaspoons, a serviette and a glass tumbler filled with deionised water for rinsing the mouth between tasting samples. The order of sample presentation was randomised over the panel. To avoid fatigue, 3 samples were tasted and after a short break, the other 3 samples were tasted.

### ***Recruitment and screening of the panel***

University of Pretoria students, who ate beans at least once a week, were invited through e-mail, posters and telephone calls to apply to be on the descriptive sensory panel. Twenty-five individuals responded and attended an introduction session to discuss details of the task. Eighteen eligible persons were screened for sensory acuity over two days using three different screening methods (1h per method), i.e. identification of basic tastes (sweet, sour, salty, bitter and umami), difference test (triangle test on cooked beans) and a texture-ranking test of the same beans with different cooking times. At the end of these tests, a panel of 10 judges was selected based on the overall performance during screening.

### ***Training of the panel***

Training of the panel was done for 8 days, 1 h per day. During training, each panellist described the differences among the 6 bean varieties at least three times. Descriptive



terms and scale anchors were developed, defined and agreed upon for evaluation using the Generic Descriptive Analysis technique as described by Einstein (1991). This technique involves careful selection of the panel. The panel is trained and maintained under the supervision of a panel leader. The panellists actively participate in developing the evaluation criteria and methodology. They describe the differences that exist among samples and reach consensus on the terms, the scale/s and references to use for evaluating the samples. Prior to evaluating the samples, the panellists' performance is checked to see if training was adequate.

### ***Sample evaluation***

The panel used nineteen descriptive terms, grouped under appearance, aroma, flavour, texture and mouthfeel attributes (Table 4.1.1). This table shows the definitions of the lexicon developed by the descriptive sensory panel. Nine-point category scales were used to measure the intensity of individual attributes. The minimum value was 1 denoting not intense or not much. The maximum point was 9 denoting very intense or very much

#### **4.1.2.3 Consumer acceptance tests**

Consumer evaluation of the beans was conducted in the sensory laboratory on two days using 100 consumers in total. On the first day consumers tasted Kranskop (FS), AC Calmont (MP), Jenny (FS), PAN 148 (MP) and PAN 150. (MP) On the second day, Jenny (MP), Kranskop (MP), PAN 148 (MP), AC Calmont (FS) and Mkuzi (MP) were tasted. Different individuals were used as panellists on the respective days. The panel comprised students and university employees. The consumers were selected if they indicated that they ate beans at least once a week. Consumers evaluated all the bean varieties from both locations except PAN 150 and Mkuzi from FS. These samples were excluded because of limited sample quantities available and the results of the descriptive sensory panel that showed similarities of the beans grown in the two locations. A 9-point hedonic rating scale with only the end categories marked with verbal scale anchors (1 = I do not like it at all; 9 = I like it very much) was used to evaluate the samples. Questions and scales were formulated in a simplified way and displayed using Compusense Five® release 4.6 (Compusense Inc., Guelph, ON, Canada). Five bean varieties were cooked on each of the

two days. Fifty consumers participated per day with each consumer tasting 5 samples. The consumer group included 48% males and 52% females of which the majority were between 21 and 30 years of age. Beans (500 g) were soaked in 2.2 l of deionised water for 16 h before cooking. Soaked beans, together with the soaking water, were placed in BB4L 300 mm x 450 mm plastic bags (O<sub>2</sub> permeability <20 ml/24 h 75 % RH) (Cryovac, South Africa) pierced in two places, with a steel rod at about 5cm from the top end to hold it. The bags with rods were then placed in 6 l cooking pots with boiling water (96 °C).

Beans were cooked for 110 min and 7.5 g of salt were added to each bean sample after 100 min of cooking. Samples (20 g) were served in preheated (50 °C) glass ramekins (covered with aluminium foil) and coded with 3 digit random code numbers. For each panellist, the samples were placed (in a random order) on a white tray with five stainless steel teaspoons, a serviette and a glass tumbler filled with deionised water for rinsing the mouth between tasting samples.

#### 4.1.2.4 Statistical analyses

The physicochemical and descriptive sensory determinations were conducted in triplicate. The effects of variety and growing location as well as their interactions on the physicochemical and sensory attributes were evaluated using analysis of variance (ANOVA) based on a 5% level of significance (Statistica version 7.1 Stat Soft, Inc). Significant differences between means were determined using Fischer's least significant difference (LSD) test.

Correlation coefficients (*r*) were determined to establish relationships between variables. Only the significant ( $p < 0.05$ ) correlation coefficients with a strong degree of association ( $r > 0.8$ ) (Bower, 2000) were considered. Principal Component classification Analysis (PCA) including the sensory and physicochemical characteristics was conducted using a correlation matrix with variety or location means in rows and characteristics in columns.

**Table 4.1.1 Lexicon used by descriptive sensory panel for cooked beans**

Term	Definition
Splitting	Visual assessment of the number of beans that were transversely or

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	longitudinally cracked after cooking.
Broth thickness	Visual assessment of the viscosity of the broth of cooked beans.
Seed coat peeling	Visual assessment of the extent to which the seed coat peeled during cooking.
Raw bean aroma	Aromatic characteristic of the smell of raw beans or legumes.
Raw bean flavour	Aromatic characteristic of the in-mouth perception of raw beans or legumes.
Cooked bean aroma	Aromatic characteristic of the smell of cooked beans or legumes.
Cooked bean flavour	Aromatic characteristic of the in-mouth perception of cooked beans or legumes.
Sweetness	Taste on the tongue associated with sugar.
Saltiness	Taste on the tongue associated with sodium chloride.
Nutty flavour	Flavour similar to what is perceived when eating raw peanuts (usually perceived in undercooked beans).
Bitterness	Taste on the tongue stimulated by caffeine, quinine or alkaloids.
Softness	The extent to which the structure of beans break down while chewing (usually an indication of well cooked beans).
Mushiness	The extent to which a mashed, paste-like texture is perceived (usually an indication of overcooked beans).
Soapy feeling	The extent to which a slippery mouthfeel associated with the hand feel of wet bathing soap is perceived.
Metallic feeling	The extent to which a flat chemical feeling factor stimulated by a copper coin on the tongue is perceived.
Seed coat residues	The extent to which the seed coat remains in the mouth after swallowing. A characteristic associated with undercooked beans.

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Consumer sensory evaluation data was analysed using a generalized linear model two-way ANOVA with samples treated as fixed and consumers as random independent effects.

Fischer's LSD test at 5% significance level was used to indicate significant differences between means.

#### **4.1.3 Results**

Significant variety, location as well as location x variety interaction effects were observed for different bean attributes (Table 4.1.2). If a significant interaction effect was found, then the significant individual variety and /or location effects were ignored.

##### **4.1.3.1 Physicochemical measurements**

There was a significant location x variety interaction effect for seed size of the uncooked beans (Table 4.1.2). For PAN 148 and Mkuzi, there were no significant size differences between beans grown in MP and FS (Table 4.1.3). However the size of Jenny, Kranskop, AC Calmont and PAN 150 beans differed significantly depending on where they were grown. In particular, AC Calmont (MP) was significantly bigger than AC Calmont (FS). Overall, Jenny beans were the largest seeds whereas Mkuzi beans were the smallest seeds.

**Table 4.1.2 P-values to test for the effects of bean variety<sup>1</sup> and growing location<sup>2</sup> on physicochemical and sensory attributes of beans**

Attributes		Variety	Location	Location x variety interaction
Physicochemical attributes	Uncooked seed size	<0.0001	<0.001	<0.0001
	Hydration capacity	<0.0001	<0.0001	<0.0001
	Swelling capacity	NS	NS	0.021
	Bulk density	0.0001	0.0001	0.0001
	Cooking time	0.025	0.049	0.002
Appearance	Cooked seed size	<0.0001	NS	0.031
	Splitting	<0.0001	NS	NS
	Thickness of broth	<0.0001	NS	<0.0001
	Seed coat peeling	0.000	NS	0.025
Aroma	Raw bean aroma	0.031	NS	NS
	Cooked bean aroma	0.006	NS	0.004
	Earthy aroma	NS	NS	NS
	Burnt aroma	NS	NS	NS
Flavour	Raw bean flavour	NS	NS	0.040
	Cooked bean flavour	0.002	NS	<0.0001
	Sweetness	NS	NS	0.001
	Nutty flavour	<0.0001	NS	NS
	Bitterness	<0.0001	NS	NS
	Saltiness	NS	0.001	NS
Texture or mouthfeel	Softness	0.000	NS	<0.0001
	Mushiness	<0.0001	NS	0.027
	Soapy feeling	<0.0001	NS	NS
	Metallic feeling	0.014	NS	NS
	Seed coat residues	0.013	NS	NS

<sup>1</sup> Jenny, Kranskop, PAN 148, AC Calmont, PAN 150 and Mkuzi

<sup>2</sup> Mpumalanga and Free State

NS=Not Significant

**Table 4.1.3 Mean ratings ( $\pm$  SD) illustrating the effects of variety and growing location on physicochemical attributes of dry beans**

Physicochemical attributes	Location	Variety					
		Jenny	Kranskop	PAN 148	AC Calmont	PAN 150	Mkuzi
Uncooked Seed size (g per 100 seeds)	MP	57.4 ( $\pm$ 1.2) <sup>h</sup>	45.9 ( $\pm$ 0.1) <sup>dc</sup>	44.6 ( $\pm$ 1.4) <sup>dc</sup>	55.1 ( $\pm$ 0.6) <sup>g</sup>	26.4 ( $\pm$ 0.1) <sup>c</sup>	20.8 ( $\pm$ 0.3) <sup>a</sup>
	FS	59.2 ( $\pm$ 0.8) <sup>i</sup>	48.2 ( $\pm$ 1.3) <sup>f</sup>	45.2 ( $\pm$ 0.3) <sup>dc</sup>	44.3 ( $\pm$ 0.2) <sup>d</sup>	23.2 ( $\pm$ 0.3) <sup>b</sup>	19.8 ( $\pm$ 0.3) <sup>a</sup>
Hydration capacity (g water kg seeds <sup>-1</sup> )	MP	1046 ( $\pm$ 50.4) <sup>c</sup>	973 ( $\pm$ 40.8) <sup>ab</sup>	961 ( $\pm$ 55.7) <sup>ab</sup>	1034 ( $\pm$ 9.6) <sup>dc</sup>	985 ( $\pm$ 29.4) <sup>c</sup>	921 ( $\pm$ 19.5) <sup>a</sup>
	FS	918 ( $\pm$ 41) <sup>a</sup>	987 ( $\pm$ 30.6) <sup>bcd</sup>	982 ( $\pm$ 24.5) <sup>bcd</sup>	1068 ( $\pm$ 14.8) <sup>c</sup>	1026 ( $\pm$ 37.4) <sup>cdc</sup>	981 ( $\pm$ 84) <sup>bc</sup>
Swelling Capacity (ml water kg seeds <sup>-1</sup> )	MP	122.7 ( $\pm$ 19.6) <sup>bc</sup>	123.4 ( $\pm$ 11.2) <sup>bc</sup>	110.0 ( $\pm$ 14.6) <sup>ab</sup>	122.8 ( $\pm$ 10.1) <sup>bc</sup>	112.0 ( $\pm$ 17.2) <sup>ab</sup>	105.0 ( $\pm$ 7.7) <sup>ab</sup>
	FS	100.5 ( $\pm$ 16.6) <sup>a</sup>	112.5 ( $\pm$ 28.6) <sup>ab</sup>	112.3 ( $\pm$ 17.3) <sup>ab</sup>	118.3 ( $\pm$ 9.6) <sup>abc</sup>	131.4 ( $\pm$ 11.5) <sup>c</sup>	119.8 ( $\pm$ 13.3) <sup>bc</sup>
Bulk density (g ml <sup>-1</sup> )	MP	1.297 ( $\pm$ 0.01) <sup>f</sup>	1.270 ( $\pm$ 0.01) <sup>c</sup>	1.279 ( $\pm$ 0.03) <sup>cdc</sup>	1.243 ( $\pm$ 0.00) <sup>b</sup>	1.287 ( $\pm$ 0.00) <sup>fdc</sup>	1.296 ( $\pm$ 0.01) <sup>fc</sup>
	FS	1.271 ( $\pm$ 0.01) <sup>cd</sup>	1.30 ( $\pm$ 0.01) <sup>f</sup>	1.301 ( $\pm$ 0.01) <sup>f</sup>	1.221 ( $\pm$ 0.00) <sup>a</sup>	1.332 ( $\pm$ 0.00) <sup>g</sup>	1.341 ( $\pm$ 0.02) <sup>g</sup>
Cooking time (min)	MP	51.5 ( $\pm$ 12.8) <sup>a</sup>	51.9 ( $\pm$ 1.0) <sup>a</sup>	84.6 ( $\pm$ 2.9) <sup>b</sup>	49.3 ( $\pm$ 3.2) <sup>a</sup>	47.5 ( $\pm$ 11.3) <sup>a</sup>	92.4 ( $\pm$ 8.4) <sup>c</sup>
	FS	97.8 ( $\pm$ 0.8) <sup>bc</sup>	42.4 ( $\pm$ 4.4) <sup>ab</sup>	48.8 ( $\pm$ 4.9) <sup>a</sup>	49.7 ( $\pm$ 7.7) <sup>a</sup>	42.9 ( $\pm$ 0.7) <sup>a</sup>	43.5 ( $\pm$ 1.3) <sup>a</sup>

abcdefghi = For a particular physicochemical measurement, mean values with different letters differ significantly ( $p < 0.05$ )

MP =Mpumalanga

FS = Free State

SD = Standard Deviation

A significant location x variety interaction effect was observed in the hydration and swelling capacity of the beans (Table 4.1.2). During soaking, the beans hydrated between 92 % and 107 % (i.e. 918 ( $\pm 41$ ) and 1068 ( $\pm 14.8$ ) g of water per kg of seeds) of their original mass (Table 4.1.3).

Significant differences between locations were observed for hydration capacities, but only for Jenny and Mkuzi beans. Jenny beans from MP hydrated significantly more than those from FS, while Mkuzi beans from FS hydrated more than those from MP. No significant location differences were observed for the swelling capacity of Kranskop, PAN 148, AC Calmont and Mkuzi beans.

There was a significant ( $p < 0.05$ ) location x variety effect for bulk density (Table 4.1.2) of beans. Bulk density of the 6 bean varieties varied from 1.22 ( $\pm 0.00$ ) g per ml to 1.34 ( $\pm 0.02$ ) g per ml, the lowest being AC Calmont (FS) and the highest being Mkuzi (FS) (Table 4.1.3). Overall, four FS varieties (Mkuzi, PAN 150, PAN 148 and Kranskop) had significantly higher bulk densities than MP varieties. Only Jenny and AC Calmont (MP) showed a significantly higher density than the same varieties grown in FS.

A significant location x variety interaction effect was also observed for cooking time of the beans (Table 4.1.2). For some varieties (Jenny, PAN 148 and Mkuzi), location significantly influenced cooking time (Table 4.1.3). Of interest was that Jenny (FS) cooked longer than Jenny (MP) while PAN 148 and Mkuzi from MP, cooked longer compared to the same varieties when grown in FS. Apart from the long cooking time of the abovementioned beans, the rest of the bean varieties cooked in less than 60 min according to the procedure followed.

#### **4.1.3.2 Descriptive Sensory Evaluation**

##### ***Appearance attributes***

In terms of appearance attributes of the cooked beans, a significant location x variety interaction effect was observed for cooked seed size, thickness of broth and seed coat peeling (Table 4.1.2). Variety, but not location, influenced splitting of cooked beans

significantly. In terms of the cooked seed size, no significant inter-location differences were observed for Kranskop, PAN 148, PAN 150 and Mkuzi beans (Table 4.1.5).

Uncooked seed size results showed Jenny beans as the largest variety and Mkuzi beans as the smallest (Table 4.1.3). The cooked seed size showed AC Calmont (MP and FS) and Jenny (FS) as the larger seeds with Mkuzi still as the smallest seeds (Table 4.1.5). Jenny (FS) had significantly larger seeds compared to beans of that variety grown in MP. For AC Calmont though, the larger seeds were grown in MP. In terms of degree of splitting (Table 4.1.5), overall PAN 150 had the most split beans while AC Calmont and Mkuzi had the least number of split beans. PAN 150 (MP) gave noticeably thicker broths while the broth of Mkuzi (MP) was the least thick. The seed coat of PAN 150 (MP) also peeled the most. Mkuzi and AC Calmont showed significantly less peeling than the other varieties. Positive correlations were observed between some attributes as shown in (Table 4.1.4). It was observed that when beans split, the seed coat also peeled more ( $r = 0.89$ ) and the resulting broth was thicker ( $r = 0.87$ ) than when they did not split.

**Table 4.1.4 Correlation between various sensory attributes of six bean varieties grown in two locations of South Africa**

Bean attributes	r	p-value
Thickness of broth vs. splitting	+0.87	0.0001
Seed coat peeling vs. splitting	+0.89	0.0001
Seed coat peeling vs. thickness of broth	+0.87	0.0001
Metallic feeling in the mouth vs bitterness	+0.86	0.0001
Soapy feeling in the mouth vs bitterness	+0.81	0.001
Uncooked seed size vs cooked seed size	+0.96	0.0001
Raw bean flavour vs cooked bean aroma	-0.79	0.002
Raw bean flavour vs cooked bean flavour	-0.82	0.001
Soapy feeling in the mouth vs cooked bean size	-0.79	0.001



**Table 4.1.5 Mean ratings ( $\pm$  SD) illustrating the effect of variety and/or growing location on appearance attributes of cooked beans**

Appearance attributes	Location	Variety					
		Jenny	Kranskop	PAN 148	AC Calmont	PAN 150	Mkuzi
Cooked seed size (1= Small; 9= Large)	MP	7.4 ( $\pm$ 0.4) <sup>d</sup>	6.9 ( $\pm$ 0.2) <sup>c</sup>	7.0 ( $\pm$ 0.2) <sup>cd</sup>	8.4 ( $\pm$ 0.2) <sup>f</sup>	3.4 ( $\pm$ 0.2) <sup>b</sup>	2.1 ( $\pm$ 0.3) <sup>a</sup>
	FS	8.0 ( $\pm$ 0.1) <sup>ef</sup>	7.4 ( $\pm$ 0.1) <sup>cd</sup>	7.1 ( $\pm$ 0.2) <sup>cd</sup>	8.0 ( $\pm$ 0.3) <sup>e</sup>	3.5 ( $\pm$ 0.4) <sup>b</sup>	2.3 ( $\pm$ 0.4) <sup>a</sup>
Splitting (1= No split beans; 9= Large number of split beans)	MP and FS	5.1 ( $\pm$ 0.4) <sup>b</sup>	5.0 ( $\pm$ 0.6) <sup>b</sup>	4.9 ( $\pm$ 0.5) <sup>b</sup>	3.8 ( $\pm$ 0.7) <sup>a</sup>	7.1 ( $\pm$ 0.1) <sup>c</sup>	4.1 ( $\pm$ 1.2) <sup>a</sup>
Thickness of broth (1= Not thick; 9 =Very thick)	MP	5.0 ( $\pm$ 0.8) <sup>bc</sup>	4.9 ( $\pm$ 0.4) <sup>b</sup>	4.7 ( $\pm$ 0.6) <sup>b</sup>	4.4 ( $\pm$ 0.3) <sup>b</sup>	7.2 ( $\pm$ 0.3) <sup>c</sup>	3.0 ( $\pm$ 0.3) <sup>a</sup>
	FS	4.8 ( $\pm$ 0.3) <sup>b</sup>	6.3 ( $\pm$ 0.3) <sup>d</sup>	4.7 ( $\pm$ 0.7) <sup>b</sup>	4.4 ( $\pm$ 0.5) <sup>b</sup>	5.8 ( $\pm$ 0.3) <sup>cd</sup>	4.3 ( $\pm$ 0.7) <sup>b</sup>
Seed coat peeling (No peeling; 9= Very much peeling)	MP	4.2 ( $\pm$ 0.6) <sup>b</sup>	3.6 ( $\pm$ 0.3) <sup>b</sup>	4.0 ( $\pm$ 0.2) <sup>b</sup>	2.3 ( $\pm$ 0.6) <sup>a</sup>	5.9 ( $\pm$ 0.3) <sup>c</sup>	2.1 ( $\pm$ 1.0) <sup>a</sup>
	FS	4.3 ( $\pm$ 0.4) <sup>b</sup>	4.4 ( $\pm$ 0.9) <sup>b</sup>	3.8 ( $\pm$ 0.1) <sup>b</sup>	2.1 ( $\pm$ 0.6) <sup>a</sup>	4.4 ( $\pm$ 0.3) <sup>b</sup>	2.6 ( $\pm$ 0.2) <sup>a</sup>

<sup>abcde</sup> = For a particular attribute, mean values with different letters differ significantly ( $p < 0.05$ )

MP =Mpumalanga

FS = Free State

SD = Standard Deviation

### ***Aroma and flavour attributes***

The raw bean aroma of different varieties differed slightly although significantly (Table 4.1.6). Relatively low mean ratings (below 3.5) were recorded. Significant negative correlations were found between raw bean flavour and both cooked bean aroma and flavour (Table 4.1.4).

A significant location x variety interaction effect was observed for raw bean and cooked bean flavours and sweet taste (Table 4.1.2). The raw bean flavour of Mkuzi beans but not the other varieties differed depending on the growing location (Table 4.1.6). Location significantly influenced cooked bean flavours of Jenny and Mkuzi beans. For Kranskop and AC Calmont beans, growing location had a significant effect on sweetness. Overall, beans grown in FS were significantly saltier (MP =  $3.86 \pm 0.47$ ; FS =  $4.42 \pm 0.54$ ), than those from MP. Nutty and bitter flavour differences were observed between bean varieties (Tables 4.1.6). The nutty flavour of Mkuzi beans was significantly more intense than the rest of the varieties, except Jenny. PAN 150 beans were significantly ( $p < 0.05$ ) bitterer compared to the other varieties.

### ***Textural and/or mouthfeel characteristics***

There was a significant location x variety interaction effect (Table 4.1.2) observed in textural attributes (softness and mushiness) of the bean varieties. Overall, the texture of Mkuzi (MP) was harder than the other varieties (Table 4.1.7). In terms of mushiness only Jenny beans showed a significant location difference. For the mouthfeel attributes (seed coat residue, soapy and metallic feeling), variety only showed significant differences (Table 4.1.2). Apart from bitterness (Table 4.1.6), PAN 150 beans also left a more intense soapy and metallic feeling in the mouth (Table 4.1.7), compared to the rest of the varieties. Mkuzi beans, also displayed a noted soapy mouthfeel. There were significant positive correlations between metallic and soapy mouthfeel in the mouth with bitterness (Table 4.1.4).

**Table 4.1.6 Mean ratings ( $\pm$ SD) illustrating the effects of variety and/or growing location on aroma and flavour attributes of cooked beans**

Attributes	Location	Variety					
		Jenny	Kranskop	PAN 148	AC Calmont	PAN 150	Mkuzi
Raw bean aroma (1= Not intense; 9= Very intense)	MP and FS	2.8 ( $\pm$ 0.6) <sup>abc</sup>	3.1 ( $\pm$ 0.5) <sup>bc</sup>	3.4 ( $\pm$ 0.7) <sup>c</sup>	2.9 ( $\pm$ 0.5) <sup>abc</sup>	2.5 ( $\pm$ 0.5) <sup>a</sup>	2.6 ( $\pm$ 0.3) <sup>ab</sup>
Cooked bean aroma (1= Not intense; 9= Very intense)	MP	6.5( $\pm$ 0.5) <sup>dc</sup>	6.4 ( $\pm$ 0.4) <sup>dc</sup>	5.7 ( $\pm$ 0.5) <sup>bcd</sup>	5.3 ( $\pm$ 0.7) <sup>abc</sup>	5.4 ( $\pm$ 0.4) <sup>abc</sup>	4.9 ( $\pm$ 0.4) <sup>ab</sup>
	FS	5.5 ( $\pm$ 0.5) <sup>abc</sup>	6.4 ( $\pm$ 0.5) <sup>de</sup>	5.9 ( $\pm$ 0.9) <sup>cde</sup>	4.8 ( $\pm$ 0.4) <sup>a</sup>	5.8 ( $\pm$ 0.7) <sup>bcde</sup>	6.6 ( $\pm$ 0.3) <sup>e</sup>
Raw bean flavour (1= Not intense; 9= Very intense)	MP	2.4 ( $\pm$ 0.4) <sup>a</sup>	3.0 ( $\pm$ 0.5) <sup>abc</sup>	2.6 ( $\pm$ 0.7) <sup>ab</sup>	3.2 ( $\pm$ 1.0) <sup>abc</sup>	2.9 ( $\pm$ 0.4) <sup>ab</sup>	4.1 ( $\pm$ 0.8) <sup>c</sup>
	FS	3.3 ( $\pm$ 0.7) <sup>abc</sup>	2.5 ( $\pm$ 0.7) <sup>a</sup>	2.5 ( $\pm$ 0.7) <sup>a</sup>	3.7 ( $\pm$ 0.4) <sup>bc</sup>	2.3 ( $\pm$ 0.5) <sup>a</sup>	2.5 ( $\pm$ 0.7) <sup>a</sup>
Cooked bean flavour (1= Not intense; 9= Very intense)	MP	7.1 ( $\pm$ 0.3) <sup>ef</sup>	6.1 ( $\pm$ 0.4) <sup>bcde</sup>	6.5 ( $\pm$ 0.5) <sup>cdef</sup>	6.2 ( $\pm$ 0.3) <sup>bcdef</sup>	5.5 ( $\pm$ 0.8) <sup>bc</sup>	4.1 ( $\pm$ 0.8) <sup>a</sup>
	FS	5.4 ( $\pm$ 0.8) <sup>b</sup>	7.1 ( $\pm$ 0.4) <sup>e</sup>	6.7 ( $\pm$ 0.4) <sup>def</sup>	5.4 ( $\pm$ 0.8) <sup>b</sup>	5.8 ( $\pm$ 0.7) <sup>bcd</sup>	6.4 ( $\pm$ 0.7) <sup>bcdef</sup>
Sweetness (1=Not sweet; 9= Very sweet)	MP	5.5 ( $\pm$ 0.5) <sup>bc</sup>	4.8 ( $\pm$ 0.5) <sup>ab</sup>	5.5 ( $\pm$ 0.4) <sup>bc</sup>	5.9 ( $\pm$ 0.6) <sup>cd</sup>	5.0 ( $\pm$ 0.4) <sup>abc</sup>	4.5 ( $\pm$ 0.3) <sup>a</sup>
	FS	4.8 ( $\pm$ 1.1) <sup>ab</sup>	6.5 ( $\pm$ 0.2) <sup>d</sup>	5.0 ( $\pm$ 0.4) <sup>abc</sup>	4.5 ( $\pm$ 0.5) <sup>a</sup>	4.8 ( $\pm$ 0.4) <sup>ab</sup>	5.2 ( $\pm$ 0.8) <sup>abc</sup>
Nutty flavour (1= Not nutty; 9= Very nutty)	MP and FS	2.7 ( $\pm$ 0.4) <sup>cd</sup>	2.1 ( $\pm$ 0.5) <sup>ab</sup>	2.0 ( $\pm$ 0.3) <sup>ab</sup>	2.2 ( $\pm$ 0.5) <sup>bc</sup>	1.6 ( $\pm$ 0.1) <sup>a</sup>	3.0 ( $\pm$ 0.6) <sup>d</sup>
Bitterness (1= Not bitter; 9= Very bitter)	MP and FS	1.5 ( $\pm$ 0.4) <sup>a</sup>	1.8 ( $\pm$ 0.5) <sup>a</sup>	1.7 ( $\pm$ 0.3) <sup>a</sup>	2.0 ( $\pm$ 0.4) <sup>a</sup>	3.5 ( $\pm$ 0.8) <sup>b</sup>	1.9 ( $\pm$ 0.9) <sup>a</sup>

<sup>abcdef</sup> = For a particular sensory attribute, mean values per attribute with different letters differ significantly( $p < 0.05$ )

MP =Mpumalanga

FS = Free State

SD = Standard Deviation

**Table 4.1.7 Mean ratings ( $\pm$ SD) illustrating the effect of variety and/or growing location of texture or mouthfeel attributes of cooked beans**

Texture or mouthfeel attributes	Location	Variety					
		Jenny	Kranskop	PAN 148	AC Calmont	PAN 150	Mkuzi
Softness (1= Not soft; 9= Very soft)	MP	8.2 ( $\pm$ 0.4) <sup>de</sup>	7.3 ( $\pm$ 0.6) <sup>cd</sup>	7.3 ( $\pm$ 0.3) <sup>cd</sup>	7.3 ( $\pm$ 0.7) <sup>cd</sup>	8.1 ( $\pm$ 0.4) <sup>de</sup>	4.4 ( $\pm$ 1.3) <sup>a</sup>
	FS	6.6 ( $\pm$ 1.2) <sup>bc</sup>	8.5 ( $\pm$ 0.0) <sup>e</sup>	8.1 ( $\pm$ 0.2) <sup>de</sup>	5.8 ( $\pm$ 1.2) <sup>b</sup>	7.9 ( $\pm$ 0.1) <sup>de</sup>	6.5 ( $\pm$ 0.5) <sup>bc</sup>
Mushiness (1= Not mushy; 9= Very mushy)	MP	6.4 ( $\pm$ 0.3) <sup>de</sup>	5.5 ( $\pm$ 0.7) <sup>bcde</sup>	5.7 ( $\pm$ 1.0) <sup>bcde</sup>	5.1 ( $\pm$ 1.1) <sup>bcd</sup>	6.1 ( $\pm$ 0.3) <sup>cde</sup>	3.3 ( $\pm$ 0.9) <sup>a</sup>
	FS	4.8 ( $\pm$ 1.0) <sup>bc</sup>	6.8 ( $\pm$ 0.5) <sup>e</sup>	6.5 ( $\pm$ 0.5) <sup>e</sup>	4.4 ( $\pm$ 1.2) <sup>ab</sup>	6.2 ( $\pm$ 0.6) <sup>de</sup>	4.6 ( $\pm$ 1.1) <sup>ab</sup>
Soapy feeling (1= Not intense; 9= Very intense)	MP and FS	1.9 ( $\pm$ 0.6) <sup>a</sup>	1.6 ( $\pm$ 0.4) <sup>a</sup>	1.7 ( $\pm$ 0.4) <sup>a</sup>	1.4 ( $\pm$ 0.3) <sup>a</sup>	3.5 ( $\pm$ 0.6) <sup>c</sup>	2.6 ( $\pm$ 0.8) <sup>b</sup>
Metallic feeling (1= Not intense; 9= Very intense)	MP and FS	1.8 ( $\pm$ 0.5) <sup>a</sup>	2.0 ( $\pm$ 0.5) <sup>a</sup>	1.7 ( $\pm$ 0.5) <sup>a</sup>	1.9 ( $\pm$ 0.5) <sup>a</sup>	2.6 ( $\pm$ 0.4) <sup>b</sup>	2.0 ( $\pm$ 0.5) <sup>a</sup>
Seed coat residue (1= No seed coat residue; 9= Very much seed coat residue)	MP and FS	3.7 ( $\pm$ 0.7) <sup>ab</sup>	3.6 ( $\pm$ 0.4) <sup>a</sup>	4.2 ( $\pm$ 0.3) <sup>bc</sup>	4.6 ( $\pm$ 0.5) <sup>c</sup>	4.1 ( $\pm$ 0.3) <sup>abc</sup>	4.2 ( $\pm$ 0.8) <sup>abc</sup>

<sup>abcde</sup> = For a specific sensory attribute, mean values with different letters differ significantly ( $p < 0.05$ )

MP = Mpumalanga

FS = Free State

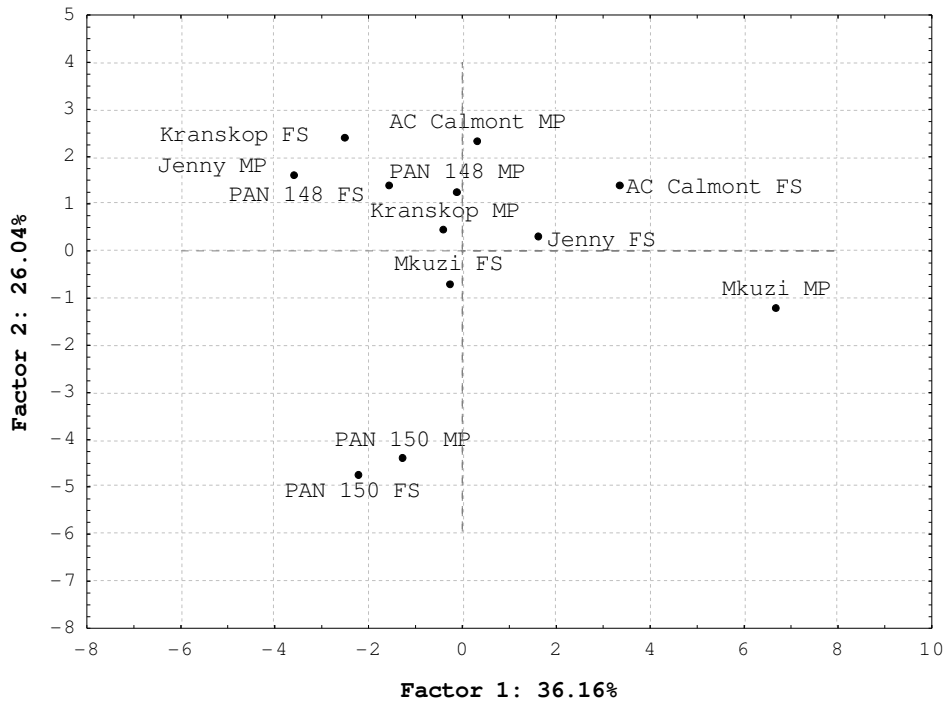
SD = Standard Deviation

### ***Principal Component Analysis (PCA)***

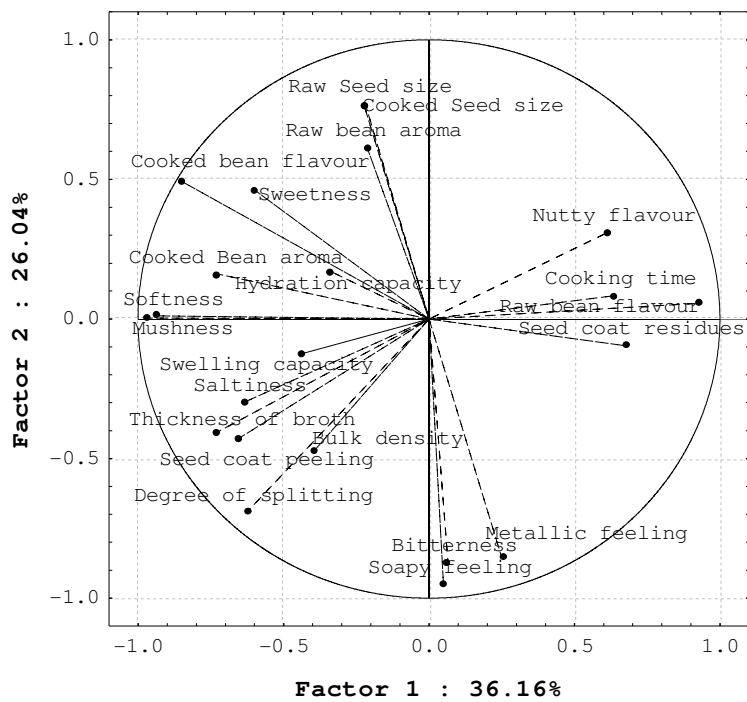
Figure 4.1.1A shows the projection of scores of the varieties (from both locations) and Figure 4.1.1 B illustrates the projection of the loadings of the attributes. The first two principal components described 62 % of the total variance in physicochemical and sensory attributes of the beans. Factor 1 explained 36 % of the total variance of the data. Varieties on the right of the plot (Jenny-FS, AC Calmont-FS and particularly Mkuzi-MP) cooked longer, had more intense raw bean and nutty flavours. These beans also left more seed coat residues in the mouth than the other bean varieties. The varieties (Kranskop- FS, Jenny-MP, PAN 148-FS and PAN 150-FS) to the left of the map were characterised by mushy and soft textures, more intense cooked bean aroma and flavour as well as thicker broths and more seed coat peeling. Factor 2 added 26 % to the explanation of variation and separated varieties with more bitterness, metallic and soapy mouthfeels such as PAN 150 (MP and FS) from the rest of the varieties. In addition, this factor separated varieties according to seed size with the bigger beans (Jenny, Kranskop, PAN 148 and AC Calmont) at the top of the plane and the smaller beans (PAN 150 and Mkuzi) at the bottom. The varieties with scores on Factor 1 close to zero (AC Calmont-MP, PAN 148-MP Kranskop-MP, Mkuzi-FS and PAN 150-MP) were not well explained by this factor. Factor 3 (Figure 4.1.2 A and B) explained an additional 13 % (making the total 75 %) of the variation. This factor mainly explained the relatively higher bulk density and cooked bean aroma of Mkuzi (FS).

#### **4.1.3.3 Consumer acceptance tests**

There was a significant difference in consumer acceptance of the different beans (Figure 4.1.3). Of the bean samples presented to consumers, samples that were rated towards 9 on the 9-point hedonic rating scale were the most preferred (e.g. Jenny-MP and Kranskop-MP) and those that were rated towards 1 were the least preferred (e.g. Mkuzi-MP, AC Calmont-FS and PAN 150-MP).



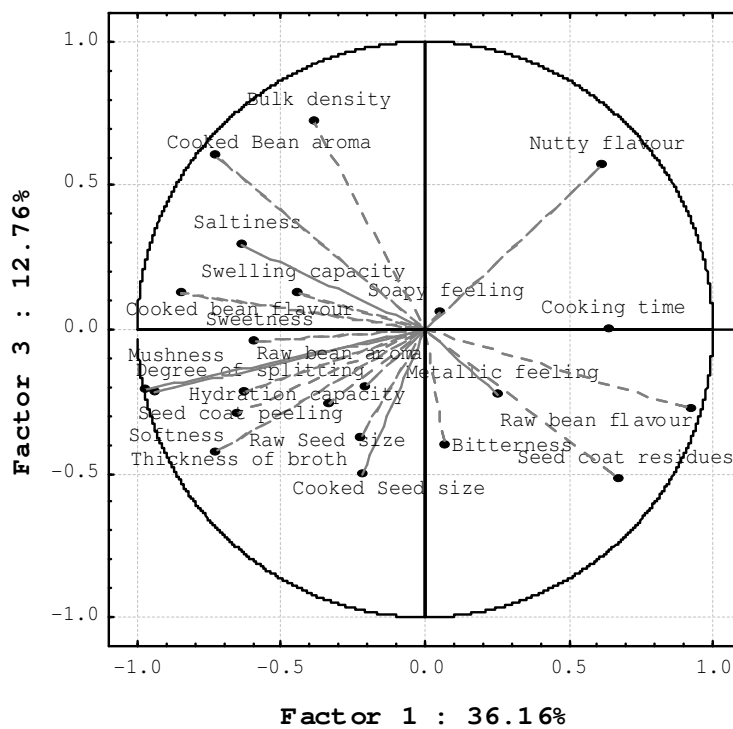
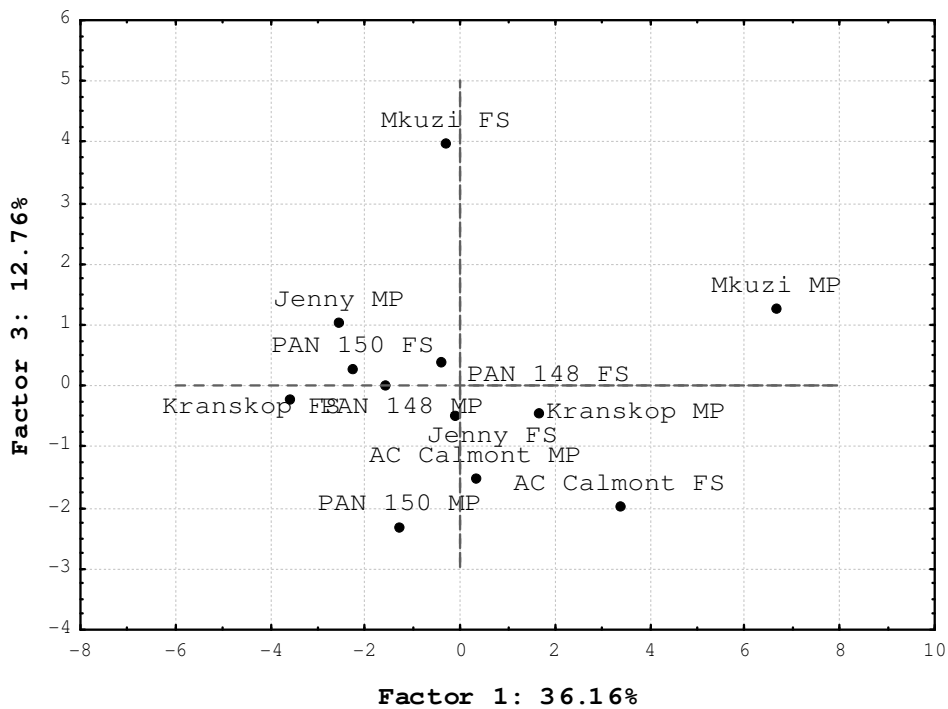
**A**



**B**

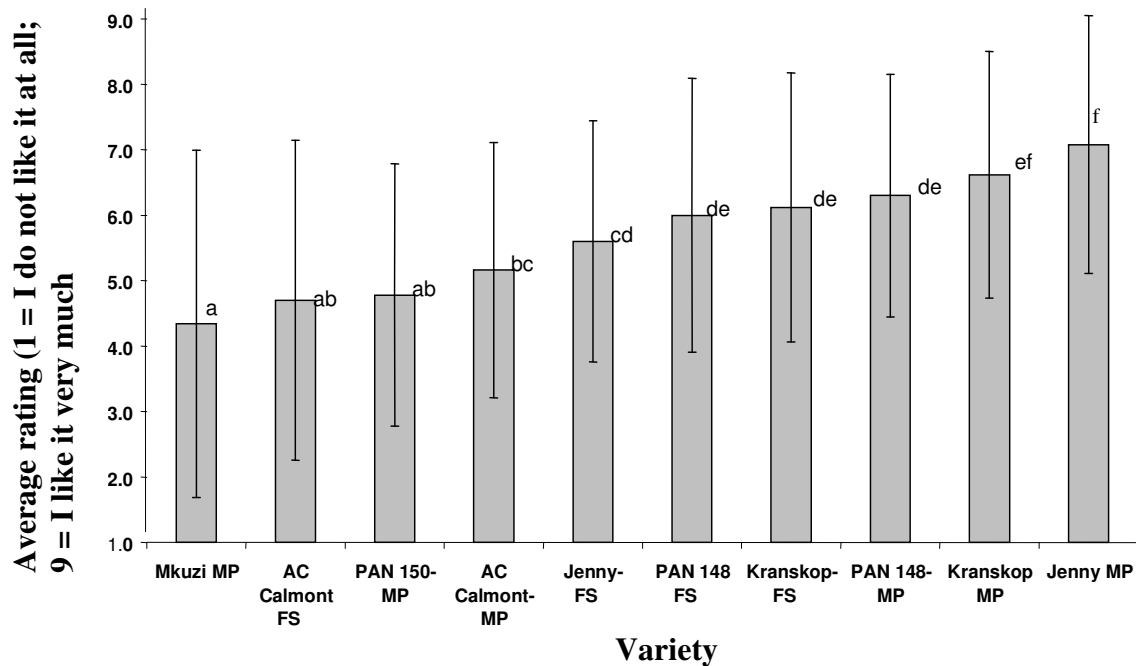
**Figure 4.1.1 Principal Component Analysis (first two principal components) of 6 bean varieties grown in MP and FS**

- A.** Plot of the first two principal component scores of the bean varieties
- B.** Plot of first two principal component loading vectors of sensory attributes and physicochemical characteristics.



**Figure 4.1.2 Principal Component Analysis (first and third principal components) of 6 bean varieties grown in MP and FS**

- A.** Plot of first and third principal component scores of the bean varieties
- B.** Plot of first and third principal component loading vectors of sensory attributes and physicochemical characteristics



**Figure 4.1.3 Consumer liking of the bean varieties grown in two locations (MP and FS)**

abcdef = Mean ratings of the bean varieties with different letters differed significantly ( $p < 0.05$ )

MP = Mpumalanga

FS = Free State

#### 4.1.4 Discussion of results

The six dry bean varieties (Jenny, Kranskop, PAN 148, AC Calmont, PAN 150 and Mkuzi) performed differently in terms of physicochemical and descriptive sensory attributes as well as consumer acceptance. The growing locations (MP and FS) also contributed to the variation found among the bean varieties.

The small sized beans (PAN 150 and Mkuzi) were among the least preferred varieties whereas the large seeded varieties (Jenny, Kranskop and PAN 148) were the most preferred during consumer testing. Although AC Calmont was large in size, consumers did not like it because of its hard cooked texture. Liebenberg *et al.* (2003) reported that small seeded varieties were discriminated against on the South African market. The question is why were these beans discriminated against? Berrios *et al.* (1999) found that small seeded beans did not hydrate after soaking for 24 h and took a long time to soften during cooking. In this study, all the bean varieties hydrated and swelled very well after 24 h of soaking, although there were variations among varieties when grown in the two locations. The high water absorption capacity could be due to the fact that beans after harvesting were well stored (temperatures lower than 30-40 °C and relative humidity less than 75%), thereby



maintaining their cooking quality (Aguilera & Stanley, 1985; Mc Watters, Chinnan, Worthington & Beauchat, 1987) Hydration and swelling capacities influenced cooking times in that all the beans that hydrated and swelled almost twice or more than their original mass, also cooked relatively fast (less than 60 min). The hydration capacity of Jenny (FS), PAN 148 (MP) and Mkuzi (MP) was less than most of the other varieties. The long cooking times of these beans could possibly be attributed to a slower rate of water absorption to the middle lamella of the cell walls limiting cell separation and softening during cooking (Wang *et al.*, 2003). The middle lamella of varieties that cooked in less than 60 min broke down more effectively as a result of high water absorption capacity, leading to cell separation during cooking (Wang *et al.*, 2003).

Seed size was not significantly related to cooking time because both small and large seeds either took long to cook or cooked fast. It is not known yet why Mkuzi beans from the two locations, which both hydrated and swelled well, had totally different cooking times ( $92.4 \pm 8.4$  min for Mkuzi-MP and Mkuzi-FS cooked in  $43.5 \pm 1.3$  min). It can only be assumed at this time, that differences in the agronomic conditions (such as temperature and rainfall pattern) of the two locations (Proctor & Watts, 1987a) might have contributed to the difference.

There is also a possibility that Mkuzi beans (MP) might have developed the hard-to-cook defect (Aguilera & Stanley, 1985; McWatters *et al.*, 1987) during storage before sample acquisition although the other bean varieties did not seem to be affected.

Long cooking times have also been associated with high amounts of insoluble dietary fibre (not measured here) that gives cells high resistance to disintegration during cooking (Vargas-Torres *et al.*, 2004). For the beans that cooked fast (less than 60 min) soluble hemicelluloses and the amorphous fraction of the cellulose might have influenced the breakdown of the seed coat structure (Casañas *et al.*, 2002), leading to softening of other cell constituents (e.g. the protein matrix) during cooking (Sefa-Dedeh *et al.*, 1979) and a soft textured well liked cooked product.

Apart from the assumption that poor storage conditions may contribute to bean hardening (Del Valle *et al.*, 1992), differences in growing locations (Proctor & Watts, 1987b) and varietal differences might have significantly influenced cooking times. This may be so because all beans supplied by the DPO in South Africa for this study were field dried although conditions may have varied.

It may also be suggested that other properties such as seed coat thickness, phytate and mineral composition (e.g. Ca and Mg content) of seed coat, may have influenced cooking times. During improper storage conditions phytic acid located in the protein bodies of the bean cotyledons, chelate divalent cations (e.g.  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ) (Hentges *et al.*, 1991; Aguilera & Stanley, 1985 & Mc Watters *et al.*, 1987). The bound cations may diffuse to the middle lamella forming insoluble pectic salts that may limit water absorption during hydration and cooking (Jones & Boulter, 1983). In addition, hardness was also associated with partial hydrolysis of phytate and deesterification of pectin during storage resulting in the formation of calcium magnesium pectate that forms a barrier to maximum water absorption during hydration and cooking. Hardened beans also tend to develop increased mechanical resistance to cellular swelling as a result of reduced water binding capacity of dissolved solutes (Del Valle *et al.*, 1992). During cooking, water uptake could also be affected by differences in the rate of starch gelatinisation, nature and amounts of non-starch constituents (such as protein) that may cause a barrier to swelling of starch granules (Deshpande & Cheryan, 1986) resulting into hard textured cooked beans.

As described by the descriptive sensory panel in this study, other factors leading to consumer discrimination of the small seeded varieties like PAN 150 and Mkuzi could be bitterness as well as metallic and soapy mouthfeel. Beans that were classified as bitter (PAN 150) had darker stripes. Bressani and Elias (1980) reported that dark coloured seeds e.g. bronze may have a higher content of phenolic compounds. Phenolic compounds in the seed coats such as condensed tannins (Guzmán-Madondo *et al.*, 1996) may contribute a bitter taste after cooking. Dehulling beans, discarding soaking water and cooking with fresh water have been reported to reduce the levels of phenolic compounds although some may still migrate from the seed coat to the cotyledons. The beans in this study had reddish stripes (Jenny, PAN148 and Kranskop), darkish stripes (PAN 150 and Mkuzi) and overall reddish colour (AC Calmont). They were cooked in their soaking water without removing the seed coats. Therefore it would be possible that the bitterness of PAN 150 beans could be attributed to the presence of phenolic compounds (tannins) in the seed coat.

The positive correlation found between splitting, thickness of broths and seed coat peeling was also reported for cowpeas (Taiwo *et al.*, 1997). The higher the number of splits during cooking, the thicker the broth, probably due to leaching of the bean contents into the cooking media. Beans that had a high number of splits also had a high amount of seed coat peeling. Splitting has been reported to increase with increased cooking time. The higher the number of split beans during cooking; the thicker the broth as was seen for PAN 150. PAN 150 (both locations) was one of the

varieties that cooked in less than 60 min (Mattson cooker). The cooking time used for descriptive sensory evaluation was 110 min, which might have been long for PAN 150 beans. This may in part explain why this variety had many split beans. The lower degree of splitting of AC Calmont (MP and FS) and Mkuzi (MP) may imply that they were not fully cooked (after 110 min) leading to incomplete breakdown of the middle lamella during cooking, causing resistance to cell disintegration. On the contrary, cooking for 110 min might have induced leaching of solutes from the cotyledon into the cooking media, of the short cooking time beans, thickening the broths (Jones & Boulter, 1983; Taiwo *et al.*, 1997). The decrease in mass due to the release of cell bound water and cell constituents as cooking progressed, probably contributed to thicker broths. Varieties with the most split beans were also soft and mushy and more acceptable. The thin broth, less split beans and hard texture of Mkuzi beans from MP, followed by AC Calmont (FS), Jenny (FS) and PAN 148 (MP) could be attributed to inhibited cell separation and subsequent lack of softening during cooking (Variano-Marston & De Omana, 1979). Other factors such as difference in physicochemical properties (e.g. starch and protein content) could also contribute to splitting of beans during cooking (Variano-Marston & De Omana, 1979). Starch gelatinises during cooking and starch gelatinisation is dependent on amylose and amylopectin ratios. Akinyele, Onigbinde, Hussain & Omololu (1986) reported a negative correlation between swelling capacity during cooking of cowpeas and amylose content. It is therefore assumed that lower amylose content (as opposed to high amylose content) may facilitate water absorption during cooking resulting into split, soft and mushy cooked beans. This was however not tested for.

The cooking time of 110 min was chosen during preliminary testing because the cooking times determined by the Mattson bean cooker, did not render the beans soft enough for consumer acceptability (assessed during preliminary testing). AC Calmont beans from both locations cooked in less than 60 min using a Mattson bean cooker. However during consumer testing, these beans were rated low as a result of hard texture. It may imply that the uniform cooking time did not soften some beans enough and a cooking time of more than 110 min was necessary to reach the softness preferred by consumers. The fact that the cooking times as determined by the Mattson bean cooker did not match consumer expectations of what is regarded as a cooked product could be attributed to the weight of the rods used in this study. The Mattson bean cooker had 90 g rods. Proctor & Watts (1987a) reported the use of 49.75 g rods for the Mattson cooker to determine the cooking time of beans that correlated with a product that was considered as cooked by a trained sensory panel.

Apart from the hard texture, AC Calmont (FS) and Mkuzi (MP) did not have strong cooked bean aroma. These varieties might have required long cooking times to ensure complete starch gelatinisation and protein denaturation (Sefa-Dedeh & Stanley, 1979b) to be necessary for the development of cooked bean flavours appreciated by consumers (Tharanathan & Mahadevamma, 2003). The distinctive differences in intensity of cooked bean aroma of Jenny and Mkuzi from the two locations need further investigation.

Mkuzi (MP) beans that had a hard texture were also described as relatively nutty while chewing. The hardness might be associated with beans that are not fully cooked. Such beans have an aromatic raw almond or legume-like character (Krinsky, 2005). Beans from FS were saltier than those from MP. This could be attributed to differences in the mineral profile (especially calcium and magnesium levels) of the soil of the two locations (Vargas-Torres *et al.*, 2004). Seed coat residues in the mouth were experienced in the hard textured beans, which could be attributed to tougher seed coats that take long to disintegrate during chewing.

Metallic and soapy feelings in the mouth were evident in PAN 150 beans. These attributes (metallic and soapy) were also positively correlated with bitterness. Apart from the assumption that Bressani and Elias (1980) made that dark coloured bean seeds might exhibit phenolic compounds in their seed coats that may contribute to bitterness, Yang and Lawless (2005) did a study on time-intensity characteristics of pure iron compounds using human subjects. It was reported that the presence of some iron compounds such as ferrous sulphate, ferrous chloride and ferrous gluconate, may also contribute significantly to bitter tastes and strong and persistent metallic flavours.

The Principal Component Analysis (PCA) summation of the physicochemical and sensory attributes results show PAN 150 from both locations and Mkuzi from MP separated from the other varieties cementing the possibility that these beans may be discriminated against by consumers on the market due to their unpopular flavours and hard textures. The bean varieties that were described by the descriptive sensory panel as sweet, having cooked bean flavours, and soft textures (Jenny-MP, Kranskop and PAN 148 (both locations) were the ones preferred by consumers. On the contrary, those varieties that were described as hard in texture, split and having raw bean flavours, bitter, soapy and metallic feeling in the mouth (Mkuzi-MP, AC Calmont-MP and FS PAN 150-MP and Jenny-FS) were the least preferred. Some of the lesser preferred varieties (e.g. Mkuzi MP and Jenny FS) required long cooking times due to limited water absorption during soaking and cooking.

#### **4.1.5 Conclusions**

Apart from small seed size, sensory characteristics such as bitter taste, soapy and metallic mouthfeel and hard texture may contribute to consumers' dislike of certain bean varieties.

Jenny (MP), Kranskop (MP and FS), and PAN 148 (MP and FS) beans were the most preferred by consumers because of their sweet taste, soft texture and cooked bean flavours. Some bean varieties (e.g. Jenny), when grown in different locations displayed different sensory properties (e.g. differences in cooking time, texture and cooked bean flavours), which influenced consumer acceptance. The 90 g rods of the Mattson bean cooker used in this study did not establish reliable cooking times for beans acceptable to consumers since it underestimated the cooking time.

Overall, varieties from Mpumalanga (Jenny, Kranskop and PAN 148) were the most preferred by consumers and producers should concentrate on bean varieties that have sensory properties similar to these for maximum consumer acceptability. It is recommended that the mineral profiles of the bean varieties be measured as well as determination of specific phenolic compounds known for causing bitterness or astringency. This would investigate possible associations of these compounds with bitterness, metallic tastes and soapiness of some beans.

#### **4.2 Consumer acceptance of designated bean varieties grown in Mpumalanga and Free State in South Africa**

##### **Abstract**

The main aim of this part of the study was to determine consumer acceptance of selected bean varieties (Jenny, Kranskop, PAN 148 and AC Calmont from Mpumalanga (MP) and Free State (FS); PAN 150 and Mkuzi from MP only). Acceptance of the cooked beans was evaluated using a 9-point hedonic rating scale with 1 denoting "I do not like it at all" and 9 denoting "I like it very much". Of the bean varieties tasted, consumers liked Jenny (MP), Kranskop (MP and FS) and PAN 148 (MP and FS) more than AC Calmont (MP and FS), PAN 150 (MP) and Mkuzi (MP). Consumers liked these beans because of their good flavour ("taste") and soft textures. Hardness and appearance of AC Calmont beans (MP and FS); flavour and hardness of PAN 150 beans (MP); flavour and appearance of Mkuzi (MP) and hardness of Jenny (FS) were the reasons for consumers disliking these beans. Sixty six percent (66%) of consumers indicated that they preferred brown coloured beans as opposed to other colours. The majority of consumers (46%) preferred medium sized beans and 31% did not mind about size.

Almost all consumers (97%) used electricity when cooking beans. Forty percent (40%) of consumers, 31% and 19 % reported cooking beans for more than 2h; 1 to 2 h and less than 1 h, respectively. Most consumers (68%) indicated good flavour as a reason for including beans in their diet whereas 22% indicated “affordability” as the main reason. Long cooking times and gas production (flatulence) were stated as the reasons why consumers did not eat beans often.

#### **4.2.1 Introduction**

Dry beans are one of the grain legumes that form part of the dietary pattern of low-income groups in most developing countries worldwide (Shimelis & Rakshit 2005). In Mexico, Central and South America, and most African countries, dry beans are used as a staple food (Berrios *et al.*, 1999). It is regarded as the poor man’s meat (Tharanathan & Mahadevamma, 2003) by some consumers.

Apart from the challenges of long cooking times of beans, several other factors such as appearance and flavour (“taste”) may also influence consumers when choosing beans for consumption. Shewfelt (1999) indicated that consumer satisfaction is normally based on product quality, which may be associated with absence of defects or degree of product excellence in terms of attributes such as sensory and other hidden factors (e.g. safety and nutrition). Sensory attributes such as visual appearance (Mukoko *et al.*, 1995; Liebenberg *et al.*, 2003; Bressani & Elias, 1980), flavour (Scott & Maiden, 1998) and textural properties (Sanzi Calvo & Attienza del Rey, 1999) present in a product, contribute significantly to choices consumers make for a particular product. For example, small seeded beans have been reported to perform poorly on the South African market (Liebenberg *et al.*, 2003). The question is; apart from the small seed size, what other factors contribute to dislike of certain bean varieties? Descriptive sensory evaluation by a trained panel (section 4.1) indicated that beans had a perceptible variation in size e.g. PAN 150 and Mkuzi (small seeds). However, differences in other sensations such as bitterness, soapiness and metallic flavour were observed, which could possibly contribute to lower acceptance of some beans on the market. Therefore the aim of this phase of the project was to determine the acceptability of selected cooked bean varieties with different sensory profiles. Questions related to bean preparation preferences and consumer behaviour in terms of bean consumption, were also included. These questions aimed at finding out consumer preferences in terms of seed colour, seed size, energy source used for cooking, cooking time and the reasons why they include/exclude beans in their diet. Information on age and educational background of consumers is shown in Table 4.2.1.

## 4.2.2 Materials and methods

The beans were supplied by the Dry Bean Producers Organization (DPO) in Pretoria, South Africa. The 6 varieties provided were: Jenny, Kranskop PAN 148 AC Calmont from Mpumalanga (MP) and Free State (FS), PAN 150 and Mkuzi from MP only. Upon acquisition, the beans were sorted of trash and broken seeds and stored at 4° C.

### 4.2.2.1 The consumer test and location

The consumer test was conducted on 8 and 9 November 2005. One hundred consumers were recruited from the University of Pretoria comprising of students and employees. The potential consumers were selected if they indicated that they ate beans at least once a week. Sample preparation and presentation was as described previously (4.1.2.3). The composition of the consumers was as shown in Table 4.2.1.

**Table 4.2.1 Gender, age and level of schooling of consumers that participated in the first and second day of bean evaluation**

<b>Description</b>	<b>First day <i>n=50</i></b>	<b>Second day <i>n=50</i></b>	<b>Total no. of consumers <i>n=100</i></b>
Gender : Males	38%	58%	48%
Females	62%	42%	52%
<b>Age(years)</b>			
18 to 20	30%	36%	33%
21 to 30	54%	46%	50%
31 to 40	14%	12%	13%
More than 40	2%	6%	4%
<b>Level of schooling:</b>			
Up to Matriculation	42%	52%	47%
Diploma/Degree	58%	48%	53%

Tasting was done in a sensory laboratory with 16 booths. Each consumer was seated in an individual booth with no distraction (Figure 4.2.1) during the tasting period. Four sessions were scheduled for each day. Each consumer was rewarded with a can of soft drink, a bar of chocolate and a packet of potato chips for participating in the project.





**Figure 4.2.1 Consumers seated in individual booths during tasting of beans**

#### **4.2.2.2 The questionnaire**

The questionnaire (Figure 4.2.2) was formulated in a way that each consumer could understand even if the level of literacy was low. Consumers answered the questions by entering responses on computers using Compusense Five® release 4.6 (Compusense Inc., Guelph, ON, Canada). A 9-point hedonic rating scale was used to evaluate the samples. Depending on the rating given (low, medium or high), different follow up questions appeared to probe the reasons for consumers' selection. Figure 4.2.2 illustrates how the questionnaire was designed in terms of introduction, instructions and the questions.

#### **4.2.3 Statistical analysis**

The effect of sample on hedonic ratings were analysed using a generalized linear model two-way analysis of variance (ANOVA) with samples treated as fixed and consumers as random independent effects. Fischer's least significant difference (LSD) test at 5 % level (Statistica version 7.1 Stat Soft, Inc) was used to indicate different means.

Individual histograms of consumer ratings for each bean variety were created. Consumer preference was regarded as low if the rating was from 1 to 3, medium if the rating was from 4 to 6 and high if the rating was from 7 to 9. The % distributions of consumers that selected different reasons for each level of acceptability for a particular bean variety were also calculated.



The % frequencies for selecting different categories in terms of preferred bean colour, bean seed size, length of cooking time, source of energy used, reason for inclusion of beans in the diet and reason for not including beans in the diet, were calculated and plotted.

#### **4.2.4 Results and Discussion**

There was a significant difference in consumer acceptance of the different beans. On a 9-point hedonic rating scale (1 = I do not like it at all; 9 = I like it very much), samples that were rated towards 9 (e.g. Jenny MP, Kranskop MP and FS) were the most preferred and those that were rated towards 1 (e.g. Mkuzi MP and AC Calmont FS) were the least preferred (Figure 4.1.3).

Figures 4.2.3 to 4.2.12 display, for each bean variety, the number of consumers that rated the beans as low, medium or of high acceptance. The figures are presented in order from highest to lowest preference according to Figure 4.1.3.

For variety Jenny (MP) (Figure 4.2.3), the majority of consumers indicated that they liked the beans very much and attributed these opinions to softness and flavour/ “taste” of these beans. The same reasons applied for the majority of consumers, who liked Kranskop (MP) beans (Figure 4.2.4). The most popular reason was taste and then softness. Figure 4.2.5 shows how PAN 148 (MP) fared in terms of consumer acceptance. Unlike Jenny (MP) and Kranskop (MP), approximately equal numbers of consumers rated PAN 148 (MP) beans between 4 and 6, and 7 and 9, respectively. The flavour/ “taste”, softness and appearance of this variety were mostly provided as reasons for the positive opinions regarding this variety. The same trend also applied to Kranskop (FS) (Figure 4.2.6) and PAN 148 (FS) (Figure 4.2.7), where most consumers, to some extent, liked these beans because of flavour/ “taste”, softness and also appearance.

**Introduction**

**Hello, my name is Alice Mkanda**

**I am doing research on the eating quality of beans.**

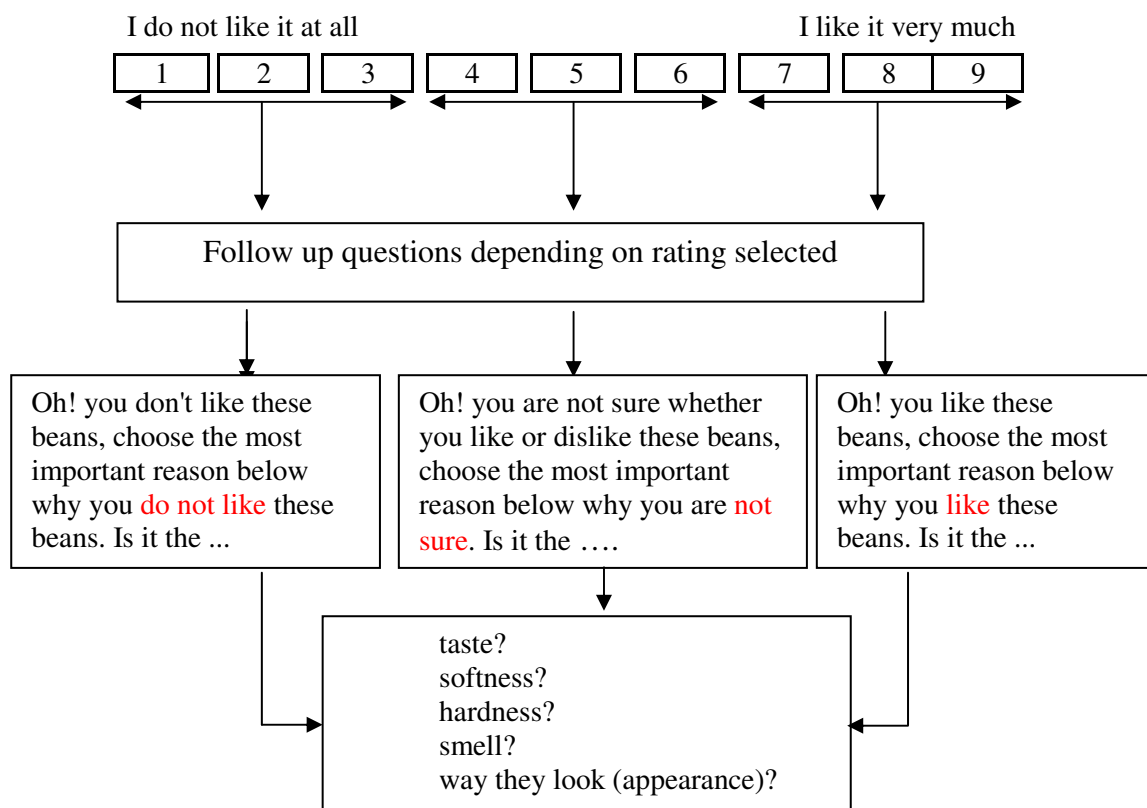
**I will appreciate your help to tell me how much you like to eat different types of beans.**

**You have received five bowls of beans.**

**Please taste the beans in the order presented from left to right.**

**Remember to take a sip of water before and in between tasting each bowl of beans.**

1. Please mark a number (1 to 9) to show how much you like this bowl of beans?



After answering question1 for each of the five samples, the following questions appeared.

**2. What colour of beans do you prefer to buy? Choose only one**

Beans with stripes

Red

White

Brown

Other

**Figure 4.2.2 The structure of the questions answered by consumers when tasting the cooked beans**

**3. What size of beans do you prefer to buy? Choose only one.**

Small size

Medium Size

Large size

The size does not matter

**4. How long do you normally cook beans in your home?**

Less than 1 hour

Between 1 and 2 hours

More than 2 hours

**5. What source of energy do you normally use for cooking beans at home?**

Electricity

Paraffin stove?

Charcoal stove?

**6. What, in your opinion, is the most important reason why you include beans in your meals?**

It is cheap

It is easy to prepare

It tastes very good

It is easy to store without a refrigerator

**7. What, in your opinion, is the most important reason why some people do not like beans?**

It takes too long to cook

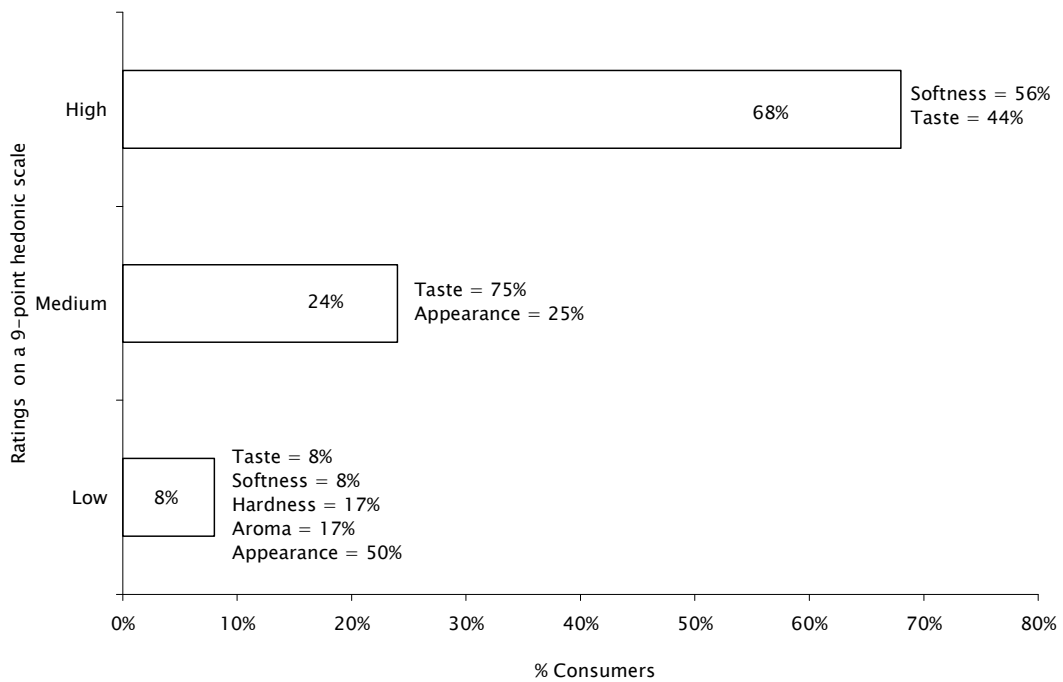
It causes heart burn

It causes gas

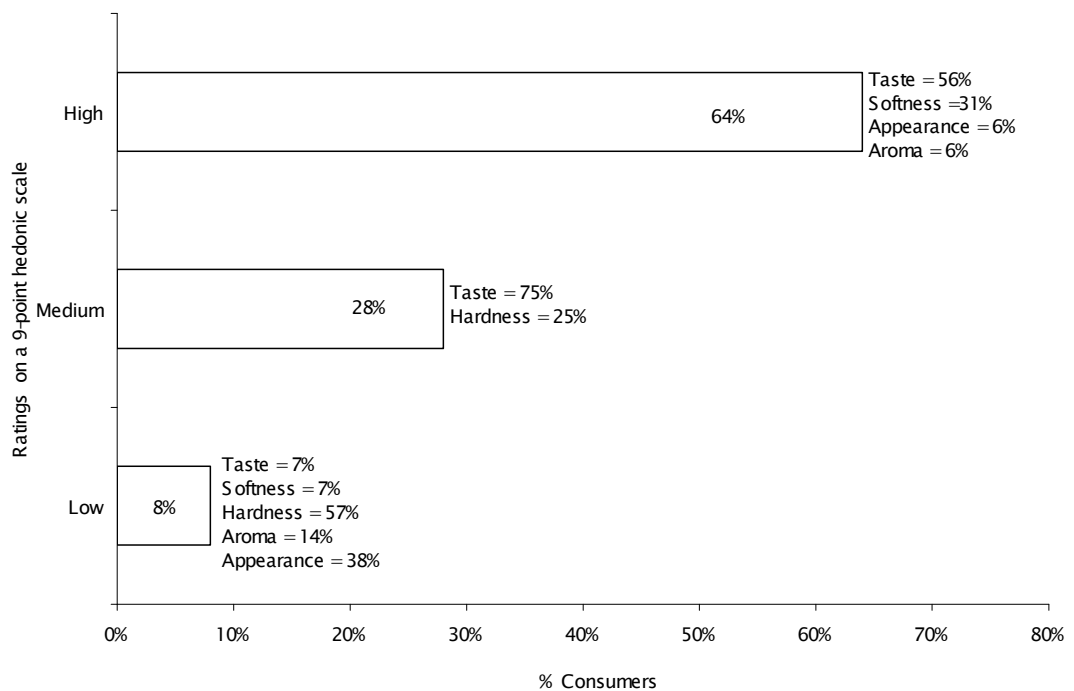
It tastes bad

It is a poor man's food

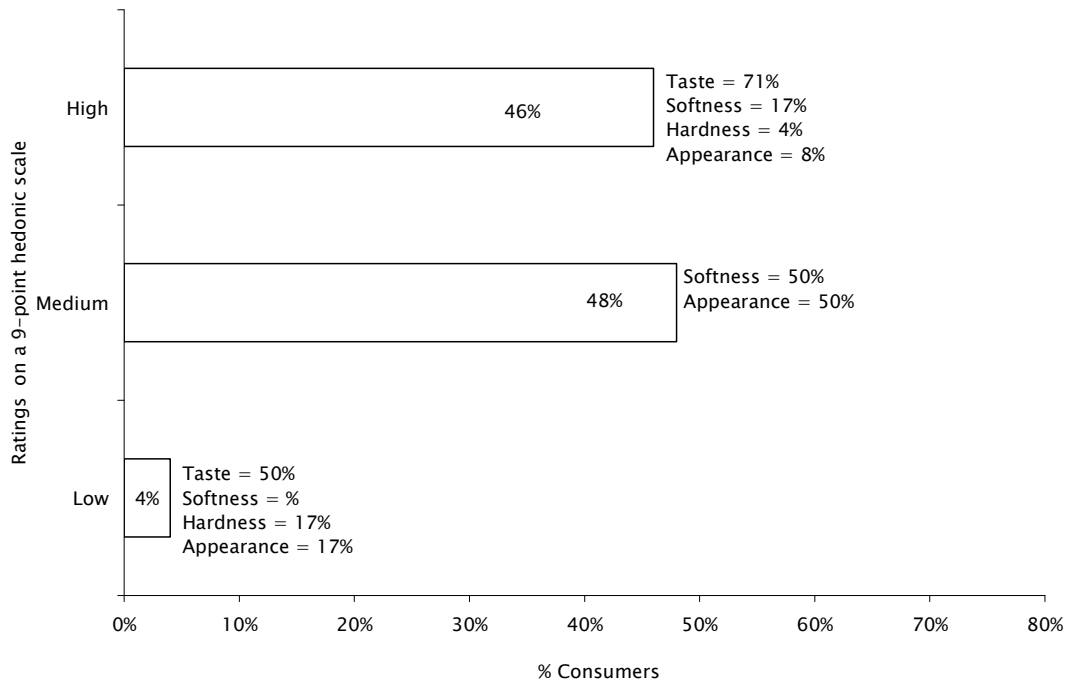
**Figure 4.2.2 The structure of the questions answered by consumers when tasting the cooked beans (continued)**



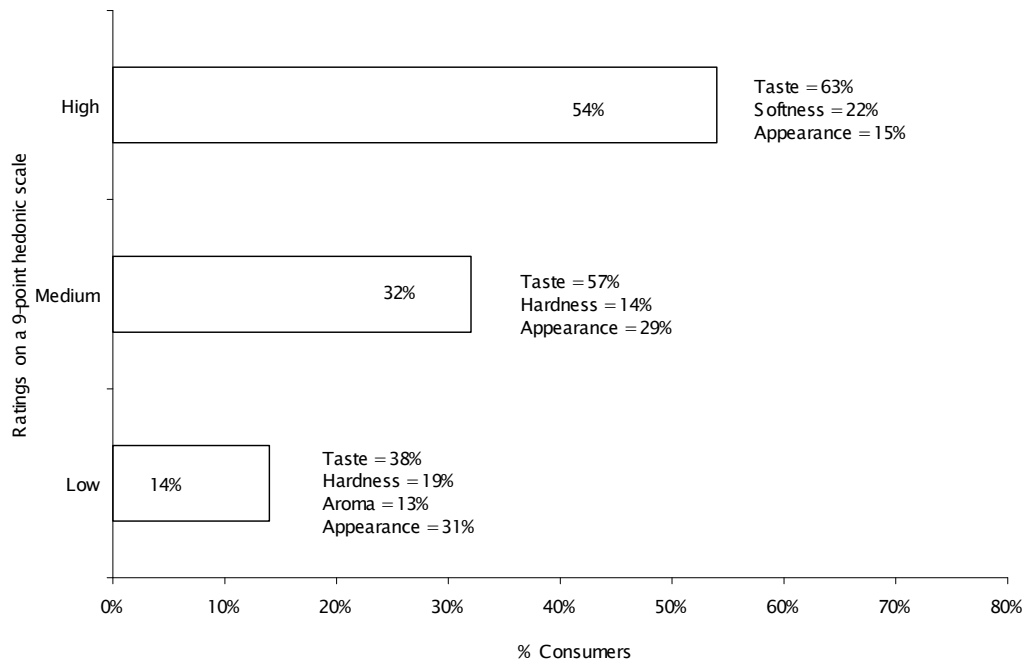
**Figure 4.2.3 Consumer acceptance ( $n=50$ ) of variety Jenny beans (MP) and the distribution (%) of reported reasons provided to explain the ratings selected**  
**Low = selection of 1-3; Medium = selection of 4-6; High = selection of 7-9 on a 9-point hedonic scale where 1 = I do not like it at all and 9 = I like it very much**



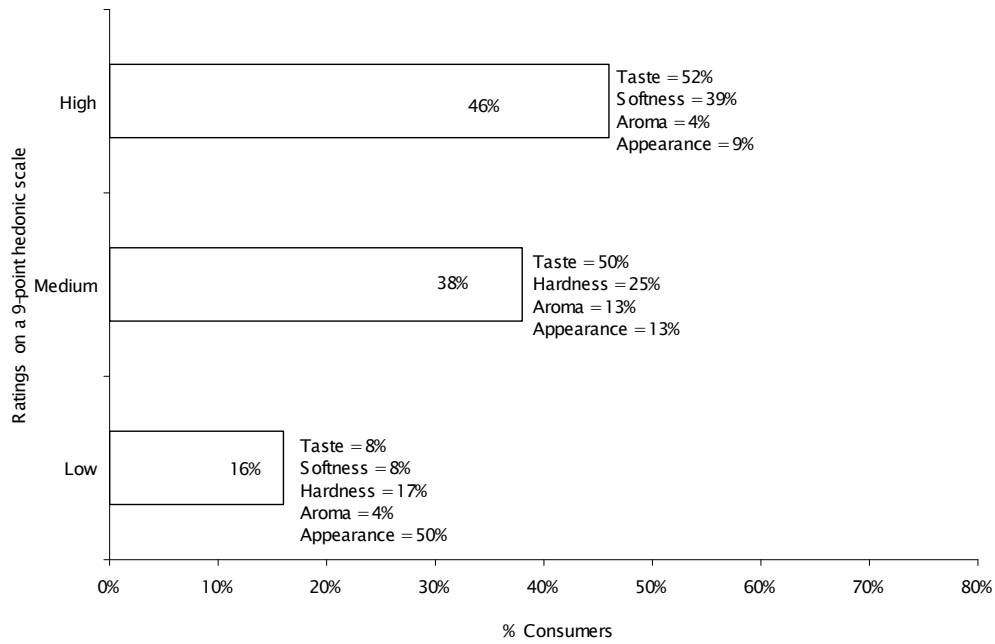
**Figure 4.2.4 Consumer acceptability of variety Kranskop (MP) and the distribution (%) of reported reasons provided to explain the ratings selected**  
**Low = selection of 1-3; Medium = selection of 4-6; High = selection of 7-9 on a 9-point hedonic scale where 1 = I do not like it at all and 9 = I like it very much**



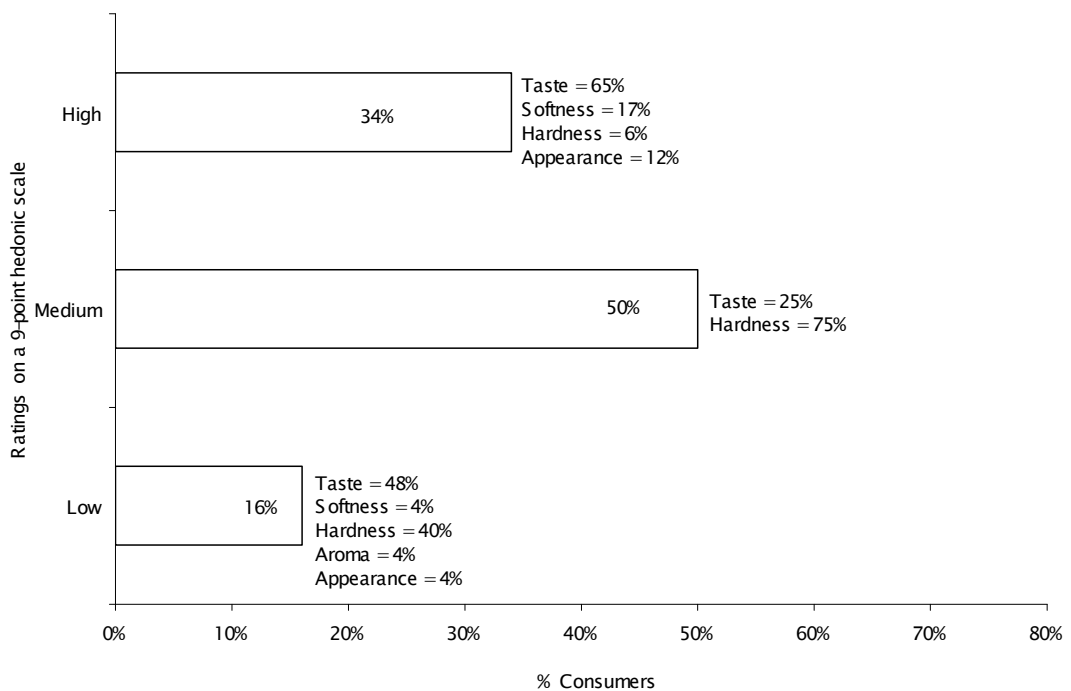
**Figure 4.2.5 Consumer acceptability of variety PAN 148 (MP) and the distribution (%) of reported reasons provided to explain the ratings selected**  
**Low = selection of 1-3; Medium = selection of 4-6; High = selection of 7-9 on a 9-point hedonic scale where 1 = I do not like it at all and 9 = I like it very much**



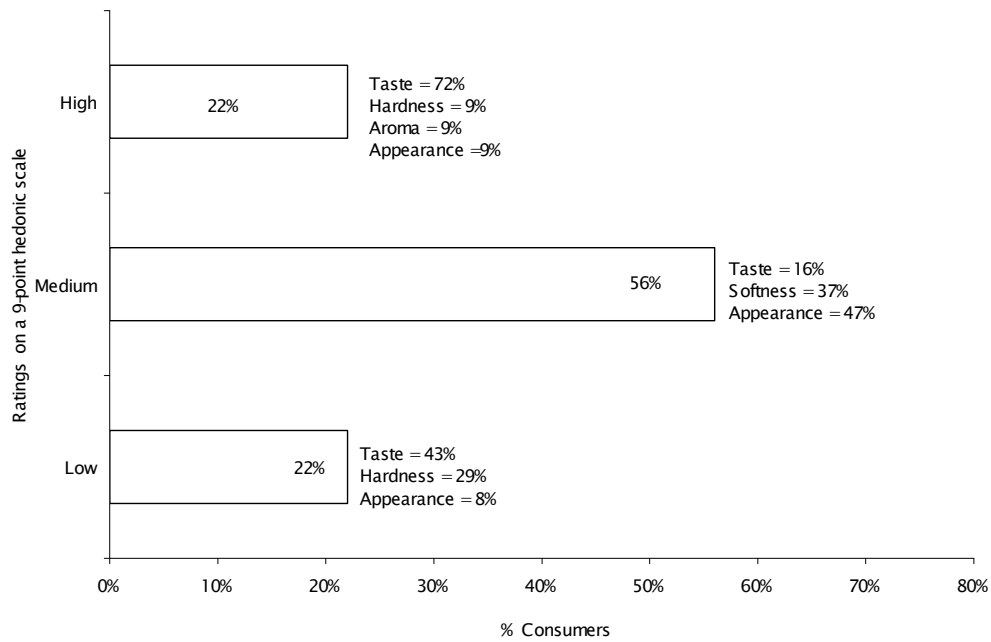
**Figure 4.2.6 Consumer acceptability of variety Kranskop (FS) and the distribution (%) of reported reasons provided to explain the ratings selected**  
**Low = selection of 1-3; Medium = selection of 4-6; High = selection of 7-9 on a 9-point hedonic scale where 1 = I do not like it at all and 9 = I like it very much**



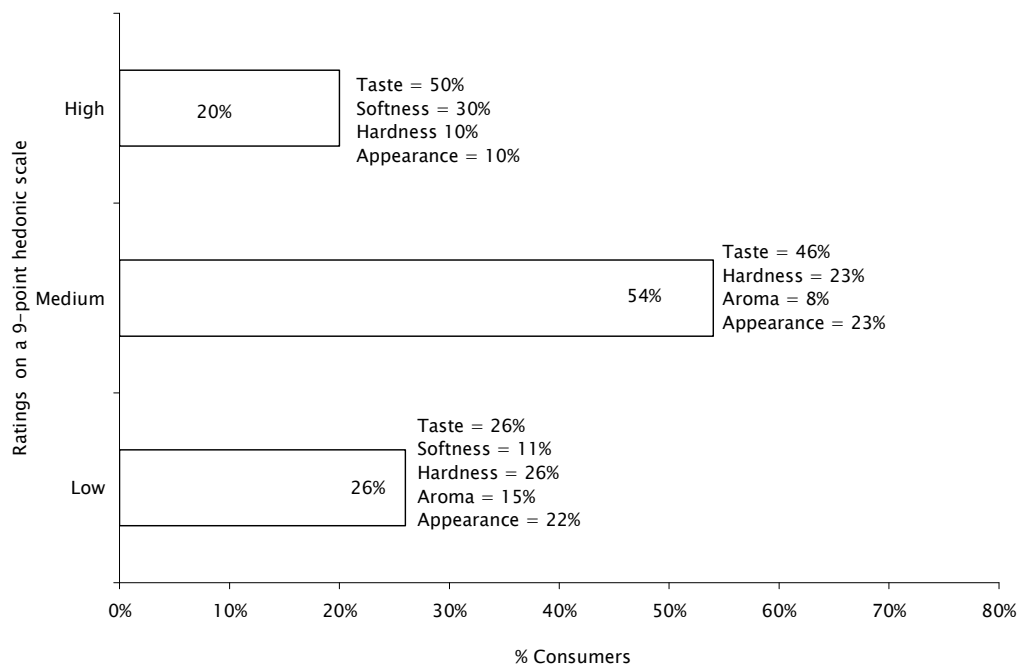
**Figure 4.2.7 Consumer acceptability of variety PAN 148 (FS) and the distribution (%) of reported reasons provided to explain the ratings selected**  
**Low = selection of 1-3; Medium = selection of 4-6; High = selection of 7-9 on a 9-point hedonic scale where 1 = I do not like it at all and 9 = I like it very much**



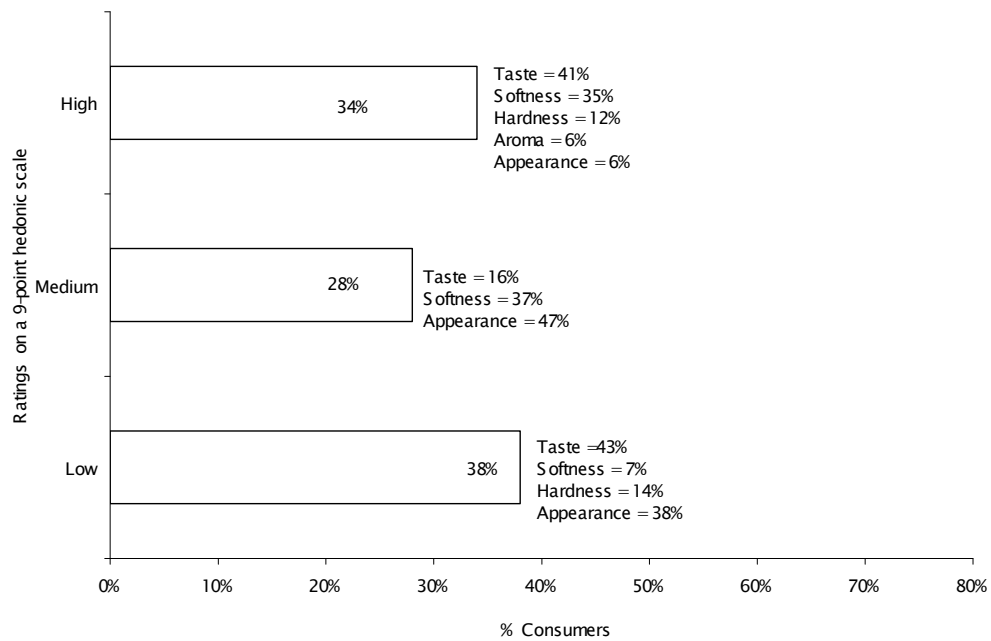
**Figure 4.2.8 Consumer acceptability of variety Jenny (FS) and the distribution (%) of reported reasons provided to explain the ratings selected**  
**Low = selection of 1-3; Medium = selection of 4-6; High = selection of 7-9 on a 9-point hedonic scale where 1 = I do not like it at all and 9 = I like it very much**



**Figure 4.2.9 Consumer acceptability of variety AC Calmont (MP) and the distribution (%) of reported reasons provided to explain the ratings selected**  
**Low = selection of 1-3; Medium = selection of 4-6; High = selection of 7-9 on a 9-point hedonic scale where 1 = I do not like it at all and 9 = I like it very much**

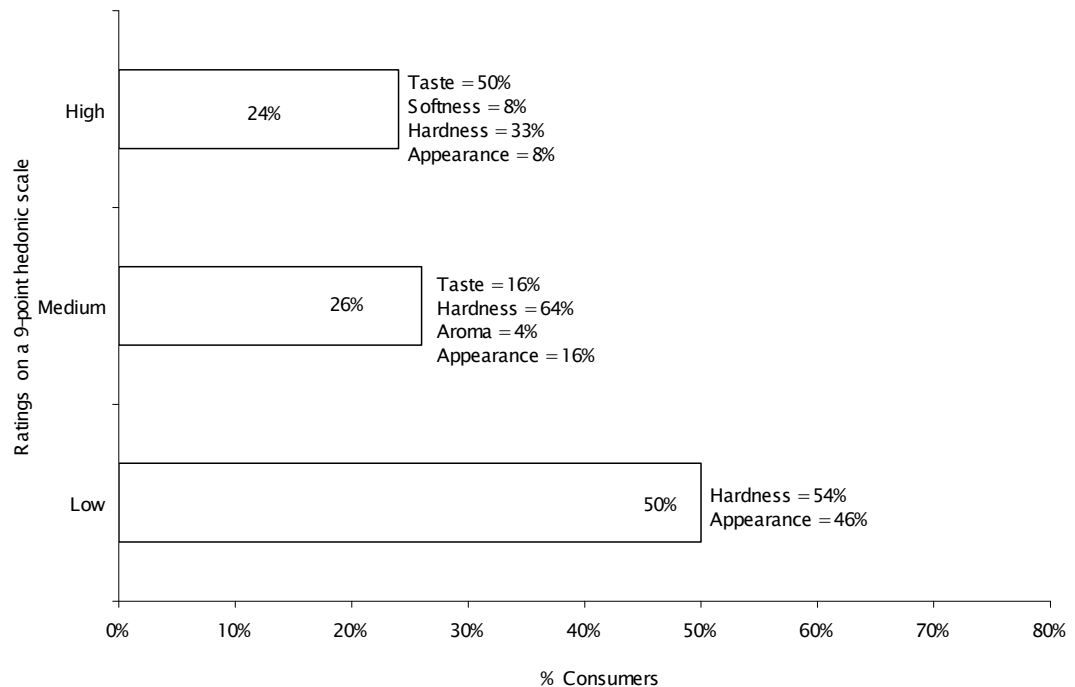


**Figure 4.2.10 Consumer acceptability of variety PAN 150 (MP) and the distribution (%) of reported reasons provided to explain the ratings selected**  
**Low = selection of 1-3; Medium = selection of 4-6; High = selection of 7-9 on a 9-point hedonic scale where 1 = I do not like it at all and 9 = I like it very much**



**Figure 4.2.11 Consumer acceptability of variety AC Calmont (FS) and the distribution (%) of reported reasons provided to explain the ratings selected**

**Low = selection of 1-3; Medium = selection of 4-6; High = selection of 7-9 on a 9-point hedonic scale where 1 = I do not like it at all and 9 = I like it very much**



**Figure 4.2.12 Consumer acceptability of variety Mkuzi (MP) and the distribution (%) of reported reasons provided to explain the ratings selected**

**Low = selection of 1-3; Medium = selection of 4-6; High = selection of 7-9 on a 9-point hedonic scale where 1 = I do not like it at all and 9 = I like it very much**



The less preferred varieties were Jenny (FS) (Figure 4.2.8), AC Calmont (MP) (Figure 4.2.9), PAN 150 (MP) (Figure 4.2.10), AC Calmont (FS) (Figure 4.2.11) and Mkuzi (MP) (Figure 4.2.12). These beans were rated below 7 on a 9-point hedonic scale by more than 60% of the consumers. For Jenny (FS) (Figure 4.2.8), the majority of consumers rated the beans medium implying that they neither liked nor disliked them. The neutral responses were attributed mostly to hardness and flavour (“taste”). The same trend applied to AC Calmont (MP) beans (Figure 4.2.9) where the majority of consumers rated the beans 4 to 6. The same reasons as for Jenny (FS) were applied for the medium rating of AC Calmont beans with the addition of appearance as another reason. PAN 150 (MP) beans (Figure 4.2.10) followed the same trend as Jenny (FS) and AC Calmont (MP) beans as the majority of consumers also rated these beans medium. Apart from hardness, flavour and appearance as well as aroma were cited as reasons for rating these beans medium. AC Calmont (FS) beans (Figure 4.2.11) showed an almost equal distribution of consumer responses (low rating-38%, medium rating-28% and high rating-34%). However, the highest percentage of consumers did not like these beans. The main reasons for the dislike were flavour (“taste”), appearance and hardness. Of all the beans included in this study, Mkuzi (MP) was not liked at all by at least half of consumers (Figure 4.2.12). There were only two reasons namely, hardness and appearance, explaining these opinions.

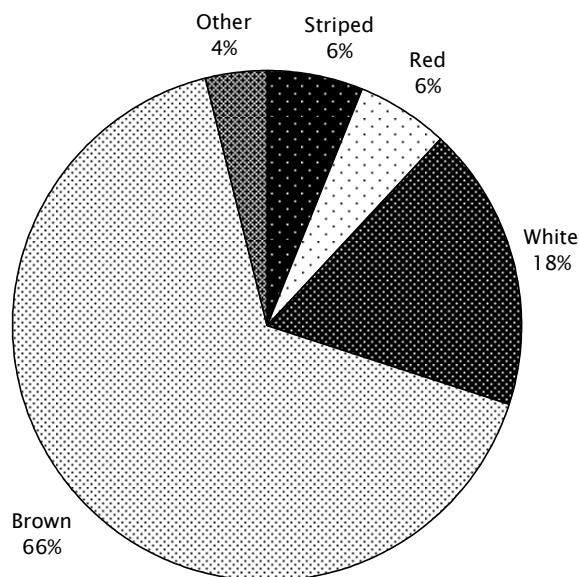
During descriptive sensory analysis of the beans (Section 4.1.3.2), Jenny-MP, Kranskop and PAN 148 (both locations) beans were described as sweet, having cooked bean flavours, and soft textures. These were the varieties consumers also preferred the most. As seen in Figures 4.2.3 to 4.2.7, the major reasons for consumers’ preferences for these beans were related to softness and flavour (“taste”). Cooked bean softness was considered as one of the driving factors for consumer preference (Tharanathan & Mahadevamma, 2003). During the determination of cooking time (using a Mattson bean cooker) it was shown that these beans also required shorter cooking times. Soft textures of cooked beans could be an indication that these beans maintained their quality under storage (Aguilera & Stanley, 1985). When beans are stored properly after harvest, they also cook fast because of free water movement within the beans during soaking and cooking. As pointed out by AGSI/FAO (2004), some beans have tough seed coats that offer resistance to water absorption during soaking and cooking thereby resulting in hard textured cooked beans. This implies that flexible seed coats admit water freely to/through the cotyledon cells during soaking and cooking resulting in soft textures. Apart from soft textures, Martin-Cabrejas, Esteban, Perez, Maina & Waldron (1997) reported that fast cooking beans also have good cooked aroma and flavour. Good flavours probably mean fully developed bean flavour and relative sweetness.

For the less preferred beans (Jenny FS, AC Calmont MP and FS, PAN 150 MP and Mkuzi MP) hardness, appearance and flavour dominated the consumers' reasons for their negative opinions. These same varieties were described as hard in texture, and having raw bean flavours, nuttiness, bitter, soapy and metallic feeling in the mouth during descriptive sensory analysis of the beans (Section 4.1.3.2). Sometimes beans develop what Stanley (1992) referred to as "hard shell", which comes about as a result of storing beans under harsh environment (warm temperatures and high relative humidity). When these beans are cooked they have hard cooked textures. This could be a possible explanation for the beans that received lower acceptance ratings. The South African Weather Bureau records of temperatures and relative humidity in the two locations (MP and FS), over the time period when beans were stored at farms on pallets before acquiring them, showed substantial variations. Maximum day time temperatures in these areas varied between 30° and 40 °C whereas relative humidity ranged between 60 to 100%. Therefore these conditions could not rule out the possibility of some beans being hardened. Aguilera & Stanley (1985) and Jones & Boulter (1983) have shown that during poor storage conditions of high temperatures and high relative humidity (between 30° and 40 °C and relative humidity of >75%), beans tend to harden due to (among others) lignification of the middle lamella. The process of lignification occurs because of oxidation and polymerisation of the polyphenolic compounds in the presence of cell wall bound peroxidase. Bressani & Elias (1980) also reported that hard textured beans were less acceptable to consumers due to high costs of preparation, changes in flavour, colour and reduced nutritive value. The disliked flavours and hard textures led to consumers' disliking these beans.

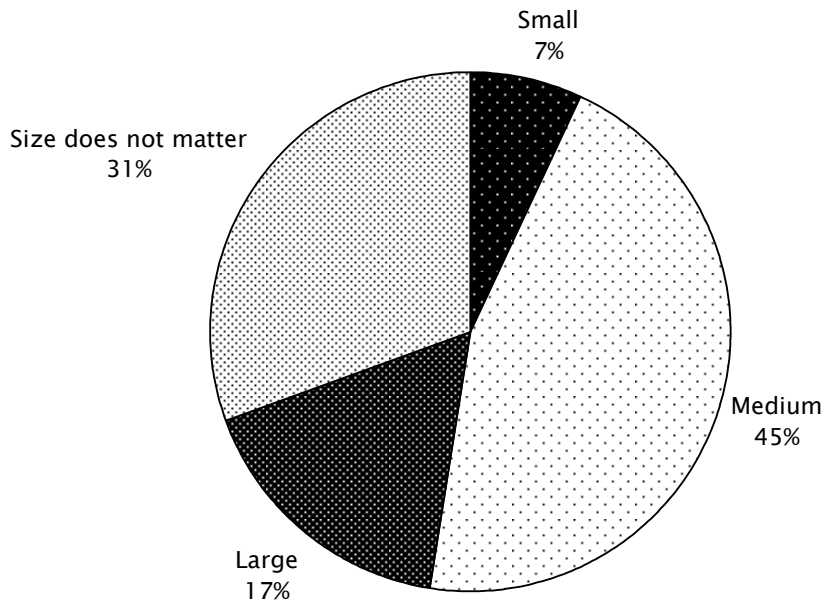
For the AC Calmont (MP and FS) beans, there were different consumer opinions in that those who rated these beans medium or low indicated appearance and taste as the reasons for ratings. These beans were reddish in colour. Some studies (Bressani & Elias, 1980) have shown that many consumers prefer light coloured seeds compared to dark coloured seeds. Light coloured beans seem to have a bland (not strong) flavour compared to dark coloured beans (black, red and bronze seed coats), which have been reported to contain considerable amounts of polyphenols (Bressani & Elias, 1980), which may lead to intense flavours and bitterness. The dislike of appearance in terms of colour for AC Calmont may be subject to consumer preferences depending on how the beans are utilised in meals. For example, some consumers prefer the reddish colour of AC Calmont because it adds colour to salads (Liebenberg *et al.*, 2003). Consumers indicated flavour, hardness and appearance, as the major reasons for disliking some beans varieties. These responses would be related to hard textures (due to undercooking or bean hardening), bitterness, soapiness

and metallic mouthfeels (as described by the descriptive sensory panel). The differences in appearance attributes of the beans can be noted in Figure 2.4.

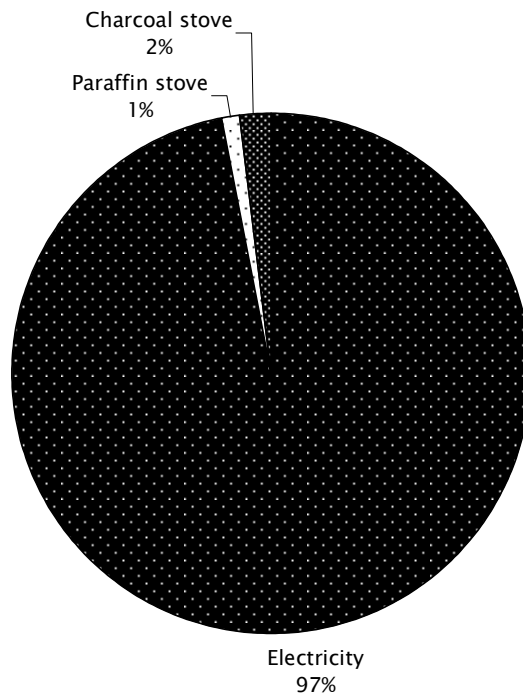
Results of the general questions regarding bean preparation and consumer behaviour in terms of consumption of beans are presented in Figure 4.2.13 to 4.2.18. For colour (Figure 4.2.13), the majority of consumers preferred brown beans compared to striped, red, white and other bean colours. However, these consumers evaluated cooked beans only. Therefore, most striped beans as were included in the study do not remain striped when soaked and cooked; they normally turn brown due to the Maillard reactions that take place during cooking. In terms of bean size (Figure 4.2.14) most consumers preferred medium sized beans followed by those who indicated that size did not matter. Almost all consumers (Figure 4.2.15) used electricity as a source of energy for cooking beans. Although beans have been associated with long cooking times, the majority of consumers (Figure 4.2.16) cooked beans for more than 1h time periods.



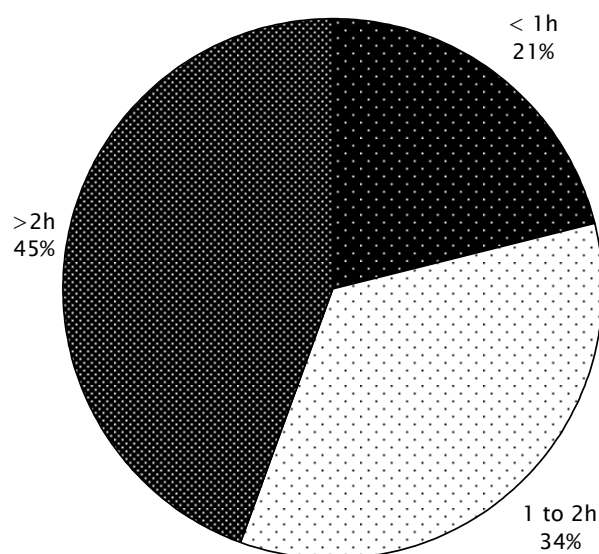
**Figure 4.2.13 Distribution % of consumers' responses ( $n = 100$ ) regarding preference for bean colour**



**Figure 4.2.14 Distribution % of consumers' responses ( $n = 100$ ) regarding preference for bean seed size**



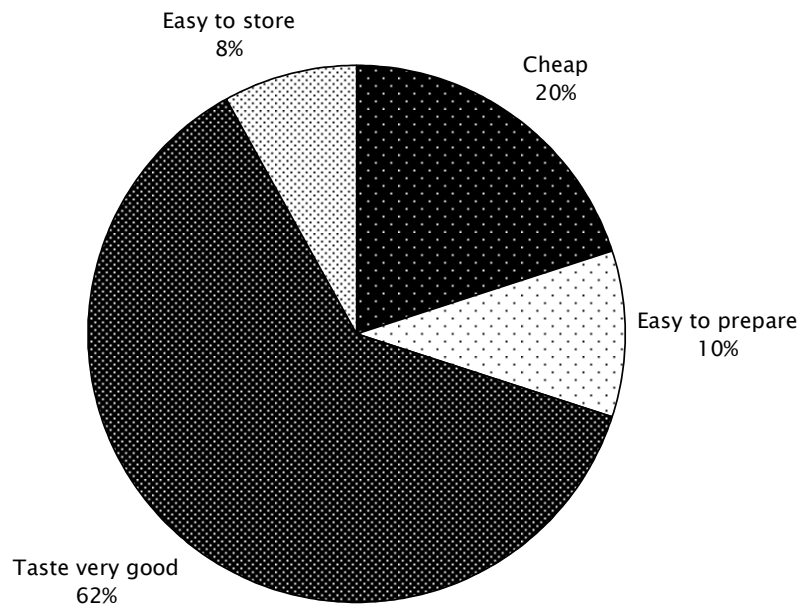
**Figure 4.2.15 Distribution % of consumers' responses ( $n = 100$ ) regarding source of energy used for cooking beans**



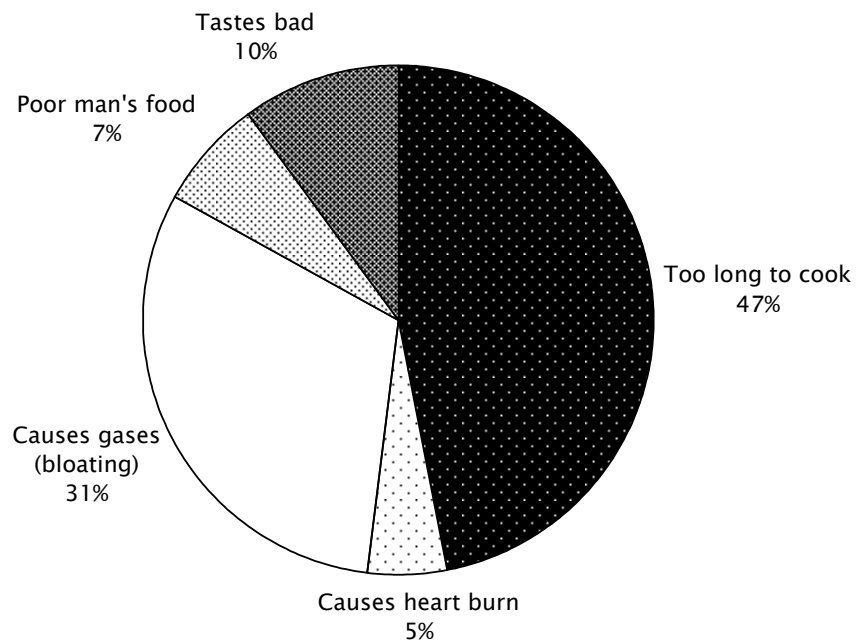
**Figure 4.2.16 Distribution % of consumers' responses ( $n = 100$ ) regarding how long it generally takes them to cook beans**

Cooking beans for longer than 120 min may explain why consumers reported that some of the beans (e.g. AC Calmont MP and FS) were still hard and with raw bean flavours after cooking for 110 min (time used for preparing these samples). Seed size did not seem to influence consumer preference as most consumers (31%) (4.2.14) indicated that size did not matter.

The consumers indicated that they included beans in their diet, mostly because of good flavour while some indicated affordability as a reason (Figure 4.2.17). When compared to other sources of protein e.g. meat (Van Heerden & Schönfeldt, 2004) beans are reasonably cheap (Perla *et al.*, 2003), and easy to store with a longer shelf life than most fruits, vegetables and animal products (Sathe & Deshpande 2003). On the contrary some of the reasons for not including beans in the diet were long cooking times, which is expensive both in terms of energy and time for preparation. The risk of flatulence (gas production) (Figure 4.2.18) was also one reason consumers indicated for not including beans in the diet.



**Figure 4.2.17 Distribution % of consumers' responses ( $n = 100$ ) regarding why they include beans in their diet**



**Figure 4.2.18 Distribution % of consumers' responses ( $n = 100$ ) regarding why other consumers do not include beans in their diet**

#### **4.2.5. Conclusions**

The main factors that contributed to consumer liking of Jenny (MP), Kranskop and PAN148 beans from both MP and FS were good flavour and soft textures. The bean varieties that consumers liked less were Jenny (FS), AC Calmont (MP) PAN 150 (MP) AC Calmont (FS) and Mkuzi (MP). The main reasons for this disliking were undesirable flavours probably due to chemical composition of the beans; hard textures probably due to possible bean hardening or undercooking and appearance probably in terms of cooked colour, splitting or intact (non-splitting).

With the aid of the descriptive sensory analysis of these same bean varieties it was found that sweetness, cooked bean aroma and flavour equals “good flavour”. Disliked bean varieties were characterised as hard, undesirable in terms of flavour, which may be associated with what the descriptive panel described as uncooked bean flavour, bitter taste, soapy and metallic mouthfeels.

Overall, varieties from Mpumalanga (Jenny, Kranskop and PAN 148) were the most preferred by consumers and it is recommended that producers should concentrate on bean varieties that have sensory properties similar to these for maximum consumer acceptability. Most consumers prefer brown coloured beans, irrespective of seed size. The major source of energy used was electricity and most of them cook beans for more than 2h. Good taste was the driving factor for including beans and long cooking time for not including beans in the diet.

### **4.3 The total polyphenol content and mineral profiles of some dry bean varieties grown in Mpumalanga and Free State in South Africa**

#### **Abstract**

The aim of this phase was to determine total polyphenol content in PAN 150 beans from Mpumalanga (MP) location because these beans were described as bitter using descriptive sensory evaluation. For comparison, two other non-bitter bean samples (AC Calmont and Jenny beans also from MP) were also analysed for total polyphenol content. Results showed that AC Calmont, which did not taste bitter, had higher total polyphenol content than Jenny and PAN 150 (MP) beans. This suggests that factors other than total polyphenol content caused the bitterness of PAN 150 (MP) beans. Further investigation was done by determining the mineral profile in whole bean flour for all six bean samples (Jenny, Kranskop, PAN 148, AC Calmont, PAN 150 and Mkuzi)

from the two locations (MP and FS). The aim was to find out whether differences in mineral content e.g. Fe, contributed to bitterness and metallic mouthfeel of certain beans.

Results showed significant ( $p < 0.05$ ) differences for P and Mn content only. Fe and Cu content did not contribute to bitterness or metallic mouthfeel of PAN 150 beans. Further investigations were recommended to determine the causes of bitterness and soapy mouthfeel of some bean varieties.

#### 4.3.1 Introduction

Descriptive sensory evaluation was conducted on six dry bean varieties (Jenny, Kranskop, PAN 148, AC Calmont, PAN 150 and Mkuzi) grown in two locations (MP and FS) of South Africa. Of the terms used to describe the bean varieties, bitter taste as well as soapy and metallic mouthfeel was identified for PAN 150 beans. In addition Mkuzi beans were also described as having a soapy mouthfeel. The other bean varieties were characterized as having sweet, nutty, raw bean and cooked bean flavours.

In general, legume seeds have been reported to contain appreciable amounts of polyphenols (Bressani & Ellias, 1980; Guzmán-Maldonado *et al.*, 1996; Troszyńska, Amarowicz, Lamparski, Wołejczo & Baryłko-Pikielna, 2006). Polyphenols have been associated with bitter taste in food. Apart from bitterness, Troszyńska *et al.* (2006) also reported astringency (described as a dry or rough sensation in the mouth), due to the presence of condensed tannins. Major amounts of phenolic compounds are located in bean seed coats, representing 11% of the total seed weight, with low or negligible amounts in the bean cotyledons (González de Mejía, Castaño-Tostado & Loarca-Piña, 1999). The most commonly found polyphenols in beans are condensed tannins (Guzmán-Maldonado *et al.*, 1996). The seed coat colour of beans (coloured or plain white) may be related to the amounts of condensed tannins in the seed coat. Major amounts of tannins (accounting up to 2 % of the total seed weight) were found in coloured bean seed coats (red, black or bronze) compared to none in white bean varieties.

Beans have been reported to provide a good source of minerals and vitamins in the diet (Kutoš *et al.*, 2002). Some minerals such as iron salts have also been reported to cause metallic, bitter and astringent sensations in model water solutions (Yang & Lawless, 2006). Bitterness and astringency have been associated with the presence of polyphenols in beans. The aim of this phase was to determine the total polyphenol content in PAN 150 from MP location (along with non bitter bean samples: AC Calmont and Jenny also from MP) as these beans were described as bitter by the



descriptive sensory panel. Another aim was also to determine the mineral profile of all the 6 bean varieties (in the whole bean flour) from MP and FS to find out whether differences in mineral content contributed to bitterness and metallic mouthfeel of the beans.

#### **4.3.2 Materials and methods**

Three MP varieties (PAN 150, AC Calmont and Jenny) were included in the total polyphenol content determination. These varieties had different seed coat colours; Jenny, a light red speckled bean; AC Calmont, a plain dark red bean and PAN 150, a dark greyish speckled bean. PAN 150 beans, in particular, had a bitter taste, soapy and metallic mouthfeel. For mineral profile determination, all six bean varieties (Jenny, Kranskop, PAN 148, AC Calmont, PAN 150 and Mkuzi) provided by Dry bean Producers Organization (DPO) in Pretoria (South Africa), were analyzed. The beans were harvested in 2004 and stored on pallets in farm grain stores in 50 kg polypropylene bags for a few months. After acquisition, samples were sorted of chuff, broken and shriveled seeds and then stored at 4° C. Whole bean seeds were ground into flour with a Falling Number mill 3100 (Huddinge, Sweden), stored at 4° C before determination of total polyphenol content the following day.

##### **4.3.2.1 Total polyphenol content determination**

The Folin-Ciocalteu method (Singleton & Rossi, 1965) as described by Waterman & Mole (1994) was used for determination of total polyphenol content of legumes in this study. The method is based on the reducing power of the hydroxyl groups of polyphenols. These compounds react with Folin-Ciocalteu phenol reagent under basic conditions to form chromogens that can easily be detected by a spectrophotometer at 760 nm. AOAC Method 945.39 (AOAC, 2000) was used to determine moisture content in the bean flour for the calculation of total polyphenol content on dry weight basis. Whole bean flour samples (5g per variety) were dried in pre-weighed moisture tins at 103° C in a hot air oven for 1h for all the moisture to evaporate from the sample. After 1h of drying in the oven, tins were cooled and reweighed as soon as room temperature was reached. The reagents used for total polyphenol content determination were sodium carbonate, Folin-Ciocalteu phenol reagent and Catechin [(+)-Catechin Hydrate, 22110 Fluka/Sigma-Aldrich, Atlas Ville, South Africa].

Total polyphenols were extracted with acidified methanol solvent (1 ml concentrated hydrochloric acid, made up to 100 ml with methanol) (Li, Wei, White & Beta, 2007). Whole bean flour samples (0.25g) of each of the three bean varieties were extracted in duplicate, using 15 ml of the solvent as

follows: 5 ml solvent was added to a 0.25 g sample in a glass centrifuge tube, vortex-mixed every 10 min for 2 h for extraction efficiency. Each of the samples was centrifuged at 3,500 rpm for 10 min at 25 ° C using a Rotanta 460R centrifuge (Hettich lab centrifuge, Tuttlingen, Germany). The sample residues were rinsed twice with 5 ml of solvent, vortex-mixed for 5 min, centrifuged again as above and decanted. The three supernatants after each centrifugation were combined and used for analysis.

Acidified methanol extracts (0.5 ml) were added to 50 ml volumetric flasks containing deionized water (25 ml) and mixed. Folin-Ciocalteu phenol reagent (2.5 ml) was then added and mixed followed by 7.5 ml sodium carbonate (20g/100ml) within 1 to 8 min after adding Folin-Ciocalteu phenol reagent. The contents were mixed and made up to volume with deionized water. The volumetric flasks were then stoppered and mixed thoroughly again. After 2 h from the addition of sodium carbonate, absorbance of the reactants was read at 760 nm using a Lambda EZ150 spectrophotometer (Perkin Elmer, USA). Catechin was used as a standard and results were expressed as mg catechin equivalent per g of sample, on dry weight basis.

#### **4.3.2.2 Determination of mineral profile**

The mineral profile of the bean varieties was determined using methods for plant and feed analysis of the Agricultural Laboratories of Southern Africa (AgriLASA, 2000). For nitrogen (N) and phosphorus (P), bean samples were digested with sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) and the elements determined colorimetrically by auto analyser. For the rest of the minerals (calcium, potassium, magnesium, sodium, copper, iron and manganese), the bean samples were digested in 1:5 nitric perchloric acid and the elements analysed using atomic absorption spectroscopy.

#### **4.3.3 Statistical analysis**

The total polyphenol content and individual mineral content of the bean samples were evaluated using analysis of variance (ANOVA) based on a 5% level of significance (Statistica version 7.1 StatSoft, Inc). Significant differences between means were determined using the Fischer's least significant difference (LSD) test. Principal Component Analysis (PCA) was performed on the mineral profiles of the bean varieties. The analysis was conducted using a correlation matrix with variety means in rows and mineral profiles in columns.

#### 4.3.4 Results and discussion

##### 4.3.4.1 Total polyphenol content

The total polyphenol content results based on catechin equivalent determination of the whole bean varieties are presented in Table 4.3.1.

**Table 4.3.1 Total polyphenol content of whole bean flour based on catechin equivalent**

Bean variety	Catechin equivalent (mg/g)
Jenny (MP), a light red speckled bean	10.95 ( $\pm$ 2.90) <sup>a</sup>
AC Calmont (MP), a plain dark red kidney bean	14.63 ( $\pm$ 1.91) <sup>b</sup>
PAN 150 (MP), a dark, grayish speckled bean	7.70 ( $\pm$ 0.72) <sup>a</sup>

<sup>ab</sup> = Mean values ( $\pm$  standard deviations) with different superscripts differ significantly ( $p < 0.05$ ).

Significant ( $p < 0.05$ ) differences in total polyphenol content were found between AC Calmont beans and the other two varieties (Jenny and PAN 150) with a higher amount of polyphenols in AC Calmont (Table 4.3.1). Black or dark pigmented beans are reported to have higher amounts of polyphenols (Barampama & Simard, 1993) and the colour of red kidney beans is associated with the presence of condensed tannins (procyanidins) (Beninger & Hosfield, 2003). Since AC Calmont beans were dark red in colour, the higher amount of total polyphenol content in these beans confer with reports by Guzmán-Maldonado *et al.* (1996) and Bressani & Ellias (1980) stating that dark coloured beans normally contain higher concentrations of total polyphenols. Unlike PAN 150 beans, AC Calmont beans were not bitter. Madhujith, Amarowicz & Shahidi (2004) reported that the presence of catechin and other related compounds such as delphinidin, and other phenolic acids (vanillin, caffeic, coumaric & ferulic acids), could be responsible for the red colour in other common bean varieties. This suggests that not all polyphenols are bitter as bitterness may be subject to the amounts of condensed tannins available in relation to these other phenolic acids. PAN 150 beans were expected to have a higher amount of total polyphenol content since its seed coat had dark grayish stripes compared to the lighter coloured Jenny. PAN 150 beans were also notably bitterer than the other two bean types. The hypothesis therefore, that the presence of higher concentrations of polyphenols in beans would contribute to bitterness, was rejected for these beans (PAN 150). However, Sandberg (2002) reported that some legumes have polyphenols that bind with Fe and inhibit Fe absorption. Therefore, it might be possible that some

polyphenols were bound to Fe making it difficult for the polyphenols to be detected by the method used for analysis. On the other hand, Salunke, Jadhav, Kadam & Chavan (1982) reported that polyphenols are also known to interact with proteins forming tannin-protein complexes which may render beans not bitter as these complexes inactivate enzymes or make proteins insoluble. Tannins in bound form cannot be perceived as bitter in the mouth.

If polyphenols did not contribute to the bitterness of PAN 150 beans, other reactions such as the Maillard reaction (non-enzymatic) that take place during cooking may also contribute to flavours like bitterness (Martins *et al.*, 2001). One of the amino acids present in beans is lysine and depending on the amount of reducing sugars available to react with free amino groups, Maillard reactions may take place resulting in formation of N-substituted glycosylamines. The instability of the N-glycosylamines causes further reactions producing ketosamines, which with further reactions may produce brown nitrogenous polymers and copolymers called melanoidins. These nitrogenous polymers may produce different flavours including bitterness (Martins *et al.*, 2001). However, it is still not clear why bitterness was perceived only in PAN 150 beans and not the other bean varieties. Heng *et al.* (2004) reported the association of compounds such as saponins in edible legumes (e.g. beans, peas) with bitterness and soapy mouthfeel.

#### 4.3.4.2 Mineral content

Table 4.3.2 shows the p-values related to the mineral profiles of beans grown in MP and FS. There were no significant ( $p > 0.05$ ) differences for Ca, K, Mg, Fe and Cu for location, variety and location x variety interaction effects.

**Table 4.3.2 Probability values (p-value) for the differences in mineral profiles of beans**

Mineral	Location	Variety	Location x Variety
	p-value	p-value	p-value
Phosphorous (P)	0.185	0.007	0.494
Calcium (Ca)	0.684	0.519	0.286
Potassium (K)	0.599	0.593	0.583
Magnesium (Mg)	0.399	0.065	0.966
Copper (Cu)	0.912	0.112	0.656
Iron (Fe)	0.406	0.056	0.372
Manganese (Mn)	0.048	0.115	0.556

Significant differences ( $p < 0.05$ ) were observed in P for variety and Mn for location only. Results (Table 4.3.3) showed lower average amounts of P (278 – 397 mg/100g), K (1018 – 1200 mg/100g) and Mg (110 – 180 mg/100g) than those reported by Sathe & Deshpande (2003) (P (380 – 570 mg/100g), K (1320 – 1780 mg/100g) and Mg (160 -320 mg/100g) for beans. The Ca, Cu, Fe and Mn contents were comparable to those reported by Sathe & Deshpande (2003). Bean samples from FS had slightly higher levels of P compared to bean samples from MP. Slightly higher levels of Mn were also evident in FS bean samples (1.4( $\pm$ 0.3) mg/100g) than those from MP (1.2( $\pm$ 0.2) mg/100g).

Different mineral composition may be due to differences in genes, geographical origin and growing environment in terms of e.g. rainfall pattern, soil fertility and temperature as suggested by Beebe, Gonzalez & Rengifo (1999). Yang & Lawless (2006) reported that the presence of minerals like Fe in a product, may display some undesirable flavours such as metallic and bitter tastes. The beans that were described as metallic (PAN 150) did not show higher Fe content compared to other beans (Table 4.3.3).

Although not significantly different, higher average amounts of Cu were found in Mkuzi beans (MP) followed by PAN 150 FS and Mkuzi FS compared to the other bean samples in the study (Table 4.3.3). Mkuzi beans had a prominent soapy mouthfeel but not metallic taste, whereas PAN 150 beans were characterized with bitter taste, soapy, and metallic mouthfeels. When conducting descriptive sensory evaluation of minerals, Lawless, Rapachi, Horne, Hayes & Wang (2003) used a sanitized copper coin as a reference for metallic taste. It is possible that a slightly higher content of Cu in PAN 150 beans contributed to its metallic taste.

The Principal Component Analysis (PCA) plot (Figure 4.3.1) shows the projection of scores of the mineral profiles of the six dry bean varieties in this study. The first two principal components described 63 % of the total variance in the mineral profiles of the beans. Factor 1 explained 39% of the total variance of data and separated beans with high P on the left from the rest of the beans, which were lower in P but higher in some of the minerals (Cu, Fe, Mn, Cu, Mg, and K). Mkuzi beans seemed to have slightly higher amounts of Mg, Cu and Fe compared to other bean varieties on the right of the plane. Factor 2 added an additional 24 % to the explanation of the variation and separated PAN 150 (FS) beans with a slightly higher K content from Jenny (FS), which had a lower K content. The other bean varieties were concentrated around the zero point. Bean varieties with scores close to zero were not well explained by this factor.

#### **4.3.5 Conclusions and Recommendations**

Total polyphenol content did not seem to explain the bitterness found in one of the bean samples (PAN 150). In comparison, beans with higher amounts of total polyphenol content, AC Calmont beans or similar amounts (Jenny MP) were not bitter.

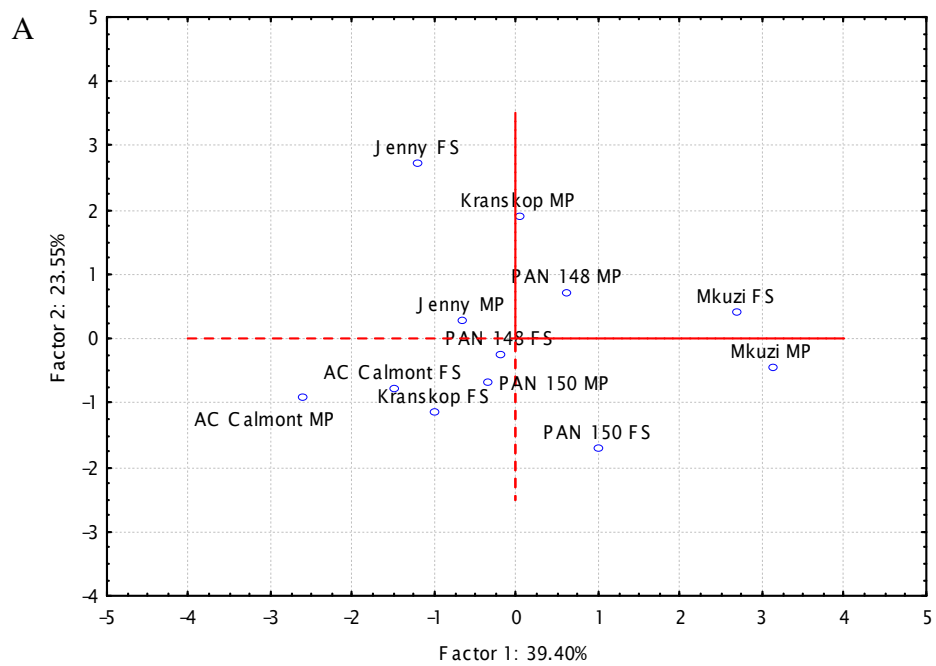
Fe and Cu did not contribute to bitterness of PAN 150 beans. The low Fe content does not support suggestions that the concentration of salts of some mineral compounds such as iron could contribute to bitterness of food products, at least not in these beans.

Since the total polyphenol and mineral content did not seem to contribute much to the bitterness of PAN 150 beans, other factors (e.g. saponins) might have contributed to the bitterness in PAN 150 beans. It is recommended that the contribution of saponins as a cause of bitterness should be investigated. The contribution of specific phenolic compounds e.g. tannins and phenolic acids to bitterness of the beans should also be further investigated.

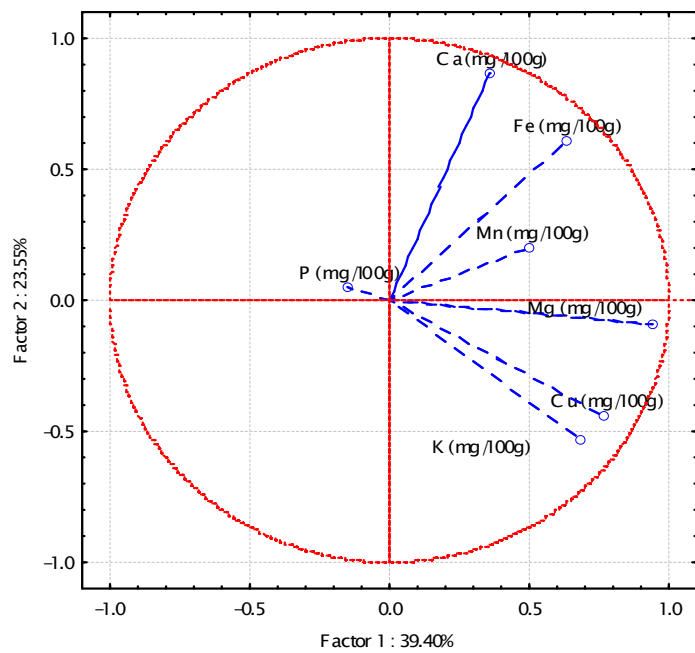
**Table 4.3.3 Average mineral contents ( $\pm$  standard deviations) designated samples of bean varieties grown in MP and FS in South Africa**

Mineral	Range (Sathe & Deshpande, 2003)	Total range (this study)	Location	Variety					
				Jenny	Kranskop	PAN 148	AC Calmont	PAN 150	Mkuzi
Phosphorous (P) (mg/100g)	380 – 570	278 - 397	MP & FS	389 ( $\pm$ 44) <sup>c</sup>	288 ( $\pm$ 22) <sup>a</sup>	350 ( $\pm$ 41) <sup>bc</sup>	353 ( $\pm$ 42) <sup>bc</sup>	378( $\pm$ 27) <sup>c</sup>	328 ( $\pm$ 32) <sup>ab</sup>
Calcium (Ca) (mg/100g)	70 – 260	80 - 135	MP	110 ( $\pm$ 14)	135 ( $\pm$ 21)	115 ( $\pm$ 21)	80 ( $\pm$ 28)	98 ( $\pm$ 11)	105 ( $\pm$ 21)
			FS	123 ( $\pm$ 32)	85 ( $\pm$ 7)	100 ( $\pm$ 42)	100 ( $\pm$ 14)	93 ( $\pm$ 18)	120 ( $\pm$ 0)
Potassium (K) (mg/100g)	1320 – 1780	1018 - 1200	MP	1038 ( $\pm$ 11)	1103 ( $\pm$ 152)	1148 ( $\pm$ 32)	1045 ( $\pm$ 106)	1128 ( $\pm$ 39)	1170 ( $\pm$ 98)
			FS	1018 ( $\pm$ 152)	1153 ( $\pm$ 46)	1130 ( $\pm$ 99)	1153 ( $\pm$ 11)	1198 ( $\pm$ 152)	1200 ( $\pm$ 42)
Magnesium (Mg) (mg/100g)	160 – 320	110 -180	MP	138 ( $\pm$ 11)	140 ( $\pm$ 14)	135 ( $\pm$ 7)	110 ( $\pm$ 28)	148 ( $\pm$ 11)	180 ( $\pm$ 57)
			FS	113 ( $\pm$ 18)	123 ( $\pm$ 4)	130 ( $\pm$ 28)	115 ( $\pm$ 7)	145 ( $\pm$ 21)	170 ( $\pm$ 42)
Copper (Cu) (mg/100g)	0.5 – 1.4	0.6 – 1.2	MP	0.6 ( $\pm$ 0.0)	0.6 ( $\pm$ 0.3)	0.8 ( $\pm$ 0.2)	0.7 ( $\pm$ 0.3)	0.8 ( $\pm$ 0.2)	1.2 ( $\pm$ 0.1)
			FS	0.6 ( $\pm$ 0.0)	0.7 ( $\pm$ 0.2)	0.8 ( $\pm$ 0.2)	0.7 ( $\pm$ 0.3)	1.0 ( $\pm$ 0.2)	0.9 ( $\pm$ 0.1)
Iron (Fe) (mg/100g)	3.34 – 13.5	3.5 – 7.2	MP	4.3 ( $\pm$ 0.4)	5.2 ( $\pm$ 2.4)	5.7 ( $\pm$ 2.5)	3.5 ( $\pm$ 0.2)	3.8 ( $\pm$ 0.0)	7.2 ( $\pm$ 0.8)
			FS	6.2 ( $\pm$ 1.3)	4.0 ( $\pm$ 1.1)	3.9 ( $\pm$ 1.3)	3.6 ( $\pm$ 0.8)	3.5 ( $\pm$ 0.2)	5.8 ( $\pm$ 1.1)

<sup>abc</sup> = Mean values ( $\pm$ standard deviations in parenthesis) in a column with different superscripts differ significantly ( $p < 0.05$ )



A



B

**Figure 4.3.1 Principal Component Analysis (first and second principal components) of mineral profiles of 6 bean varieties grown in MP and FS**

A. Plot of the first two principal component scores of the bean varieties

B. Plot of first two principal component loading vectors of mineral profiles

MP = Mpumalanga

FS = Free State



## 5. GENERAL DISCUSSION

The main objective of the study was to relate consumer preferences to sensory and physicochemical properties of dry bean varieties grown in South Africa. The study was done in four phases, namely determination of physicochemical characteristics (phase 1), descriptive sensory evaluation (phase 2) and consumer acceptance tests (phase 3) of the selected bean varieties. The fourth phase involved mineral and total phenol determination of selected bean varieties in an attempt to determine possible reasons for consumer liking and disliking of certain bean varieties. Therefore this section (general discussion) will critically evaluate some of the methodologies used in the experimental design in terms of their strengths and weaknesses. Finally driving factors of consumer preferences of certain bean varieties will also be put forward.

### 5.1 Strengths and weaknesses of the methodologies used

The initial phase of this study dealt with determination of the physicochemical characteristics (seed size, hydration and swelling capacity, cooking time and bulk density) of 6 dry bean varieties obtained from the Dry bean Producer's Organization (DPO) in Pretoria, South Africa. These beans (Jenny, Kranskop, PAN 148, AC Calmont, PAN 150 and Mkuzi) were grown in two locations (Mpumalanga and Free State) in South Africa.

Despite visual differences in the bean varieties, seed size was determined because of differences in growing locations. One of the methods for seed size determination involves counting of the number of seeds in a 100 g sample of bean seeds (Liebenberg *et al.*, 2003). The method measures seed size in terms of whether beans are small, medium or large seeded. The larger the number of seeds in a 100 g sample, the smaller the seed size whereas the smaller seeded beans (e.g. Mkuzi) were lighter in weight. Another method uses the mass of 100 seeds ( $\text{g } 100 \text{ seeds}^{-1}$ ) (Shimelis & Rakshit, 2005). It was decided that this second method would be used because it required a smaller number of seeds and limited samples were available for experimentation. In this method, 100 bean seeds were physically counted from each sample and weighed. The process was repeated three times. In this case the heavier the beans the larger the seeds (e.g. Jenny) whereas the smaller seeded beans are normally represented by a smaller weight (e.g. Mkuzi). The method is simple and inexpensive. Although the 100-seed mass method was used, the results were comparable with those of Liebenberg *et al.* (2003), who also reported on the same bean varieties.

The differences in seed size of the bean varieties especially between locations, was an indication that hydration and swelling capacities would also be affected. Therefore as part of the first phase, hydration and swelling capacities were determined by soaking beans in deionised water for 24 h (Shimelis & Rakshit, 2005) at room temperature (22°C). The increase in mass of the hydrated beans was considered as the hydration capacity (g of water kg seeds<sup>-1</sup>). Swelling capacity was calculated based on the displaced volume of water of hydrated seeds measured as ml of water kg seeds<sup>-1</sup> (Shimelis & Rakshit, 2005). Soaking for 24 h, seemed too long as some bean samples showed some signs of foaming, an indication of the onset of fermentation by bacteria. Berrios *et al.* (1999) reported that beans stored under refrigerated hypobaric conditions and ambient conditions showed rapid water uptake during the first 10 h of soaking. In their results it was found that after 12 h of soaking, no increase was observed in water absorption capacity of beans. Soaking for 24 h may just increase the time for preparation of beans. To reduce soaking time, soaking temperature should also be considered. Abdel Kader (1995) reported that when faba beans were soaked at 20°C for 10h, a 90% total absorption was achieved. The same amount (90%) of water absorption was achieved when beans were soaked at 50°C for 2.5h due to increase of diffusion rate of the bean constituents in the presence of heat.

Due to limitation of available samples, the same samples used for hydration capacity were also used for swelling capacity. Immediately after adding deionised water to the samples for hydration measurement, volume was also noted for the measurement of swelling capacity. After 24 h of soaking, all samples were toweled dry with an absorbent paper and reweighed. After reweighing, the samples were put back in the measuring cylinders and the same amount of fresh deionised water added to note the new volume of water displaced by the hydrated beans. The trend in hydration capacity was the same as in swelling capacity in that the higher the hydration capacity the higher the swelling capacity. However, to avoid irregularities in sample handling, it would be recommended in future to measure hydration and swelling capacities using separate samples of the same bean varieties.

Cooking time indicates the amount of time required for beans to reach the cooked texture that is considered acceptable to consumers. Evaluation of cooking quality of pulses in general has been demonstrated by cooking time (Moscoso *et al.*, 1984). This study had 6 bean varieties from 2 growing locations totaling up to 12 samples. Each sample required its own cooking time especially because of variations that might exist in the two growing

locations. The most commonly used method by most researchers for the determination of cooking time has been the use of the Mattson bean cooking device (Mattson, 1946) method, modified by Jackson & Varriano-Marston (1981). As described earlier in section 2.1.3, this device has been used differently by different researchers in terms of the weight of the piercing rods and even the time considered as the cooking time. Some researchers considered 100 % (Berrios *et al.*, 1999) of rods going through the beans, 92 % (Proctor & Watts, 1987b), and 80 % (Akinyele *et al.*, 1986) (for cowpeas), as cooking time. Proctor and Watts (1987a) reported that rods as light as 49.75 g provided the best indication of cooking time. In this study, the Mattson cooker used was custom made and each rod weighed about 90 g. A 92 % (Proctor & Watts, 1987b) falling of the rods was considered as cooking time based on an assumption that the last 8 % of rods might imply that beans might have had a hardening effect or the rods were not positioned very well on the rack. However, the cooking times determined by Mattson cooker in this study ranged between 40 to 100 min.

According to the personal opinion of the research team, some of these cooked beans were still relatively hard in texture and with raw bean flavour an indication that the beans were undercooked for consumer acceptability. As a result, cooking time was increased to 110 min for all the bean varieties for the descriptive and consumer panels. With this cooking time (110 min) varieties Jenny-FS, PAN 148-MP and Mkuzi-MP were still perceived to be undercooked.

Results from different studies that have used the Mattson bean cooker to determine cooking time can not easily be compared because of differences in sample handling (e.g. pre-treatment, length of cooking time, the weight and number of rods used). This method (Mattson cooker method) is also time-consuming, as it requires constant attention throughout the cooking process of a particular sample. There is need therefore to automate the method so that as the rods drop down, time should automatically be recorded throughout the cooking process. Overall, the Mattson cooker did not seem to be useful for determining cooking time for consumer acceptance as some beans were perceived undercooked. To further understand the impact of differences in seed size, hydration and swelling capacities, and cooking time, bulk density was measured to determine its effect on hydration and cooking characteristics. Different methods have previously been used by different researchers. Fasina *et al.* (1999), calculated bulk density by placing bean seeds in a metal funnel and allowed them to flow from 15.5 cm height into a 500ml metal cup. Without pressing, the beans are levelled with a

metal scraper and weighed. Bulk density is then calculated by the ratio of the weight of the sample in the metal cup to the volume of the cup expressed as  $\text{kg m}^{-3}$ . The method by Shimelis & Rakshit (2005) measures density by weighing bean seeds (100 g) and transferring them in a measuring cylinder where 100 ml of distilled water at 20° C is added. Seed volume is then calculated (ml per 100 g) by subtracting 100 ml from the total volume after addition of water. The ratio of mass to volume in  $\text{g ml}^{-1}$  gives density. This method may not allow samples to be used again for other assays because seeds may start to hydrate and swell if not removed and towelled dry immediately. However, both methods are simple and inexpensive. The first method (Fasina *et al.*, 1999) was adopted in this study because the beans would not be in contact with water. In the case of inadequate sample availability, samples could be used again for other assays. The method was slightly modified based on sample availability in that instead of using a 500 ml metal cup, a 60 ml metal cup was used.

The second phase involved descriptive sensory evaluation, which utilised students, who ate beans at least once a week. They were invited (25 members), screened (18 members) and trained (10 judges) as described in section 2.2. The number of members kept reducing because some of them were disqualified for absconding screening sessions for more than three times on the prescribed times. A panel of 10 judges was selected based on the overall performance (scores) during screening sessions from the highest to the lowest score. Training was planned for 6 days but was increased to 8 days to increase reliability of results. Descriptive sensory terms and scale anchors were developed, defined and agreed upon for evaluation of the bean samples. Generic Descriptive Analysis (GDA) technique as described by Einstein (1991) was used. Descriptive sensory evaluation is useful in that training is done over a number of days, and allows discussion among members. Members become familiar and free with each other and contribute effectively to the description of the product. Many studies have previously used between 6 and 12 judges. One advantage is that, this method can identify outliers in the evaluation process, which can call for further training. It is also efficient in that results can be obtained immediately with the use of Compusense Five® release 4.6 (Compusense Inc., Guelph, ON, Canada). One of the challenges of the descriptive sensory evaluation is the use of human subjects who might be affected by various forms of set backs (e.g. emotional, social and physical conditions) during training and evaluation of samples. Such conditions can have a negative impact on the results. There were a total of five samples and each panellist received all of them at once. Lawless & Heymann, (1999) reported that a maximum of four samples should be evaluated at a time as fatigue may set in that can reduce maximum concentration of

the panel. Although a descriptive panel is not the same as the consumer panel, dealing with many samples (e.g. > 4 samples) may require a break in between.

The third phase involved a consumer acceptance test ( $n = 100$ ), which was conducted to determine the consumer acceptability of the selected bean samples. The methodology used was as described in section 4.1.2.3. The hedonic rating incorporated a branching follow up question probing why consumers disliked, neither liked/disliked or liked very much a particular bean sample. The questions were easy to understand and seemed to work very well. Consumers had to be guided still by giving them suggestion of reasons in relation to bean appearance, flavour and texture. Usually, consumer sensory evaluation requires a minimum of 50 people (Lawless & Heymann, 1999), who have to be screened in relation to consumption and/or allergenicity of the product. As a motivation, consumers are rewarded for participation in the tasting session. The danger is that some consumers may focus on the reward rather than the task, and end up giving unreliable judgements on the sample. It is therefore important to recruit and encourage participation of members in relation to the experience gained during the evaluation rather than highlighting rewards given after the task.

The final phase involved mineral profile and total polyphenol content determination. Previous studies regarding the possible contribution of minerals (Yang & Lawless, 2006) and total polyphenol content in beans to bitterness and metallic mouthfeels (Bressani & Elias, 1980; Guzmán-Maldonado *et al.*, 1996) were reported. These analyses (mineral profile and total polyphenol content determination) were included in an attempt to answer some of the questions generated from the physicochemical, descriptive sensory and consumer sensory tests. The questions included why some beans were bitter in taste or hard in texture and disliked by the consumers. The methods for soil and plant analysis (Agricultural Laboratories of South Africa (AgriLASA), 2000) as described in section 4.3.2.2, were used to determine the mineral content in beans. The advantage of the method is that mineral concentrations can be calculated directly based on the molar absorptivity of the chromogen-mineral complex as described by Carpenter & Hendricks (2006). A colorimetric method is also advantageous for its specificity and can still function in the presence of other minerals.

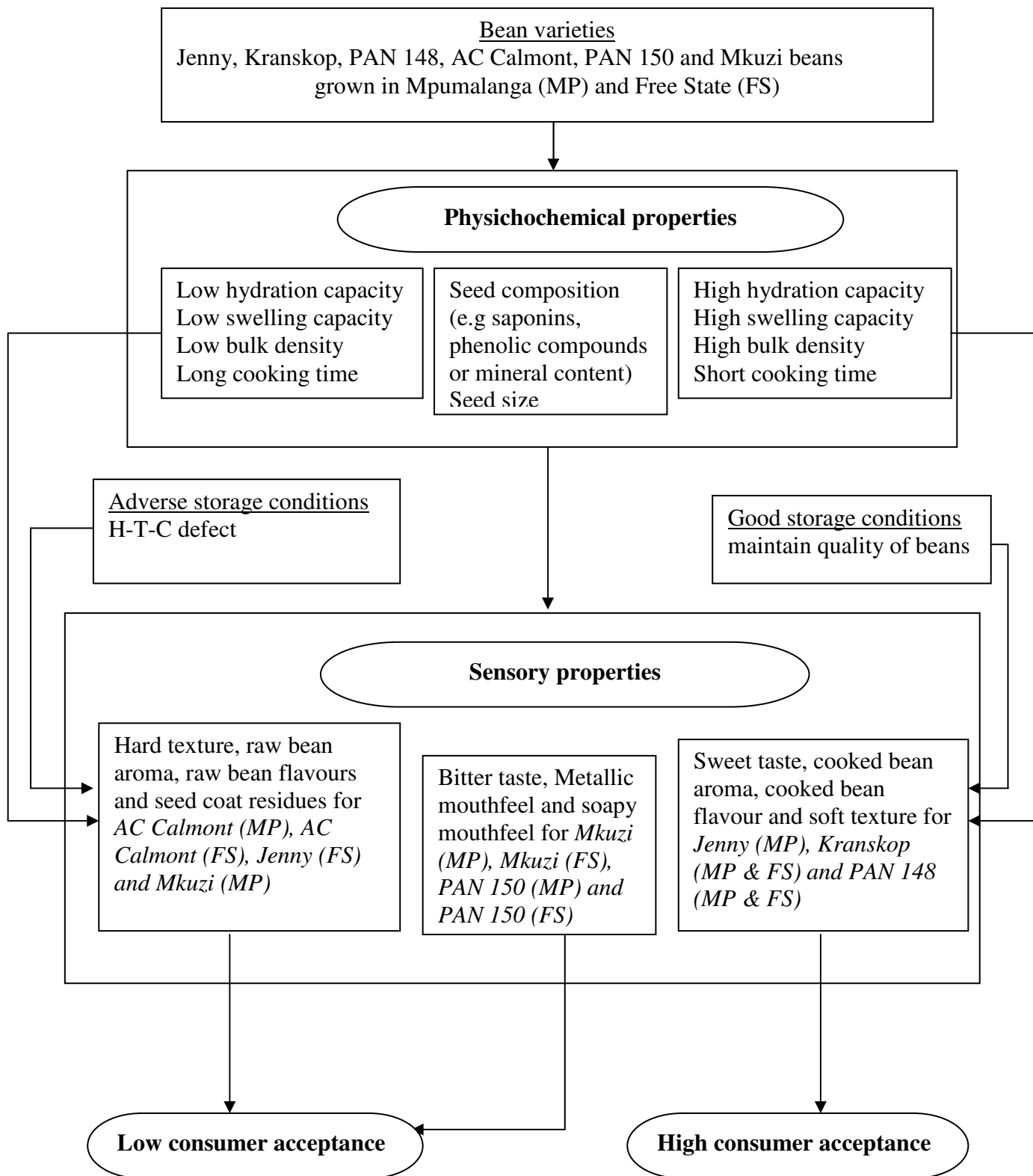
Total phenol content in the beans was determined using the Folin-Ciocalteu method as described by Waterman & Mole (1994). The method is based on the reducing power of the hydroxyl groups of phenolic compounds as described in section 4.3.2.1. Waterman & Mole

(1994) showed that this method quantifies the total concentration of phenolic hydroxyl groups without specifying molecules in which they occur. One disadvantage of this method is that Folin-Ciocalteu is an oxidation-reduction method; therefore any other substance present in the sample capable of being oxidised can produce the reduced forms of the reagent (coloured), which would appear as phenolics (Waterman & Mole, 1994). As such, overestimation of the phenol content would be possible. One of the substances that have been reported to interfere with determination of total phenols is ascorbic acid (Deshpande, Cheryan & Salunkhe, 1986), which is not available in beans. One of the limitations of this method is that one does not know the specific types of phenolic acids present in the sample. Another test that would be recommended in future is determination of condensed tannins in the bean seed coat, where they are found in abundance (Beninger & Hosfield, 2003; Guzmán-Maldonado *et al.*, 1996)

## 5.2 Critical review of results found

Consumer acceptance of the beans included in this study was different. With reference to the flow diagram (Figure 5.1), beans that received low consumer acceptability ratings included Jenny (FS), Mkuzi (MP), PAN 150 (MP) and AC Calmont (MP and FS). High preference was given to Jenny (MP), PAN 148 (MP and FS) and Kranskop (MP and FS). Small seeded beans may receive low consumer acceptance because of size as has been previously reported by Liebenberg *et al.* (2003). In this study, the small seeded PAN 150 and Mkuzi beans were also rated low probably because of their seed size and also other sensory attributes as found by the descriptive sensory panel (bitterness, soapy and metallic mouth feels). The low consumer acceptance of the large seeded beans could be attributed to many factors such as cooked bean flavour and texture (Figure 5.1). For Jenny (FS) and AC Calmont (MP and FS), the low acceptance was attributed to hard texture, which mostly came as a result of long cooking time and tough seed coat of AC Calmont beans from both locations.

Overall, Figure 5.1 summarises the effect of physicochemical and sensory properties that influenced consumer acceptability of these beans. When beans are exposed to different storage conditions they differ in cooking time, hydration capacity, swelling capacity and bulk density. Of these factors, cooking time was the main physicochemical property that differed significantly and resulted in cooked beans with different textures. Differences in cooking time of beans as seen in Jenny FS, PAN 148 MP and Mkuzi MP (long cooking time) could be attributed to differences in hydration and swelling capacities.



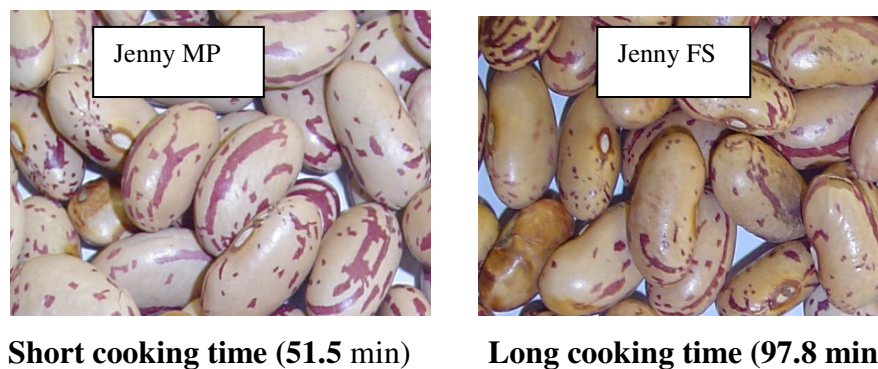
**Figure 5.1 Conceptual framework for relating consumer preferences to sensory and physicochemical properties of designated dry bean varieties grown in two locations**



The same variety of beans could have different cooking times when grown in different locations with different agronomic conditions as Wang *et al.* (2003) reported. This was also true for Jenny FS, PAN 148 MP and Mkuzi MP, which resulted in low consumer acceptance as the beans still remained hard in texture, leaving seed coat residues in the mouth when chewing.

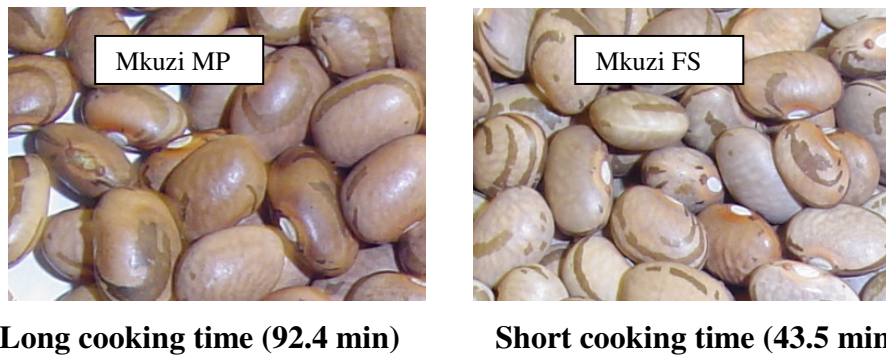
Some small seeded beans may contribute to low consumer acceptability because of hard texture mainly because of failure to hydrate fully during soaking and failure to become soft during cooking (Berrios *et al.*, 1999). However, if the small seeded beans hydrate properly as did PAN 150 and Mkuzi beans in this study, other factors such as flavour and mouth feel may contribute to low consumer acceptability. For instance, PAN 150 and Mkuzi hydrated very well but had bitter taste, soapy and metallic mouthfeel that consumers did not like.

Hard bean texture can also result from failure of beans to hydrate well during soaking and cooking especially if they were exposed to harsh conditions during storage. The state of the bean seed in terms of freshness or hardness (Del Valle *et al.*, 1992) has been reported to result in variations in cooking times. Adverse conditions such as high temperature and high relative humidity may bring about hardening in beans (Aguilera & Stanley, 1985). As it was seen for some of the beans in this study, the long cooking time beans also showed signs of discolouration (Fig. 5.2), supporting the possibility of unfavourable storage conditions before samples were acquired. High temperature (30 - 40° C) and high relative humidity (> 75%) induces lignification of the middle lamella due to oxidation and polymerisation of the polyphenolic compounds (Aguilera & Stanley, 1985; Jones & Boulter, 1983).



**Figure 5.2 Same bean varieties with different seed coat colour and cooking times grown in MP and FS**





**Figure 5.2 Same bean varieties with different seed coat colour and cooking times grown in MP and FS (continued)**

According to the South African weather bureau, the two growing locations (MP and FS) in this study also showed variations in terms of temperature and relative humidity during the time period before acquiring the bean samples. For example, Mpumalanga showed maximum temperatures between April and August, 2004 measuring up to 40° C and minimum temperatures of less than 20° C. Relative humidity varied from i.e. 50% to 100% in one day. For FS, the variations in temperature and relative humidity were minor e.g. temperatures of up to 30° C and relative humidity between 60 and 80%. This is evident in that the bean samples for this location had similar cooking characteristics except for Jenny beans.

Beans with different types of polyphenols (e.g. condensed tannins, phenolic acids) and different concentrations may affect the cooking quality of beans. High polyphenol content especially condensed tannins may migrate from the seed coat to the cotyledon during poor storage conditions, strengthening the cell walls (Stanley, 1992). These tannins form complexes with proteins making it difficult for cells to hydrate and separate easily during cooking. For example, AC Calmont beans, which had a hard texture, had the highest total polyphenol content and were also less acceptable to consumers than Jenny. These beans, had a rich dark red colour and absorbed more water e.g. more than double its original size (between 1034 – 1068 g of water per kg seeds), but still remained hard after cooking. Reduced binding of water occurs due to cell membrane degradation of the hardened beans (Del Valle *et al.*, 1992), causing impaired osmotic potential of cell constituents. During this time, phytic acid may chelate the divalent cations ( $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ) forming phytates. High temperatures and high relative humidity activate phytase releasing the bound divalent

cations, which may also migrate to the middle lamella to form Ca/Mg pectates (Del Valle *et al.*, 1992),

High consumer acceptance of beans (e.g. Jenny MP, PAN 148 MP and FS) was attributed to sensory attributes such as sweet taste, cooked bean aroma, cooked bean flavour and soft texture. These attributes came as a result of (among others), high hydration and swelling capacity, good cooking quality (e.g. short cooking times), and good storage conditions as pointed out by Berrios *et al.* (1999). Well stored beans tend to maintain their freshness and usually cook faster than hardened seeds (Wang *et al.*, 2003). The whole bean microstructure (from the seed coat to the cotyledons) does not obstruct water entry during soaking and cooking as do the hardened beans.

In general, descriptive sensory evaluation answers question about the nature of the differences between samples. This study compared the bean varieties from the two locations and there was a need to know how these varieties differed. The description of the nature of difference between beans may also not be enough to advise the production or marketing industries on product or profit maximization. As such, it is also important to determine consumer preferences or acceptability of such beans. This is why after descriptive sensory evaluation a consumer acceptance test was also conducted.

Descriptive sensory evaluation results showed differences in the attributes of bean samples studied. Of the different attributes; bitterness, soapiness and metallic sensations, contributed to low consumer acceptability. In an attempt to determine the cause of bitterness in PAN 150 beans, total polyphenols were determined using the Folin-Ciocalteu method (Waterman & Mole, 1994). The expectation was that PAN 150 beans with bitter sensation would show high total polyphenol content. Surprisingly enough, the higher total phenol content was observed in AC Calmont and Jenny not in PAN 150 beans. For AC Calmont, which had a dark red seed coat colour, the results were supporting those of Bressani & Elias (1980) reporting that higher polyphenol content is found in dark coloured bean seed coats. These results mean that the bitter taste and metallic mouthfeel of PAN 150 did not originate from a higher total polyphenol content. Bearing in mind that total polyphenol content does not specify the molecules present in the concentration of the phenolic hydroxyl groups (Waterman & Mole, 1994), it is therefore difficult to suggest that bitterness would be

detected using the total polyphenol content determination method. In addition, Guzmán-Maldonado *et al.* (1996) reported that condensed tannins in the whole bean flour may migrate to the cotyledons with time especially if not determined within 6 to 24 h of grinding. When polyphenols have migrated, they may form complexes with the proteins of the cotyledons and may not be detected because they are in bound form.

The postulation of Yang & Lawless (2005) that bitterness and metallic taste could come from the presence of minerals such as iron compounds in model solution may not be applicable to cooked beans. In terms of metallic sensation of PAN 150 beans, it was expected that higher concentrations of copper would cause metallic taste, but the amounts were not higher than those reported by Sathe & Deshpande (2003) in beans. In fact, PAN 150 beans had the lowest amount of copper content compared to other bean varieties included in the study. This may suggest that contribution of minerals to bitterness and metallic taste of beans may be very minimal (undetected).

Another school of thought in terms of bitterness of beans would include determination of other compounds such as saponins (assay not done in this study), high molecular weight glycosides (Shi, Arunasalam, Yeung, Kakuda, Mittal & Jiang, 2004). Saponins have been reported to occur naturally in cells of a wide variety of edible legumes and can contribute to bitter and soapy taste of legumes such as beans and peas (Heng *et al.*, 2004). Saponins are thermal sensitive and soluble in water such that if beans are soaked and cooked in their soaking water, it is possible to perceive soapiness in cooked beans when eating. The distinctive sensations of PAN 150 beans were bitter taste, metallic and soapy mouthfeels whereas Mkuzi beans displayed mainly the soapy mouthfeel. No cause of soapiness in PAN 150 and Mkuzi beans was found using the analyses done in this study. It may be possible that the presence of saponins, if any (Heng *et al.* 2004) contributed to these sensations in Mkuzi and PAN 150 beans. However, it requires further investigation.

## 6. CONCLUSIONS AND RECOMMENDATIONS

Beans that received high consumer acceptance were Jenny (MP), PAN 148 (MP and FS) and Kranskop (MP and FS). The sensory attributes associated with highly acceptable cooked beans were sweet taste, cooked bean aroma, cooked bean flavour and softness. The accepted sensory attributes seemed to be due to high hydration and swelling capacity and short cooking time as a result of quality maintenance during storage.

Beans that received low consumer acceptance were Jenny (FS), Mkuzi (MP), PAN 150 (MP) and AC Calmont (MP and FS). The small seeded varieties (PAN 150 and Mkuzi beans) from both locations were among the least accepted beans. The low consumer acceptability of these beans were not because they did not hydrate nor swell, but mostly because of hard texture (Jenny FS; AC Calmont MP and FS; Mkuzi MP) bitterness, soapy and metallic mouthfeel (PAN 150 MP and FS) and the distinctive soapy mouthfeel of Mkuzi (FS) as described by a descriptive sensory panel. For Jenny (FS) and Mkuzi (MP), the discolouration of the seed coat colour suggested the onset of the hard-to-cook defect.

The Mattson bean cooker used for determination of cooking time of beans did not give reliable results for some beans (AC Calmont and Mkuzi MP) as these beans were not fully cooked and soft when tested for consumer acceptance. It is therefore recommended that cooking time for beans for consumer acceptability testing should not be determined by the Mattson cooker with rods weighing more than 50 g but should be cooked until tender enough as assessed by humans.

The mineral profile determinations did not seem to contribute to understanding of bitterness of some of the beans. However, some reports suggest that the presence of saponins in beans might contribute to bitter and soapy sensations of beans. Further investigation of the presence of saponins is therefore recommended in future specifically in PAN 150 and Mkuzi beans. In addition, determination of total polyphenols in the whole bean flour may not be appropriate for investigating bitterness in some beans. Bitterness is normally associated with the presence of tannins in the bean seed coat. It is therefore further recommended that tannins should be determined in seed coat flour of beans that are perceived as bitter by consumers.

From the results obtained here for the studied bean varieties, farmers should concentrate on the production of Kranskop (MP & FS), (PAN 148 MP) and Jenny (MP) beans for profit maximization and high consumer acceptance. Factors responsible for causing the undesirable sensory properties of PAN 150 and Mkuzi should possibly be attended to by a team of plant breeders, geneticists and soil scientists to improve consumer acceptability. As bean hardening was suspected in Jenny (FS), PAN 148 (MP) and Mkuzi (MP), the importance of storing at proper temperatures (e.g.  $<30^{\circ}\text{C}$ ) and relative humidity (e.g.  $<75\%$ ) should be emphasized to minimize the development of the hard-to-cook defect over long storage periods.

## 7. REFERENCES

ABBU-GHANNAM, N. 1998. Modelling textural changes during the hydration process of red beans. *Journal of Food Engineering* 38, 341-352.

ABDEL KADER, Z.M. 1995. Study of some factors affecting water absorption by faba beans during soaking. *Food Chemistry* 53, 235-238.

AGBO, G.N., HOSFIELD, G.L., UEBERSAX, M.A. & KLOMPARENS, K. 1987. Seed microstructure and its relationship to water uptake in isogenic lines and a cultivar of dry beans (*Phaseolus vulgaris* L.). *Food Microstructure* 6, 91-102.

AGRICULTURAL LABORATORIES OF SOUTHERN AFRICA (AGRILASA). 2000. Methods for Plant and Feed Analysis.

AGRO-INDUSTRIES AND POST-HARVEST MANAGEMENT SERVICE (AGSI) /FOOD AND AGRICULTURE ORGANIZATION (FAO), 2004. Chapter IV. *Phaseolus* beans: Post-harvest operations; <http://www.fao.org/inpho/content/compand/text/ch04.htm>. (Accessed in September, 2006).

AGUILERA, J.M. & STANLEY, D.W. 1985. A review of textural defects in cooked reconstituted legumes – The influence of storage and processing. *Journal of Food Processing and Preservation* 9, 145 - 169.

AKINYELE, I.O., ONIGBINDE, A.O., HUSSAIN, M.A. & OMOLOLU, A.1986. Physicochemical characteristics of 18 cultivars of Nigerian cowpeas (*V. unguiculata*) and their cooking properties. *Journal of Food Science* 51, 1483-485.

AOAC International, 2000. Official methods of analysis, Ed. Horwitz, W. (17<sup>th</sup> edition), Chapter 32 p 43.

BARAMPAMA, Z. & SIMARD, R.E. 1993. Nutrient composition, protein quality and antinutritional factors of some varieties of dry bean (*Phaseolus vulgaris* L.) grown in Burundi. *Food Chemistry* 47, 159 –167.

BEEBE, S., GONZALEZ, A.V. & RENGIFO, J. 1999. Research on trace minerals in common beans. A workshop hosted by the International Rice Research Institute, Los Banos, Philippines organized by the International Food Policy Research Institute.

BENINGER, C.W. & HOSFIELD, G.L. 2003. Antioxidant activity of extracts, condensed tannin fractions, and pure flavonoids from *Phaseolus vulgaris* L. seed coat colour genotypes. *Journal of Agriculture and Food Chemistry* 51, 7879 – 7883.

BERRIOS, JOSE DE J, SWANSON, B.G. & CHEONG, W.A. 1999. Physicochemical characterization of stored black beans. *Food Research International* 3, 669-676.

BISHNOI, S. & KHETARPAUL, N. 1993. Variability in physico-chemical properties and nutrient composition of different pea cultivars. *Food Chemistry* 47, 371-373.

BOWER, J.A. 2000. Statistics for Food Science – Correlation and regression (part B). *Journal of Nutrition and Food Science* 2, 80-85.

BRESSANI, R. & ELIAS, L.G. 1980. The Nutritional Role of Polyphenols in Beans. Proceedings of the 36th Institute of Food Technologists Symposium, 10-13 June 1979 St. Louis, Mo., Hulse, J.H (Ed) International Development Research Centre, Ottawa, Canada, pp 72-111.

BUETTNER, A. & SCHIEBERLE, P. 2000. Influence of Mastication on the concentrations of aroma volatiles-some aspects of flavour release and flavour perception. *Food chemistry* 71, 347-354.

CARPENTER, C.E. & HENDRICKS, D.G. 2006. Mineral analysis. In Nielsen, S.S. 2006. Food analysis, 3<sup>rd</sup> edition, pp.189-203. Kluwer Academic/Plenum publishers, New York.

CASAÑAS, F., POJULA, M., BOSCH, L., SANCHEZ, E. & NUEZ, F. 2002. Chemical basis for the low sensory perception of the Ganxet bean (*Phaseolus vulgaris* L.) seed coat. *Journal of the Science of the Food and Agriculture* 82, 1282-1286.

DAVID, S. 1999. Beans in the farming system and domestic economy of Uganda. A tale of two parishes. Network on bean research in Africa. *Occasional publications series 28*, CIAT, Kampala, Uganda.

DE LEON, L.F., ELIAS, L.G. & BRESSANI, R. 1992. Effect of salt solutions on the cooking time, nutritional and sensory characteristics of common beans (*Phaseolus vulgaris* L.). *Food Research International* 25, 131-136.

DEL VALLE, J.M. COTTRELL, T.J., JACKMAN, R.L. & STANLEY, D.W. 1992. Hard-to-cook defect in black beans: the contribution of proteins to salt soaking effects. *Food Research International* 25, 429-436.

DEL VALLE, J.M., STANLEY, D.W. & BOURNE, M.C. 1992. Water absorption and swelling in dry bean seeds. *Journal of Food Processing and Preservation* 16, 75-98.

DESHPANDE, S.S. & CHERYAN, M. 1986. Water uptake during cooking of dry beans (*Phaseolus vulgaris* L.). *Plant Foods for Human Nutrition (Formerly Qualitas Plantarum)* 36, 157-165.

DESHPANDE, S.S., CHERYAN, M. & SALUNKHE, D.K. 1986. Tannin analysis of food products. *Critical Review in Food Science and Nutrition* 24, 401-449.

EINSTEIN, M.A 1991. Descriptive techniques and their hybridisation, In *Sensory Science: Theory and Application in Foods*, Ed. by Lawless, H.T and Klein, B.P. Marcel Dekker. Inc, New York, pp.317-330.

ELMAKI, H.B., ABDELRAHAMAN, S.M., IDRIS, W.H., HASSAN, BABIKER, E.E. & EL TINAY, A.H. 2007. Content of antinutritional factors and HCL-extraction ability of minerals from white bean (*Phaseolus vulgaris* L.) cultivars: Influence of soaking and /or cooking. *Food Chemistry* 100, 362-368.

FASINA, O.O., TYLER, R.T., PICKARD, M.D. & ZHENG, G.H. 1999. Infrared heating of hull-less and pearled barley. *Journal of Food Processing and Preservation* 23, 135-151.



FISCHER, N. & WIDDER, S. 1997. How Proteins Influence Food Flavour. *Food Technology* 51, 68-74.

GONZÁLEZ DE MEJÍA, E., CASTAÑO-TOSTADO, E. & LOARCA-PIÑA, G. 1999. Antimutagenic effects of natural phenolic compounds in beans. *Mutation Research* 441, 1-9.

GRAHAM, P.H. & RANALLI, P. 1997. Common Beans (*Phaseolus vulgaris* L.). *Field Crops Research* 53, 131-146.

GUZMÁN-MADONDO, H., CASTELLANA, J. & GONZÁLEZ DE MEJÍA, E. 1996. Relationship between theoretical and experimentally detected tannin content of common beans (*Phaseolus vulgaris* L.). *Food Chemistry* 55, 333-335.

HENG, L., VAN KONINGSVELD, G.A., GRUPPEN, H., VAN BOEKEL, M.A.J.S., VINCKEN, J.-P., ROOZEN, J.P. & VORAGEN, A.G.J. 2004. Protein-Flavour interactions in relation to development of novel protein foods. *Trends in Food Science & Technology* 15, 217-224.

HENTGES, D.L., WEAVER, C.M. & NIELSEN, S.S. 1991. Changes of selected physical and chemical components in development of Hard-to-Cook bean defect. *Journal of Food Science* 56, 436-442.

HSIEH, H.M., POMERANZ, Y. & SWANSON, B.G. 1992. Composition, cooking time, and maturation of common beans (*Phaseolus vulgaris* L.). *Cereal Chemistry* 69, 244-248.

HSIEH, R.J. 1994. Contribution of lipoxygenase pathway to food flavours. In *Lipids in food flavours*, Chi-Tang Ho & Hartman, T.G. (Ed) ACS symposium series 558.

IQBAL, A., KHALIL, A., ATEEQ, N. & KHAN, M. S. 2006. Nutritional quality of important food legumes. *Food Chemistry* 97, 331-335.

JACKSON, G.M. & VARRIANO-MARSTON, E. 1981. Hard- to- cook phenomenon in beans: Effect of accelerated storage on water absorption and cooking time. *Journal of Food Science* 46, 799-803.

JONES, P.M.B. & BOULTER, D. 1983. The cause of reduced cooking rate in *Phaseolus vulgaris* L. following adverse storage conditions. *Journal of Food Science* 48, 623-626.

KRINSKY, B.F. 2005. The development of lexicons for frozen vegetable soybeans and effect of blanching time on sensory and quality parameters of vegetable soybeans during frozen storage. MSc. Thesis, Department of Food Science, North Carolina State University.

KUTOŠ, T., GOLOB, T., KAČ, M. & PLESTENJAK, A. 2002. Dietary fiber of dry processed beans. *Food Chemistry* 80, 231-235.

LAWLESS, H. T., RAPACHI, R., HORNE, J., HAYES, A. & WANG, G. (2003). The taste of calcium chloride in mixtures with NaCl, sucrose and citric acid. *Food Quality and Preference*, 15, 83-89.

LAWLESS, H.T. & HEYMANN, H. 1999. *Sensory Evaluation of Food: Principles and Practices*. Gaithersburg, Maryland: Aspen publications. pp1 -26.

LAWLESS, H.T. & LEE, C.B. 1993. Common chemical sense in food flavor. In: T.E. Acree and R. Teranishi, (Ed), *Flavor science*, American Chemical Society, Washington pp. 21–65.

LI, W., WEI, C., WHITE, P.J. & BETA, T. 2007. High-amylose corn exhibits better antioxidant activity than typical and waxy genotypes. *Journal of Agriculture and Food Chemistry* 55, 291-298.

LIEBENBERG, A.J., HEENOP, H. & FOURIE, M.C. 2003. Dry bean cultivar recommendations for 2003 to 2004. Agricultural Research Council ARC-LNR, Pretoria.

LIU, K., PHILLIPS, R.D., HUNG, Y-C., SHEWFELT, R.L. & McWATTERS, K.H. 1992. Hard-to-cook defect in cowpeas: storage-induced and treatment-induced development. *Journal of Food Science* 57, 1155-1160.

MADHUJITH, T., AMAROWICZ, R. & SHAHIDI, F. 2004. Phenolic antioxidants in beans and their effects on inhibition of radical-induced DNA damage. *Journal of the American Oil Chemists' Society* 81, 691 –696.

MARTIN-CABREJAS, M., ESTEBAN, R.M., PEREZ, P., MAINA, G. & WALDRON, K.W. 1997. Changes in physicochemical properties of dry beans (*Phaseolus vulgaris* L.) during long-term Storage. *Journal of Agriculture and Food Chemistry* 45, 3223-3227.

MARTINS S.I.F.S., JONGEN W.M.F. & VAN BOEKEL M.A.J.S. 2001. A review of Maillard reaction in food and implications to kinetic modeling. *Trends in Food Science & Technology* 11, 364-373.

MATTSON, S. 1946. The cookability of yellow peas: a colloid-chemical and biological study. *Acta Universitatis Agriculturae Sueciae Agraria* 2, 185-231.

McLEOD, L. 2003. Effect of low concentrations of salicylic acid on plant growth. Website: <http://www.virtualsciencefair.org/2003/mcleo3l/public.html/> accessed in September 2005.

McTIGUE, M.C., KOEHLER, H.H. & SILBERNAGEL. M.J. 1989. Comparison of four sensory evaluation methods for assessing cooked dry bean flavor. *Journal of Food Science* 54, 1278-1283.

McWATTERS, K.H., CHINNAN, M.S., WORTHINGTON, R.E. & BEAUCHAT, L.R. 1987. Influence of storage conditions on quality of cowpea seeds and products processed from stored seeds. *Journal of Food Processing and Preservation* 11, 63-76.

MKANDA, A.V., MINNAAR, A. & DE KOCK, H.L. 2007. Relating consumer preferences to sensory and physicochemical properties of dry beans (*Phaseolus vulgaris* L.). *Journal of the Science of the Food and Agriculture* 87, 2868-2879.

MOSCOSO, W., BOURNE, M.C. & HOOD, L.F. 1984. Relationship between the hard-to-cook in red kidney beans and water absorption, puncture force, pectin, phytic acid and minerals. *Journal of Food Science* 49, 1577-1583.

MTEBE, K. & GORDON, H. 1986. Volatiles derived from lipoxygenase-catalysed reactions in winged beans (*Psophocarpus tetragonolobus*). *Food Chemistry* 23, 175-182.

MUKOKO, O.Z., GALWEY, N.W. & ALLEN, D. J. 1995. Developing cultivars of the common bean (*Phaseolus vulgaris* L.) for Southern Africa: bean common mosaic virus resistance, consumer preferences and agronomic requirements. *Field Crops Research* 40, 165-177.

MWANGWELA, A.M., WANISKA, R.D. & MINNAAR, A. 2006. Hydrothermal treatments of two cowpea (*Vigna unguiculata* L. Walp) varieties: Effect of micronisation on physicochemical and structural characteristics. *Journal of the Science of Food and Agriculture* 86, 35-45.

ONWUKA, U.N. & OKALA, O. 2003. Effects of selected salts on the cooking time, protein content and sensory properties of African yam beans and cowpeas. *Food Service Technology* 3, 3-7.

OSORIO-DÍAZ, P., BELLO-PÉREZ, L.A., SÁYAGO-AYERDI, S.G., DEL PILAR BENÍTEZ-REYES, M., TOVAR, J. & PAREDES-LÓPEZ, O. 2003. Effect of processing and storage time on *in vitro* digestibility and resistant starch content of two bean (*Phaseolus vulgaris* L.) varieties. *Journal of the Science of Food and Agriculture* 83, 1283-1288.

PERLA, O., LUIS, A.B., SONIA, G.S., MARIA, P.B., JUSCELINO, T. & OCTAVIO, P.L. 2003. Effect of processing and storage time *in vitro* digestibility & resistant starch content of two bean (*Phaseolus vulgaris* L.) varieties. *Journal of the Science of Food and Agriculture* 83, 1283 – 1288.

PROCTOR, J.P. & WATTS, B.M. 1987a. Development of a modified Mattson bean cooker procedure based on sensory panel cookability evaluation. *Canadian Institute of Food Science* 20, 9-14.

PROCTOR, J.P. & WATTS, B.M. 1987b. Effect of cultivar, growing location, moisture, and phytate content on the cooking time of freshly harvested navy beans. *Canadian Journal of Plant Science* 67, 923-926.

- PRODANOV, M., SIERRA, I. & VIDAL-VALVERDE, C. 2003. Influence of soaking and cooking on the thiamin, riboflavin and niacin contents of legumes. *Food Chemistry* 84, 271-277.
- REHINAN, Z., RASHID, M. & SHAH, W.H. 2004. Insoluble dietary fibre components of food legumes as affected by soaking and cooking processes. *Food Chemistry* 85, 245-249.
- RESURECCION, A.V. 1998. *Consumer sensory testing for product development*. Gaithersburg, Maryland. Aspen Publication.
- REYES-MORENO, C. & PAREDES-LOPEZ, O. 1993. Hard-to-cook phenomenon in common beans-a review. *Critical Review in Food Science and Nutrition* 33, 103-544.
- SALUNKE, D.K., JADHAV, S.J., KADAM S.S. & CHAVAN, J.K. 1982. Chemical, biochemical, and biological significance of polyphenols in cereals and legumes. *Critical Review. Food Science and Nutrition* 17, 277-305.
- SANDBERG, A-S. 2002. Bioavailability of minerals in legumes. *British Journal of Nutrition* 88, S281-S285.
- SANZI CALVO, M. & ATTENZA DEL REY, J. 1999. Sensory analysis of beans (*Phaseolus vulgaris* L.). *Biotechnology, Agronomy and Social Environment* 3, 201-204.
- SATHE, S.K. & DESHPANDE, S.S. 2002. Dry Bean Protein Functionality. *Critical Reviews in Biotechnology* 22, 175-223.
- SATHE, S.K. & DESHPANDE, S.S. 2003. Beans. *Encyclopedia of Food Science and Nutrition*, 2<sup>nd</sup> Ed. Vol. 1. Pp 403-412.
- SCOTT, J. & MAIDEN, M.1998. Socio-economic survey of three bean-growing areas in Malawi. *Occasional paper series* No. 24, CIAT, Kampala, Uganda.
- SEFA-DEDEH, S. & STANLEY, D.W. 1979a. Textural implications of the microstructure of legumes. *Food Technology* 10, 77-83.

SEFA-DEDEH, S. & STANLEY, D.W. 1979b. The relationship of microstructure of cowpeas to water absorption and dehulling properties. *Cereal Chemistry* 56, 379-386.

SEFA-DEDEH, S., STANLEY, D.W. & VOISEY, P.W. 1979. Effect of storage time and conditions on the Hard-to-cook defect in cowpeas (*Vigna unguiculata*). *Food Science* 44, 790-796.

SEMENOVA, M.G., ANTIPOVA, A.S., MISHARINA, T.A. & GOLOVNYA, R.V. 2001. Binding of aroma compounds with legumin. 1. Binding of hexyl acetate with 11S globulin depending on the protein molecular state in aqueous medium. *Food Hydrocolloids* 16, 557-564.

SHEWFELT, R.L. 1999. What is quality? *Post harvest Biology and Technology* 15, 197-2000.

SHI, J., ARUNASALAM, K., YEUNG, D., KAKUDA, Y., MITTAL, G. A. & JIANG, Y. 2004. Saponins from edible legumes: Chemistry, processing, and health benefits. *Journal of Medical Food* 7, 67-78.

SHIMELIS, E.A. & RAKSHIT, S.K. 2005. Proximate composition and physicochemical properties of improved dry bean (*Phaseolus vulgaris* L.) varieties grown in Ethiopia. *LWT-Journal of Food Science and Technology* 38, 331-338.

SINGLETON, V.L. & ROSSI, J.A. 1965. Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagent. *American Journal of Enology and Viticulture* 16, 144-158.

STANLEY, D.W. 1992. A possible role for condensed tannins in bean hardening. *Food Research International* 25, 187-192.

TAIWO, K.A., AKANBI, C. & AJIBOLA, O.O. 1997. The effects of soaking and cooking time on the cooking properties of two cowpea varieties. *Journal of Food Engineering* 33, 337-346.

TAIWO, K.A., AKANBI, C.T. & AJIBOLA, O.O. 1998. Regression relationships for the soaking and cooking properties of two cowpea varieties. *Journal of Food Engineering* 37, 331-344.

THARANATHAN, R. N., & MAHADEVAMMA, S. 2003. A Review: grain legumes a boon to human nutrition. *Trends in Food Science & Technology* 14, 507 –518.

TROSZYŃSKA, A., AMAROWICZ, R., LAMPARSKI, G., WOŁEJSZO, A. & BARYŁKO-PIKIELNA, N. 2006. Investigation of astringency of extracts obtained from selected tannin-rich legume seeds. *Food Quality and Preference* 17, 31-35.

VAN HEERDEN, S.M. & SCHÖNFELDT, H.C. 2004. The need for food composition tables for Southern Africa. *Journal of Food Composition and Analysis* 17, 531-537.

VAN RUTH, M., DINGS, L., BUHR, K. & POSTHUMUS, A. 2004. In vitro and in vivo volatile flavour analysis of red kidney beans by proton transfer reaction-mass spectrometry. *Food research International* 37, 785-791.

VARGAS-TORRES, A., OSORIO-DÍAZ, P., ISLAS-HERNÁNDEZ, J.J., TOVAR, J., PAREDES-LÓPEZ, O. & BELLO-PÉREZ, L.A. 2004. Starch digestibility of 5 cooked black beans (*Phaseolus vulgaris* L.) varieties. *Journal of Food Composition and Analysis* 17, 605-612.

VARRIANO-MARSTON, E. & DE OMANA, E. 1979. Effects of sodium salt solutions on the chemical composition and morphology of black beans (*Phaseolus vulgaris* L.). *Journal of Food Science* 4, 531-536.

WANG, N., DAUN, K.J. & MALCOMSON, J.L. 2003. Relationship between physicochemical and cooking properties, and effects of cooking on ant nutrients, of yellow field peas (*Pisum sativum*). *Journal of the science of Food and Agriculture* 83, 1228-1237.

WATERMAN, P. G., & MOLE, S. (1994) *Analysis of Plant Metabolites*. Oxford: Alden Press Limited. pp 1-16.

WHITAKER, J.R. 1985. Mechanisms of oxidoreductases important in food component modification. In: *Chemical changes in food during processing*, RICHARDSON, T. & FINLEY, J.W. (Eds). Canada: AVI Publishers, Pp 121-170.

YANG, H.H. & LAWLESS, H.T. 2005. Time-intensity characteristics of iron compounds. *Food Quality and Preference* 17, 337-343.

YOUSIF, A.M., BATEY, J.L., LARROQUE, O.R., CURTIN, B., BEKES, F. & DEETH, H.C. 2003. Effect of storage of adzuki beans (*Vigna angularis*) on starch and protein properties. *Lebensm-Wiss. U-Technology* 36, 601-607.