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DETERMINING THE CANNING QUALITY OF SMALL SEEDED WHITE BEANS (*PHASEOLUS VULGARIS* L.)

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Drybeans, small seeded white beans, canning quality, micro-canning method, GxE interactions, principal components, canonical correlations, canonical variate analysis, AMMI analysis

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DETERMINING THE CANNING QUALITY OF SMALL WHITE CANNING BEANS (*Phaseolus vulgaris* L.)

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Introduction

Bean cultivar, environment of production, bean quality at harvest, handling, food processing methodology and storage conditions have been reported to affect canning quality, including colour, flavour, texture and nutrient retention. The importance of incorporating food quality attributes in the breeding program of dry beans has been recognised. Varieties developed without considering food quality attributes may not meet the requirements of processors and consumers (Chang, 1988).

A barrier to higher yields or 'yield plateau' has been reached in beans in the United States some time ago. There are a number of reasons for yield barriers in crops; the least common denominator is the variety. The variety possesses a certain genetic potential prescribed by its genetic complement to produce under a given set of circumstances. When circumstances are optimum, the variety will produce at a maximum. If circumstances change and prevailing conditions

limit the genetic potential of a variety, this variety then must be replaced with one that can minimise its genetic potential in terms of productivity. Hence, the plant breeder, perhaps more so than any other agriculturist, holds the key to open the lock to higher yields (Hosfield and Uebersax, 1978).

Canning characteristics of dry beans largely influence final product acceptability. The canning industry has established a definite set of acceptability standards for dry beans that are rigorously adhered to when accepting a variety for processing. The major characteristics responsible for desirable bean canning quality may be grouped as follows:

1. Physical characteristics of the seed
2. Processing and cooking characteristics
3. Chemical composition of legumes (Hosfield and Uebersax, 1978).

Incorporating the dimension of quality improvement into a bean breeding program places an additional heavy burden on the breeder to develop efficient selection practices. To maximise time and resources, the breeder must possess some knowledge of the range of variability and the nature of gene action for food-quality traits and suitable

screening methods. In addition, the methodology and criteria used by the breeder in making canning quality evaluations must simulate commercial processing practices (Hosfield and Uebersax, 1980).

CHAPTER 1

LITERATURE REVIEW

1. Canning quality- definition and factors that influence canning quality

1.1. Structure of dry beans

1.1.1. Physical structure

Primary factors in determining the product quality are the physical and chemical properties of dry beans. The dry bean structure is comprised of a seed coat, cotyledons, and embryonic axis.

Structurally, the seed coat is the outermost tissue layer, which protects the embryonic structure. The major components in the seed coat structure include a cuticle layer, palisade cell layer, hourglass cells and thick cell-walled parenchyma cells. The seed coat consists of approximately 7-8% of the total dry weight in the mature bean with a protein content of 5% dry basis (db) (Uebersax and Ruengsakulrach, 1989).

Seed coat thickness, seed volume, and hilum size along with protein content were all factors in regulating water uptake (Sefa-Dedeh and Stanley, 1979).

The cotyledon is approximately 92% (db) of the mature dry bean. The cotyledon contributes a valuable component to the appearance, texture, flavour and nutritive value of the bean (Uebersax and Ruengsakulrach, 1989). Parenchyma cells make up the major portion of the cotyledon, which are bound by a distinct cell wall and middle lamella with few vascular bundles. The cell walls are comprised of an organised phase of cellulose micro fibrils surrounded by a continuous matrix. The cell walls are composed primarily of pectic substances (Uebersax and Ruengsakulrach, 1989) and function to give rigidity to the cotyledon tissue by providing adhesion to adjacent cells resulting in the integrity of total tissue. In addition, pectic substances also allow divalent cation cross-linking and thus, forming intercellular polyelectrolyte gels that significantly contribute to the textural quality. The cell wall constituents contribute an important source of crude fibre (3.4-7.2%); however, the significant proportion of the crude fibre (80-93%) is localised in the seed coat (Uebersax and Ruengsakulrach, 1989).

1.1.2 Composition of dry beans

The compositional components including protein, starch, fibre (non-starch polysaccharides) and minerals (Table 1.1) are generally very similar among dry beans and influence quality directly.

Table 1.1. Carbohydrate content of navy beans (Reddy, Pierson, Sathe and Salunkhe, 1984).

Composition (% db)	**Navy beans, %**
Total carbohydrates	58.4
Starch	27.0-52.7
Amylose	22.1-36.0
Total soluble sugars	5.6-6.2
Oligosaccharides:	
Sucrose	2.2-3.5
Raffinose	0.4-0.7
Stachyose	2.6-3.5
Verbascose	0.1-0.5
Dietary fiber	17
Lignin	0.1
Cellulose	3.2
Hemicellulose	2.2
Undigested starch, protein and some ash	11.5

1.1.2.1. Carbohydrates

The total carbohydrates of dry beans range from 24-68%, depending on the type of bean, with total soluble sugars representing only a small percentage. Among the sugars, oligosaccharides of the raffinose family (raffinose, stachyose, verbascose, and ajugose) predominate in most legumes and account for 31,1% to 76% of the total sugars. Oligosaccharides have been implicated in the flatulence problem associated with consumption of dry beans, since these sugars are not hydrolysed and absorbed in the small intestine. Therefore, substrate is formed for microbial fermentation in the lower parts of the gut (Olsen *et al.*, 1982; Sgarbieri, 1989). These sugars generally account for about 31-76%(db) of total sugars. The physico-chemical properties and internal molecular structures of bean starches differ depending on the original source, maturation and environmental factors.

1.1.2.1. Starch

Starch is a glucose polymer and is usually stored as microscopically small granules in the seeds and roots of plants. It is more soluble than cellulose and serves as slowly available food supply for the plant organ during dormancy and germination.

Most bean starch granules have wide variability in size and shape although most bean starch granules are slender (greater length than width) but spherical, ovoid, elliptical and irregular granules are also found (Reddy *et al.*, 1984). This wide variation in granule size and shape could be due to genetic control and seed maturity. This variability in shape is found in starch granules from the same source.

Most starches contain two types of glucose polymers, amylose and amylopectin. Amylose is a linear chain molecule consisting of alpha-1, 4 linkages between the glucose units such that the chain can twist and coil around an axis. Amylopectin is a branched molecule containing one alpha-1, 6 linkage per 30 alpha-1, 4 linkages (Bennion, 1980; Sgarbieri, 1989). There is a wide range of amylose content in legume starches ranging from 10.2% for the great northern bean starch to about 44,0% for the black gram starch (Reddy *et al.*, 1984; Sgarbieri, 1989). Amylose may influence starch solubility, lipid binding, and other functional properties.

Amylose and amylopectin are responsible for the structural form of starch granules (Reddy *et al.*, 1984). A high degree of amylose polymerisation may confer

structural stability on the granule but may also be partially responsible for its resistance toward *in-vitro* alpha-amylolysis. Starch granules contain both crystalline (ordered) and amorphous (unordered) regions (Reddy *et al.*, 1984).

Most legume starches have gelatinisation temperatures of 60°C to 90°C and are characterised by no distinctive lasting peak, but rather very high viscosity that remains constant or increases during cooling. Indigestible or resistant bean starch and its possible role in flatulence is an area of interest in bean fibre research.

1.1.2.3. Non-starch polysaccharides (NSP)

An important feature of dry beans is their relatively high content of non-starch polysaccharides (NSP), and their reported hypocholesterolemic and hypoglycaemic effects. A cholesterol depressing effect by daily ingestion of appreciable amounts of grain legumes was reported, which was associated with a significant increase in fecal steroid excretion, especially of bile acids (Sgarbieri, 1989).

Although beans contain, in general, slightly more insoluble than soluble fibre, they are rich sources of

soluble NSP. Cellulose is the major component of fibre in red kidney and navy beans, while in other legumes (lupines, lentils, broad beans, etc.), hemicellulose is the major component. Cotyledon cell walls contain higher levels of pectin than cellulose (Uebersax and Ruengsakulrach, 1989). The seed coats are primarily composed of cellulose (29-41%) with small amounts of lignin (1.2-1.7%).

1.1.2.4. Dietary fibre

The dietary fibre consisted of a complex carbohydrate entity defined as remnants of cell walls which are not hydrolysed by digestive enzymes of man and lignin as plant material which are resistant to digestion by the secretions of the human gastrointestinal tract. Other minor polysaccharides in beans include pectic substances, arabinogalactans and xyloglucan (Sgarbieri, 1989).

Navy beans contained a water-soluble polysaccharide composed mainly of arabinose followed by low quantities of xylose, glucose and galactose (Sgarbieri, 1989).

1.1.2.5. Protein

Dry beans are dense sources of plant protein, with reported protein content of *P. vulgaris* ranging from 18.8

to 29.3%. The storage proteins are predominant (±80%) in the globulin fractions (Sgarbieri, 1989) while the metabolic proteins are primarily found in the albumin fraction.

Amino acid composition of beans indicate limiting amounts of sulfur amino acids, methionine, cysteine and cystine; fairly low concentrations of tryptophan and high concentrations of lysine. This explains their complementation with cereal grains (deficient in lysine) in plant-based diets. Most bean proteins contain carbohydrates in the molecules in addition to amino acids; therefore are glycoproteins (Sgarbieri, 1989). The globulin fraction contains the lowest content of sulfur amino acids and sugar. The albumins presented the highest contents of sulfur amino acids, tryptophan and sugar, among the isolated glycoproteins (Sgarbieri, 1989).

Bioavailibility of amino acids is influenced by various factors like digestibility, stimulation to endogenous loss, chemical and physical modifications of the proteins during storage and industrial or domestic preparation for consumption (Sgarbieri, 1989).

1.1.2.6. Protein digestibility

Raw beans of the *P. vulgaris* species are toxic and must be cooked prior to consumption. The low digestibility of bean proteins is one of the main causes of their low nutritive value. The *in vivo* true digestibility of white beans is 84,1% (Sgarbieri and Whitaker, 1982).

There is considerable variability in protein digestibility among different commercial classes of *P. vulgaris* and among cultivars within a market class. Digestibility appears to decrease as the content of pigment in the seed increases (Sgarbieri and Whitaker, 1982).

The pigments are, in general, phenolic compounds and it is likely that they interact with the bean proteins, decreasing their digestibility and utilisation (Sgarbieri and Whitaker, 1982). Heating for longer than 30 min at 121°C in a canning medium, results in lowered protein quality and decreased availability of lysine of *P. vulgaris*. The Protein Efficiency Ratio (PER) of raw and cooked legumes is approximately 0 and 1.2, respectively. The hard shell phenomenon lowered PER of the beans (Molina *et al.*, 1975).

Common beans (*P. vulgaris*) contain various proteins to which have been attributed toxic or anti-nutritive properties. Lectins (hemagglutinins), inhibitors of trypsin and chymotrypsin and inhibitors of pancreatic α-amylase are the ones which have been identified and studied to a greater extent (Sgarbieri, 1989).

Phytohaemagglutenin (PHA) or lectin is a tetrameric heat labile glycoprotein (subunit, ca. MW 30 0000 daltons) exhibiting anti-nutritional responses due to disruption of intestinal microvilli, to agglutinate red blood cells and reduce nutrient absorption. These lectins show a high degree of specificity toward different blood groups of human and animals (Sharon and Lis, 1990). Andrews, (1974) isolated a lectin from the navy bean, which had both strong erythroagglutinating and leukoagglutinating activities. It was characterised as a tetramer with four identical subunits of MW 32 000 daltons.

It has been suggested that lectins act during maturation of the plant to contribute to an orderly arrangement of the storage proteins in the protein bodies (Uebersax and Reungsakulrach, 1989). Proper and thorough heating is essential for inactivation of this factor (Coffey *et al.*, 1985).

The lectins are a complex system of isoglycoproteins that are not inhibited by simple monosaccharides or derived sugars but only by more complex carbohydrate moieties, normally attached to glycoproteins or peptides. They agglutinate erythrocytes and leukocytes to a different extent and also exhibit stimulating action on lymphocytes, resulting in morphological changes and division (mitosis). Several lectins are poorly digested by the gut proteolytic enzymes and through their sugar-reactive sites they bind to and disrupt the luminal surfaces of the small intestine.

Additionally, a proportion of the lectins are specifically transported across the intestinal epithelium into the circulation where they induce systemic effects including the stimulation of humoral immune response (Sgarbieri, 1989; Coffey *et al.*, 1985).

Lectins are heat-labile substances that are destroyed under normal conditions of domestic and industrial preparation of foods (Sgarbieri, 1989).

1.1.2.7. Inhibitors of digestive enzymes

There are two protein type inhibitors of digestive enzymes in dry beans. These are the inhibitors of the

trypsin and chymotrypsin (proteolytic enzymes) and the α-amylases from animal and insect sources (Sgarbeiri, 1989).

There are two types of trypsin inhibitors, based on the amino acid at the specific binding site on the inhibitor. The bean protease inhibitors form quite strong complexes with trypsin and often less tight complexes with chymotrypsin (Sgarbieri, 1989).

Heat treatment of beans decreases their toxicity and improves their nutritional quality. Cooking of beans in order to destroy the protease inhibitors and lectins is a problem because prolonged cooking decreases the digestibility and amino acid availability of beans (Sgarbieri and Whitaker, 1982).

1.1.2.8. Minerals and vitamins

The total ash content of *P. vulgaris* ranges from 3.5% to 4.1%(db). Beans are generally considered to be substantial sources of calcium and iron. They also contain significant amounts of phosphorus, potassium, zinc and magnesium (Table 1.2).

Table 1.2. Mineral and vitamin content of Navy beans (mg/100g, dry weight basis) (Sgabieri, 1989).

Mineral	Small white-Raw	Small white-cooked	Vitamins	Raw	Cooked
Ca	150	170	Niacin	2.68	1.78
Cu	1.15	0.89	B1	0.94	0.72
Fe	6.28	5.93	B2	0.228	0.164
Mg	180	160	Folacin	0.260	0.197
Mn	1.8	2	Pyridoxine	0.499	0.365
P	440	450	Carotene	0.03	-
K	1.58	1.44	Tocopherol	1.51	-
Na	11	3.4	Ascorbic acid	3.0	-
Zn	3.5	3.6			

Ash content decreases after cooking due to leaching, with losses ranging from 10 to 70%. The wide range of reported losses could be due to different soaking and cooking methods. The main problem in connection with the mineral contribution of beans is related to bioavailability. Several components of bean seeds (fiber components, phenolic compounds, phytic acid) have the ability to react with minerals under certain conditions, contributing to lower bioavailability. Phosphorus in beans is largely present in phytic acid which form a complex with proteins and complex dietary essential minerals such as calcium, zinc, iron, and magnesium and

renders them biologically unavailable for absorption (Uebersax and Ruengsakulrach, 1989).

Dry edible beans provide several water-soluble vitamins (thiamine, riboflavin, niacin and folic acid), but very little ascorbic acid and fat-soluble vitamins. However, variability of vitamin content is high. Bioavailability of vitamins of beans could be a problem. Commercial methods of preparation of canned beans cause a significant loss of water-soluble vitamins (Uebersax and Ruengsakulrach, 1989).

1.1.2.9. Lipids

Dry beans possess relatively low total fat content, generally 1-2%. Neutral lipids are the predominant class and account for 60% of the total lipid content. Phospholipids make up 24-35%, while glycolipids account for up to 10% of the total lipid content of legume seeds. The fatty acid composition of legumes shows a significant amount of variability, however, legume lipids are generally highly unsaturated (1-2%), with linolenic acid present in the highest concentration. Palmitic acid is the predominant saturated fatty acid (Table 1.3). Due to the low overall concentration of lipids in dry beans their nutritional contribution, as a source of dietary

calories, is not important. Dry bean lipids may be implicated in the deterioration of bean quality and nutritive value through its oxidation and degradation products by reacting with protein and other bean components like carbohydrates and vitamins through free radicals and carbonyl-amino reactions. These reactions are likely to cause loss of nutritive value as a consequence of a decrease in protein digestibility and essential amino acid bioavailibility and cause deterioration of colour and flavor (Sgarbieri, 1989).

Table 1.3. Fatty acid composition of small white beans (Sgarbieri, 1989).

Fatty acid	**California small white**	**Kidney bean**
Saturated fatty acid,%		
16:0 Palmitic	12.2	13.4
18:0 Stearic	0.65	0.74
Total saturated fatty acid,%	12.85	14.14
Unsaturated fatty acid,%		
18:1 Oleic	9.7	8.3
18:2 Linoleic	23.2	26.9
18:3 Linolenic	54.3	50.60
Total unsaturated fatty acid,%	87.2	85.8

1.1.2.10. Tannins, polyphenols and antinutritional components

The procyanidin and condensed tannin content of dry beans ranges from 0.4 to 1.0. Despande and Cheryan (unpublished) report that tannin content decreased with dehulling with 68-95%. Thus it appears that tannins are concentrated in the seed coat and were prone to leaching from the seeds with soaking. The hydroxyl groups of the phenol ring enable the tannins to form cross-links with proteins, which may be implicated in post-harvest seed hardening or decreased digestibility.

Coloured varieties contained higher phytate levels than

white varieties (CIAT, 1987). Dehulling increased the phytate content of the beans. Trypsin, chymotrypsin and amylase inhibitory activity also increased (Table 1.4) significantly upon dehulling (Despande and Cheryan, unpublished).

Table 1.4 Effect of dehulling on protein content and antinutritional factors (Despande and Cheryan, unpublished).

Treatment	**Protein**	**Phytic Acid**	**Tannin**	**Trypsin**	**Chymo-trypsin**	**Amylase**
Whole bean	21.3	21.6	122.1	257	217	531
Dehulled	23.6	29.1	10.4	261	271	881

Protein - %
Phytic acid - (mg/g)
Tannin - (mg catechin equivalents/100g)
Trypsin - Units/ g $x10^{-3}$
Chymotrypsin - Units/ g $x10^{-3}$
Amylase - Units/g

1.2. Influence of storage and processing on chemical, structural and nutritional properties of dry beans.

Preparation of beans involves preliminary soaking or blanching followed by various heat treatments to inactivate toxic compounds, improve digestibility, and develop a tender, palatable product. Water and heat play an important role in chemical reactions, heat transfer and chemical transformations, such as protein denaturation and starch gelatination (Uebersax and Ruengsakulrach, 1989).

1.2.1. Seed storage

Dry and processed bean quality deterioration increased with increases in storage relative humidity and temperature. Stable quality was obtained in beans stored at 75% relative humidity or less with temperatures of 20°C or lower. Mold growth occurred on beans stored at 20°C and 30°C when the relative humidity was greater than 75% (16% moisture) (Uebersax and Bedford, 1980).

A rancid off-flavour is also detected when beans were stored at high temperatures. Oxidation and polymerisation of lipids may cause changes in water permeability, which

in turn affect the cooking time (Muneta, 1964; Morris and Wood, 1955).

Exposure to high temperature and humid storage conditions may potentiate phytase which hydrolyses phytate, thus reducing chelation of Ca^{++} and Mg^{++} ions within the middle lamella.

1.2.1.1. Moisture Changes:

Constant equilibrated weights occurred in beans stored at 75% relative humidity. Weight gains increased with storage time at higher relative humidities and with increased storage temperatures. Highest weight gains occurred in beans stored for 84 days at 29°C, 100% relative humidity. The greatest weight gains occurred in the beans with the highest mould count. No significant moisture changes occurred in beans stored at 75% relative humidity. Equilibrium moisture was not obtained for beans stored at higher humidities because of mould growth (Uebersax and Bedford, 1980).

Moisture content increased with storage time and with higher relative humidities. Except for beans having mould counts (93 and 100% relative humidity at 20°C and 29°C for 70 and 84 days), the calculated moisture contents

were similar. With high mould counts, the determined moisture contents were much lower than those determined on the basis of weight gain (Uebersax and Bedford, 1980).

1.2.1.2. Mould growth during storage

Mould growth increased with an increase in relative humidity and storage time and with storage temperature in the 79 to 100% relative humidity ranges. At 75% relative humidity, maximum growth occurred at 20°C. These results indicated that, under a static system, mould growth would occur at 16% moisture, 75% relative humidity (RH) at temperatures of 12°C or higher (Uebersax and Bedford, 1980).

1.2.1.3. Dry bean surface colour

The Hunter L values, a measure of black to white surface colour, decreased with increased relative humidity, storage time and temperature. The greatest change occurred in beans stored for 84 days at 29°C, and 93 and 100% relative humidity. Hunter a_L (red-green character) and b_L (yellow-blue character) values increased with increased RH, temperature and storage time. The decrease in L (lightness) and increase in a_L and b_L values generally correspond to non-enzymatic browning of beans. Mould growth was partially responsible for colour changes

at the higher temperature and humidities (Uebersax and Bedford, 1980).

1.2.1.4 Hard-to-cook beans

Hardshell is a term that is applied to dry mature seeds. It describes a condition in which the seed fails to imbibe water within a reasonable time when it is moistened (Bourne, 1967).

Storage of dry beans at high temperature and humidity conditions will result in 'hard-to-cook' (HTC) phenomenon. This defect is characterised by extended cooking time required for adequate cotyledon softening and a lowered water absorption ratio (Aguilera and Rivera, 1992) is distinguished from a defect termed 'hard shell'.

It is reasonable to conclude therefore that the increase in moisture content due to high relative humidity during storage, is one of the key factors in the initiation of hardening. It permits restricted metabolism which leads to membrane breakdown which in turn causes reduced leakage and imbibition value, also allowing access of bivalent cations from hydrolysed phytin to the pectin (Jones and Boulter, 1983).

Molina *et al.* (1976) studied the relationship between soaking time, cooking time, and nutritive value as a function of time and conditions of storage for the black bean, var. S-19N, cultivated in Guatemala. They stored the beans for 3 months at 22-25°C and 60-70% relative humidity and also for 6 months at 21°C and 77% relative humidity. Their main findings were:

1. there was an increase in cooking time (121°C) from 10 to 30 min in both sets of conditions;
2. there was a significant decrease in the protein efficiency ratio (PER) as a result of storage under both sets of conditions, which was proportional to storage times;
3. the solubility of the proteins in water and salt solution decreased with storage time, they reported an increase of total available methionine and of available lysine, with no correlation with the decrease of PER.

Significant changes in drained weight, percentage splits and firmness has been reported during 0-9 month storage for a number of bean types. Soaking time played an important role in these changes (Nordstrom and Sistrunk, 1979).

Changes in cooking time and water absorption that occur in a bean seed during storage, can be summarised as follows:

Stage I (fresh seed), where cooking time is very nearly the same for most varieties and is independent of water absorption. The hydration capacity of the seeds remained constant, the texture (Instron apparatus) is 200kg force, the cooking time is 60 min and the PER value is 1.01 (Antunes and Sgarbieri, 1979).

Stage II (intermediate) in which cooking time increases and becomes correlated with water absorption. The texture of the cooked beans increased to 250kg force, the cooking time increased to 95-116 minutes (under different temperatures and relative humidity) and the PER value dropped to 0.66-0.43 (Antunes and Sgarbieri, 1979).

Stage III (seeds with hard seed coat), where cooking time reaches a maximum and is no longer correlated with water absorption (CIAT, 1980). The texture reaches values greater than 500kg force after storage under 37°C and 76% relative humidity, cooking time increased to 300 minutes and the PER dropped to so low as 0.10 (Antunes and Sgarbieri, 1979).

1.2.1.5. Correlation between density and hardshell in dry beans

The relative density of dry beans (*P. vulgaris*) decreases as the beans imbibe water during soaking prior to cooking. However, the relative density range of beans is too wide to enable differences in density between normal and hardshell beans to be used as a method of separating hardshell beans. The size distribution of a given lot of dry beans follows a normal distribution pattern, but the hardshell beans are concentrated in the smaller sizes. The incidence of hardshell beans in a lot of unsoaked dry beans can be reduced by size grading and rejecting the hardshell-rich smaller sizes. Rejection of the smallest 20% of the beans removes 75% or more of the hardshells. Normal beans imbibe water and swell during soaking, but hardshell beans do not swell, and hence are further concentrated into the smaller sizes during soaking. Hardshell beans can be practically eliminated from normal beans by size grading after soaking. Rejection of 1% of the smallest beans after soaking will usually take out all the hardshells, altough a canner would find a rejection of 1% of beans economically unacceptable (Bourne, 1967).

1.2.2. Structural changes during processing

Thermal processing induces the largest alteration in structure and the initiation of diverse chemical reactions among bean constituents. There is an increase in solubility of protein during thermal processing, but the starch granules stay relatively unchanged (Uebersax and Ruengsakulrach, 1989). During the soak/blanch treatment, native proto-pectin may also form soluble protein and pectin, which will rapidly polymerise. Soluble protein and pectin may leach causing increased viscosity of the cooking media (Uebersax and Ruengsakulrach, 1989). It has been proposed that the differences in pectin composition could be a major factor determining cookability of dry beans beans (Uebersax and Ruengsakulrach, 1989). Good correlation existed between firmness and soluble pectin in raw and canned pinto beans (Uebersax and Ruengsakulrach, 1989).

Soluble pectin in raw and canned navy beans had high negative correlations, r=-0.97 and -0.97, respectively with the firmness of canned navy beans. The results suggest bean cultivars with higher soluble pectin content produced less firm canned beans if $CaCl_2$ is not added (Chang, 1988).

Soaked/blanched beans are subjected to further heating

under pressure during retort processing. The absorbed water and heating initiate thermal degradation or inter-cellular and cohesive materials (middle lamella) and thus allows cells to separate and soften. Results demonstrated that in dry, soaked (30 min at 21°C) and blanched (30 min at 88°C) beans, fracture occurs across the cell wall; however, in the canned bean, fracture occurs in the middle lamella leaving the cell intact. The cell separation may account for the notable texture differences exhibited.

Various significant chemical changes have been induced within the cell inclusions during heating. Protein bodies lose their normal spherical structure due to swelling and denaturation. Several changes occur when starch granules are heated in the presence of water. The order-disorder phase transition is the most important change, although the starch granule shape conformation alters, uptake of heat and hydration of the starch granule accompanied by granule swelling also occurs simultaneously. Starch granules demonstrate the deformation, expansion and loss of birefringence associated with gelatinisation, although the presence of intact cell walls impedes conformational changes. The gelatinisation phenomenon is complex and depends not only on starch granule structure but also on factors such as granule size, phosphorus content, bound

lipids and protein.

Reddy *et al.*, (1984) mentioned that swelling of the starch granule is the first stage of hydration-related properties. The swelling may proceed in two stages in the case of navy bean starches. Water absorption of legume starches is inversely related to solubility and directly related to swelling. The starch structure-gelatinisation temperature relationship is described as follows:

1) in starches containing appreciable amounts of amylopectin, the associated amylopectin chain clusters constitute the crystalline entity which affects the gelatinisation temperature range.

2) gelatinisation temperature is affected by degree of amylopectin branching to the extent that excessive branching diminishes rigidity of the starch granule.

3) High amylose content resists the gelatinisation process due to its insolubility in aqueous solutions (Reddy *et al.*, 1984).

Intracellular starch gelatinisation (76°C-95°C) and protein denaturation occurs during moist heating, which develops a uniform smooth texture. The characteristic

cooked bean flavour develops through the degradation or interaction of native tissue constituents mediated by Maillard reaction namely proteins and carbohydrates (Uebersax and Ruengsakulrach, 1989).

Rockland and Jones (1974) stated that the middle lamella of plant tissue is generally considered to be composed of pectic substances associated with divalent cations such as calcium and magnesium and possibly proteinaceous material. Divalent cations bridge and support the pectinaceous matrix between bean cells. During normal cooking in boiling water, intercellular structure softens and permits separation of adjacent whole cells. It is suggested that the separation of bean cells during cooking may also be related to the transportation or removal of divalent cations, particularly calcium and magnesium, from bridge positions within the pectinaceous matrix of the middle lamella. Therefore, the elimination of the cation bridge by a metal chelating agent allows softening of the middle lamella and separation of whole cells. During cooking of whole beans, mechanical stresses, imparted during starch gelatinisation, protein denaturation, swelling and heat convection, may further facilitate cell separation and the development of the uniform, smooth texture in fully cooked beans.

1.2.3. Compositional changes during processing

1.2.3.1. Carbohydrates

Starch functional properties influencing process yield and product texture include swelling, solubility, gelatinisation temperature and pasting characteristics. *In vitro*, several changes occur upon heating a starch-water system, including extensive swelling, increase in viscosity, translucency, solubility, and loss of birefringence. Reddy *et al.* (1984) suggested that the swelling ability and solubility depend on starch source, temperature and pH.

An initial lower moisture content was found to be associated with a lower tendency for the starch to gelatinise *in situ*. Factors which influence this property may include the size and shape of the starch granules, the ionic charge on the starch, the kind and degree of crystallinity within the granules, the presence or absence of fat and protein, and the molecular size and degree of branching of the starch fractions (Uebersax and Ruengsakulrach, 1989).

Complete gelatinisation of starch granules in seed legumes may be due to the barrier imposed by cellular

structures such as cell walls and protein and/or the inherent structural characteristics of the starch granules. Most bean starches show some tendency to retrograde during cooling and have relatively constant cold-paste viscosity during a holding period at 50°C. Retrograded starch present in final canned bean products may contribute to their relatively low digestibility (Uebersax and Ruengsakulrach, 1989).

1.2.3.2. Monosaccharides and oligosaccharides

Although total sugars represent only a small percentage of the total carbohydrate, these reducing sugars can participate in non-enzymic browning reactions and contribute to flavour formation. The sugar content of soaked beans is a function of soaking time, but not the bean-to-water ratio. The sucrose, raffinose, and stachyose content of dry beans decreased approximately 20%, 35% and 45%, respectively after soaking. Sugar losses during soaking are not proportional to the solubility of the respective sugars, however, heat treatments increase sugar solubility and enhances leaching from the tissue. The increased permeability of cell membrane to ions and small molecules during the thermal processing of plant tissues allows diffusion of the saccharides between the beans and brine. The thermal

degradation of the oligosaccharides to mono- and disaccharides also influenced the distribution of saccharides in the processed beans (Drumm *et al.*, 1990).

Substantial amounts of flatus-producing components in beans,of which starch is the major contributor to flatulence in dry beans, can be reduced by various common processes (soaking, cooking and discarding the cooking water, germination or fermentation). Since the sugars of the raffinose family are water soluble, discarding the soaking and cooking waters will remove most of these sugars; however, substantial losses in total solids, vitamins and minerals are also sustained (Uebersax and Ruengsakulrach, 1989).

1.2.3.3. Proteins

Cooking dry beans is necessary not only to tenderise the seed coat and cotyledons and develop acceptable flavour and texture, but also to reduce toxic factors to an acceptable level. It is also necessary to make the bean protein more digestible (Sgarbieri, 1989).

Generally, proteins react non-covalently with substances in their environment primarily through hydrophobic forces and ionic bonding. The macromolecular structure of

proteins and the large differences in the intrinsic reactivities of their side chains dramatically influence water interaction and functional properties (Uebersax and Ruengsakulrach, 1989). Four to ten percent of the protein of the raw beans was leached into the cooking brine.

On a dry weight basis, cooked beans have a protein content that was 70-86% of the raw beans. The loss in protein is attributed to the extraction of soluble proteins, hydrolysis of protein to free amino acids, and non-enzymatic browning reactions. Nitrogenous compounds, including free amino acids and short chain polypeptides, were leached from the tissue during soaking and canning. These compounds are also precursors of the Maillard (non-enzymic browning) reactions which form heterocyclic compounds which contribute to the unique flavour characteristics of dry beans (Drumm *et al.*, 1990).

1.2.3.4. Minor Constituents

Losses of total bean solids, N compounds, total sugars, oligosaccharides, Ca, Mg, and three water-soluble vitamins (thiamin, riboflavin and niacin) were measured and found to be very small at soaking temperatures up to 50°C; however, a three to four fold increase was found when the soaking temperature was raised above 60°C (Kon,

1979). There have been few published reports on the effects of processing on the lipid composition of legumes (Drumm *et al.*, 1990).

Lipid oxidation, catalysed by heat, enzymes, light or metals, leads to the formation of hydroperoxides that further decompose to produce off-flavours. These decomposition products (carbonyl compounds) can chemically interact with peptides to yield cross-linked end products. Thus, the storage of legumes can result in a loss of quality (off flavours and odours), nutritional value and functionality. Drumm *et al.* (1990) indicated that the effects of processing on the lipid content and composition of dry beans were minimal and reflected changes in the distribution of the lipid class components as a result of hydrolysis of the ester linkages. Total lipid, lipid class, fatty acid and sterol contents were relatively unchanged. Soaking treatments contribute to the minimal amount of lipid degradation observed, in that lipoxygenase is inactivated during blanching (Drumm *et al.*, 1990).

Dry beans contain 3.9 to 4.8% total ash and considerable losses of these mineral constituents leach during both soaking and cooking procedures (Drumm *et al.*, 1990). Greatest losses occur as a result of increased solubility

and tissue breakdown as preparation temperatures increase.

Phenolic acids have increasingly been recognised to influence quality of dry beans during storage and subsequent thermal processing due particularly to reaction and cross-linking with proteins. Processing contributed to a decrease in the total phenolic acid contents of the dry beans which may be attributed to oxidation and decarboxylation of the phenolic acids to their respective phenols, hydrolysis of the esterified and insoluble phenolic acids to the free acids, and solubilisation and leaching of the free phenolic acids from the tissue (Uebersax and Ruengsakulrach, 1989). These free phenolic acids and phenols are characterised as having sour, bitter, astringent and phenol-like flavour properties (Drumm *et al.*, 1990).

The predominant phenolic acids found in dry navy beans are p-coumaric, furulic and sinapic acids. Saponins are significantly decreased in processed dry beans although saponins are steroid or triterpenoid glycosidic compounds and are not water-soluble and therefore leaching from the tissue would be minimal. A possible mechanism for the observed decrease in the saponin content of the soaked and canned beans with processing in the hydrolysis of the

glycosidic bond between the sapogenin and glucosidic residue during thermal processing (Drumm *et al.*, 1990).

1.3. The effect of the water quality on the canning quality.

It was shown that water quality influenced the final product performance. Water hardness, or total calcium and magnesium, has been shown to have profound influence on the process procedure and bean quality. Water hardness is an important parameter in bean processing because it results in:

1) direct interaction with food constituents, such as pectin, to dramatically influence textural properties;
2) decreased sanitation efficiency through reduced detergency and propensity for film deposits; and
3) the development of tenacious scale deposits in water handling equipment causing decreased efficiency of heat transfer and increased maintenance or equipment replacement cost (Uebersax *et al.*, 1987).

All natural waters contain varying amounts of impurities. The common impurities include dissolved solids, suspended solids, hardness, alkalinity (pH), free mineral acids, dissolved gases, sulphates, chlorides, silica, nitrate, iron, manganese, sulphides and ammonia. Theoretically, hardness of water is the sum of the concentrations of all

the dissolved salts of calcium and magnesium. The most common of these salts are calcium and magnesium bicarbonate, calcium and magnesium chloride, and calcium and magnesium sulphate. Bicarbonates are often the principal hardness salts formed by the action of water and carbon dioxide on substance such as limestone. Usually, the hardness contributed by iron, aluminium, manganese strontium, zinc, etc. is insignificant and is disregarded; however, in some water types these ions must be taken into consideration (Uebersax *et al.*, 1987).

Among the water hardness principles, calcium and magnesium ions play the major roles in fruit and vegetable processing. The characteristics of the cell wall and middle lamella of plant tissues and the changes in these components during thermal processing and freezing have a significant influence on the texture and consumer acceptability of the product. The intact cells and firm molecular bonding between constituents of cell walls maintain integrity of plant tissues. The pectic substances are extensively used in structure stabilisation through cross-linking of their free carboxyl groups with polyvalent cations such as Ca^{++} and Mg^{++}. This increases firmness through enhanced cross-linking and the formation of relatively insoluble calcium pectate. These stabilised structures support the tissue

mass, and the integrity is maintained even through heat processing. Most common firming agents include calcium chlorides, calcium citrate, calcium sulphate, calcium lactate, and monocalcium phosphate. However, an excessive amount of calcium ions can also cause various textural defects such as toughening of canned dry beans (Uebersax *et al.*, 1987).

1.3.1. Calcium in bean soaking and blanching:

Soaking of dry beans aids the uniform expansion of individual grains, ensures product tenderness and improves colour. A positive correlation was found between increasing concentrations of calcium and bean firmness. It is postulated that the calcium ions combine with the pectin in cell walls and strengthen the binding between cells forming tough pectin-metal complexes (Uebersax *et al.*, 1987).

Uebersax and Bedford (1980) substantiates earlier work showing that increased calcium concentrations resulted in firmer processed beans and when calcium was added in the presence of heat the firming effect was even greater. Van Buren *et al.* (1986) reported that the addition of $CaCl_2$ to soak and brine waters has contributed to a significant reduction in seed coat splitting of kidney beans. Levels

of 150 to 350 ppm $CaCl_2$ resulted in lower weight gain during soaking, reduced drained weight, firmer processed beans and less seed coat splitting (Larsen *et al.*, 1988). Calcium addition to either soak or blanch water has generally shown greater effects than that added to the cover sauce or brine.

1.3.2. Expression of water hardness

Water hardness may be expressed as calcium carbonate or calcium ions. Hardness may be expressed as ppm (i.e. milligrams per litre). Classification of water hardness is indicated in Table 1.5

Table 1.5. Classification of water Hardness (Uebersax *et al.*, 1987).

Class	CaCO3 (ppm)	Ca++ (ppm)
Soft	0-60	0-24
Moderately hard	60-120	24-48
Hard	120-180	48-72
Very hard	Over 180	Over 72

Uebersax *et al.*, (1987) stated that bean processors could recognise cost-effective control of quality by partial softening and blending if excessive hardness is encountered.

1.4. Effect of processing methodology on food quality attributes of dry beans

A knowledge of the initial moisture content of bean seeds is important because it is known to affect the rate of water uptake during soaking (Hosfield and Uebersax, 1978). Care should therefore be exercised to standardise the initial moisture of the seed prior to soaking and processing. Soak and water pick-up properties of beans were not associated with textural differences (Hosfield and Uebersax, 1978). During soaking, beans generally undergo an 80% increase in weight due to water imbibition and equilibrate with water in the canning medium until they reach a final moisture content of approximately 65%. The washed drained weight of processed beans is the weight of beans after washing away the sauce or starch exuding into the brine. It is assumed that intact beans undergo little loss of solids during thermal processing while excessive bean breakdown during cooking results in starch exudation into the canning medium and may result in sauce 'graininess' and 'clumping' of individual beans. Beans must soften during processing yet still maintain their individual integrity. Variation noted among genotypes suggests that inherent differences exist in these beans for factors influencing the hydration of the cotyledonary matrix (Hosfield and Uebersax, 1978).

Changes in phenolic acid content related to HTC defect were studied by (Uebersax and Ruengsakulrach, 1989). Navy beans were stored for nine months under conditions (5°C/40% RH, and 35°C/80% RH) to produce different degrees of HTC. Canned product quality characteristics associated with adverse storage were an undesirable darker colour (decreased Hunter L, a and b values) and increased firmness. Several researchers attributed this darker colour to polymerisation of phenolic compounds (Uebersax and Ruengsakulrach, 1989). Changes in free hydroxy cinnamic acids, hexane soluble and methanol soluble hydroxy cinnamic acids, cell wall bound hydroxy cinnamic acids, and lignin content were determined. Storage induced HTC beans contained higher levels of hydroxy cinnamic acids (especially ferulic acid) than the control beans in all fractions prepared from seed coats and cotyledons except for the methanol soluble and cell wall bound phenolic acid fractions from cotyledons. No significant changes in lignin content were detected among the treatments. Large increases in free hydroxy cinnamic acid content were associated with the degree of hardening, thus suggesting a relationship between the two phenomena (Uebersax and Ruengsakulrach, 1989).

Moscosco *et al.* (1984) stated that the rate of softening of beans during cooking, and the rate of dissolution of pectin during cooking followed apparent first-order kinetics and their apparent rate constants correlated highly with each other. The apparent softening rate constants decreased with increasing time of storage. The loss of cookability in mature bean seeds stored under high temperature-high humidity conditions probably results from a decrease in phytic acid phosphorus and alterations in the ratio of monovalent to divalent cations in the tissue (Moscosco *et al.*, 1984).

The total pectic substance in the seed coat and cotyledons showed a larger decrease of pectic substances after cooking for 45 min. The apparent rate constants for the dissolution of the pectic substances in both the seed coats and cotyledons were highest at 32°C tissue (Moscosco *et al.*, 1984). A consistent decrease in the apparent rate constants was observed during storage of beans at 32°C. This evidence supports the theory that changes in the pectic substances are responsible for the changes in the cooking properties of the dry beans (Moscosco *et al.*, 1984; Sefa-Dedeh *et al.*, 1979).

The phytic acid phosphorous content of soaked beans correlated well with the softening rates of beans and the

rate constants for the dissolution of pectic substances in the seed coats and cotyledon tissue (Moscosco *et al.*, 1984). These observations that high phytic acid phosphorus content in the beans favour rapid rate of softening and solution of the pectic substances making the beans more cookable. The high correlation between firmness of cooked beans and phytic acid phosphorous of the uncooked soaked beans suggests that phytic acid content could be used as an index of the cookability of red kidney beans. A phytic acid phosphorous level less than about 400mg per 100g dry bean showed reduced cookability (Moscosco *et al.*, 1984).

Calcium decreased during cooking, and the decrease was greater in beans stored at 4°C than beans stored at 32°C tissue (Moscosco *et al.*, 1984). The magnesium levels were one-third to one-fourth of the calcium levels but they showed a trend similar to the calcium during cooking tissue (Moscosco *et al.*, 1984). High values of calcium and magnesium in the seed coats seem to be associated with high firmness of the cooked bean, high total pectic substances and high water soluble pectic substances. The seed coats of beans stored at 32°C had a high potassium level that was almost unchanged after 15 minutes of cooking and then declined slowly with longer cooking time. The potassium content of the seed coats was not

well correlated with the bean firmness, the total pectic substances or the water insoluble pectic substances content. Magnesium and potassium were lost during bean storage and bean cooking but there was little change in the calcium content of seed stored at 4°C and little decrease in seed stored at 32°C during cooking (Moscosco *et al.*, 1984).

The observation that aged beans with low phytic acid content, due to hydrolytic cleavage by phytase, show a considerable loss of potassium ions from the cotyledons.

1.4.1. Soak methods and soak additives

The purpose of the soaking and blanching treatments of beans is to ensure a uniform and complete water uptake prior to the autoclaving step, so that further uptake and expansion of beans occurs in the can and to ensure that no hard seeds end up in the product. The weight of water absorbed is approximately equal to the original weight of the bean (i.e. water uptake = 100% or moisture content achieved is 50-55%) (Priestley, 1978).

Priestley (1978) reported that there are two principal methods of achieving water uptake, the first employing a long soak in cold water and the other using a shorter,

high-temperature treatment. Previously, the long cold soak method was used almost universally but there was a shift towards the high-temperature treatment. The long cold soak involves soaking beans in water at around 20°C for periods ranging from 6-18 hours. This method has unfavourable aspects regarding control of the swelling and microbiological stability. Germination often occurs with lengthy soaking processes with an outgrowth from the germ which is invariably broken off during subsequent processing steps. Small pieces of worm-like material can be observed in the final product. After Priestley (1987) obtaining data to can dry beans in tomato sauce from the South African commercial sector, he recommended temperatures of 88°C and treatment times of 40 minutes which is lower temperatures and longer soaking times than the processes employed in the South African commercial sector for the hot soak treatment.

The composition of soaking solutions, and time and temperature of soaking can be manipulated to produce desirable changes in the quality of canned dry beans. The magnitude of changes depended on the composition and colour of the different bean types. Acid soak solutions improved colour of all bean types tested by Junek *et al.* (1980) when compared to water soaking.

Junek *et al.* (1980) conducted a study on three bean types (Pinto, Red Kidney, and Navy), three soaking times, eleven soaking solutions, three soaking temperatures and three storage times of canned beans to determine their influence on quality attributes. Navy beans were higher in percentage splits than Pinto and Red Kidney. Beans, soaked in solutions at 25°C, rated higher in quality than those soaked at 15°C and 53°C. Shearpress values were lower in beans soaked at 35°C. Acidifying the soaking solutions with either malic or citric acid resulted in an improved colour, but firmness was increased only in Navy beans. Longer soaking times decreased firmness in Pinto and Red Kidney while percentage splits and drained weight increased. There was an increase in splits, lightness (L), and redness (a_L) in Pinto and Red Kidney after 18 months of storage.

Wiese and Jackson (1993) found that the wahed drained weight for navy beans increased significantly if it were soaked for two hours instead of a soaking/blanching method of 16 hours. This implies that the beans could not absorb the moisture from the brine during processing to compensate for lower initial moisture levels in the beans. The drained weight of the navy beans consistently increased as the initial bean moisture increased. It is therefore necessary to increase the fill weight when the

beans are only soaked for two hours to compensate for the final drained weight comparable to beans soaked for 16 hours and blanched. Fully soaked beans are necessary for optimum economy in the commercial processing industry.

Davies (1976) reported that matting of navy beans occurs when blanching is eliminated, although the cooking process had a greater effect on firmness than blanching method. Therefore, steam blanching and cooling or water blanching is preferable.

Water uptake rate and volume increase in navy beans was directly related to soak time within each soaking procedure, and was accelerated at higher soak temperatures. Increased calcium levels in the soak water reduced the rate and amount of water uptake and this effect increased at higher soak temperatures. Water uptake varied also with storage conditions and time, with years and with locations (Uebersax and Bedford, 1980).

1.4.2. Canning methods

Beans canned in tomato sauce have lower drained weights than those canned in water, probably due to the reduction of starch and protein swelling at the lower pH. The National Canners Association of America recommends that

for the 410g can, a canning temperature of 50 min at 121°C although Nordstrom and Sistrunk (1979) use 45 min at 121°C.

Rotation in an agitating retort, increases the rate of heat transfer, permitting a reduction in process time and also reduces the gelation tendency of the sauce.

Process temperature, rather than process time, had a more significant effect on navy bean softness. To obtain the desired tenderness, data indicate that the processor should increase process temperature rather than lengthen process time (Davies, 1976).

Heinen and Van Twisk (1976) reported that dry bean breeding lines produced in South Africa, varied greatly in respect to bean size and bean volume but these were unrelated to differences in water absorption capacity. They found that beans with that absorbed water absorption between 90 and 95% of their initial weights might not always comply with the standard requirement for mass after draining unless a correction factor for filling mass is applied. They also recommended that seed size determinations be done in order to determine the effect of the seed size on canning quality.

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1.4.3. Evaluation of canned dry beans

1.4.3.1. The micro canning method

Quality determined by one or more experts, who render some particular judgement about samples, is subjective. The subjective approach suffers because the standards set forth vary with time and judges. Quality must be defined in an objective manner and then enlist some mechanism(s) for routinely measuring it qualitatively, precisely, and rapidly (Hosfield and Uebersax, 1990).

Consumers are conscious of bean colour and appearance, ease of preparation, wholesomeness, mouthfeel and texture. The processors are restricted by the expectations of consumers, yet seek properties of beans that are related to cookability and more efficient means of product preparation. They seek beans that expand rapidly and uniformly in the can during processing, leave no sludge at the bottom of the container, have acceptable drained weights and texture after cooking, and cook to tenderness rapidly and uniformly (Deshpande *et al.*, 1983).

1.4.3.2. Processed bean evaluations (Canning)

1.4.3.2.1. Texture (Kg and KgS)

Texture is a primary canning quality character because texture affects the perceived stimulus of chewing and, hence, influences to a large degree a consumer's acceptance of a food product. Sefah-Dedeh and Stanley (1979) reported that softening of beans during cooking are accompanied by structural changes in the seed. The major changes were gelatinisation of starch and softening and breakdown of the middle-lamella cementing material found in the cotyledon. The microstructure influences water-absorption characteristics and texture of soaked and cooked legumes.

Textural changes during soaking are dependant on the water-absorption pattern; thus any structural, chemical, and/or physical change that affects the water-absorption pattern can similarly affect the soaked-bean texture. The rate and degree of softening of the middle lamella and the gelatinisation of the starch showed no great micro-structural changes. Sefah-Dedeh and Stanley (1979) suggested that other factors in addition to the breakdown of the middle lamella might influence the texture of cooked legumes. The inherent susceptibility of the starch

granules and the protein matrix within the cotyledon cells to softening during cooking may play an important role in the degree of softening.

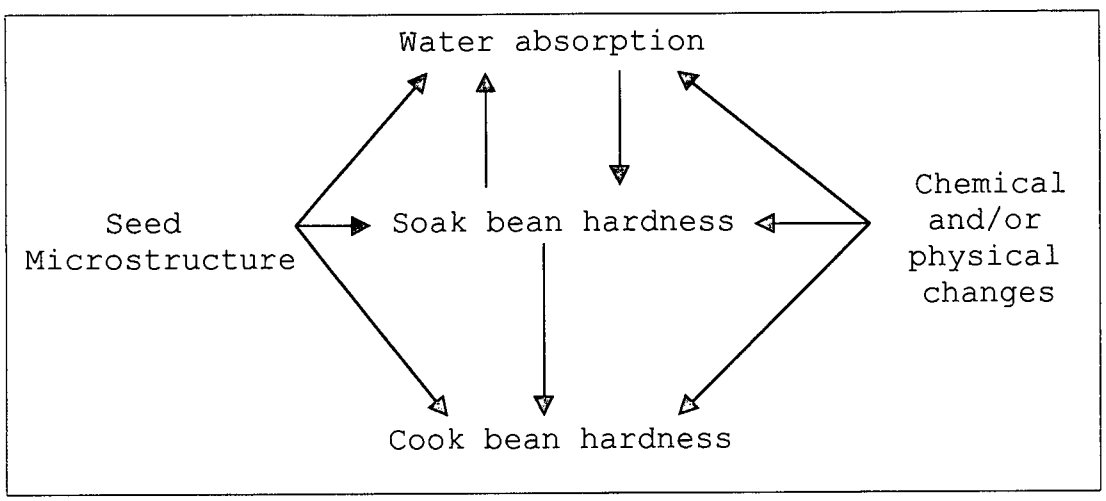


Fig. 1.1. Possible interrelationships among legume seed microstructure, texture, and chemical and/or physical changes (Sefa-Dedeh and Stanley, 1979).

The correlation between the moisture absorption and the texture of the cooked beans is therefore not very high.

Cooked bean texture, as examined by a shear press, have instrument recorded shapes of two kinds (Hosfield and Uebersax, 1980). Shear press recordings of 35 cooked dry beans accessions fell into a Type A curve which showed a large contribution due to shearforce involved in the extrusion of beans between the slots in the sample cut as

the head descended, and a curve (Type B) which was characterised by a predominant compoenet due to compression (Fig. 1.2). The curve types appeared to be a characteristic of the genotype rather than of seed-colour, size of bean, or final moisture percentage (Hosfield and Uebersax, 1980).

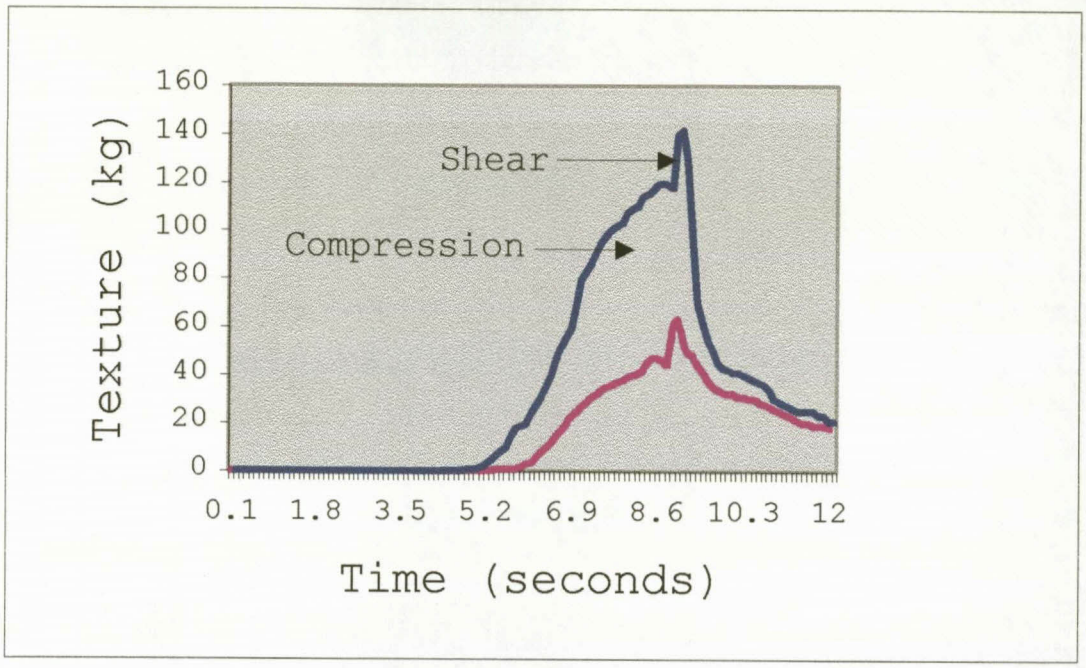


Fig.1.2. A typical texture curve, of two different cultivars, indicating the change in pressure (kg/100g sample) over time.

Bourne *et al.* (1978) demonstrated that computer-assisted readout of data from texture profile analysis (TPA) curves was an accurate and rapid method of measuring the

texture. They indicate that a loadcell of the texture press system (TPS) to a computer would eliminate the time required to trace curves by hand and any errors caused by pen response of the recorder. Rapid advances in computer technology allowed a wider use of TPA with more accuracy.

The maximum force (Kg) correlated significantly with sensory firmness and the energy for extrusion (KgS) with sensory chewiness (Anzaldua-Morales and Brennan, 1982). Product temperature influences textural perception (Machiorlatti *et al.*, 1987). Over the temperature range of 5°C to 60°C, processed bean texture decreases in a linear fashion as temperature increases.

Textural properties of processed beans must fall within prescribed acceptability limits. Deviations from the range of acceptance reduce bean quality and may lead to variety rejection. Beans can be unacceptable if they are too firm ('tough beans') or too soft ('mushy beans') after cooking (Hosfield and Uebersax, 1980).

Texture and final moisture content of the processed beans (percentage moisture after canning) were highly and negatively correlated (r=-0.63**) in the beans as a group. Closer examination of this correlation revealed a strong negative association between texture and final

water content in black tropical, a moderate negative association in non-black tropical, and no (non-significant) association in navy bean genotypes (Hosfield and Uebersax, 1980).

Research has demonstrated that bean texture is influenced by the following factors:

1. Agronomic traits such as variety and growing conditions (Hosfield *et al.*, 1984; Ghaderi *et al.*, 1984; Redden *et al.*, 1993)
2. Storage conditions with moisture, temperature and time as factors (Moscoso *et al.*, 1984)
3. Processing systems that include soak/blanch technique, water composition and thermal process conditions as variables (Nordstrom and Sistrunk, 1979; Uebersax and Bedford, 1980).

1.4.3.2.2. Equilibration

During the first seven days of equilibration there is increased water migration activity within the can. This dynamic system becomes uniform over time. The decreased length of shear in conjunction with increased drained weight indicates that over time, uniform hydration occurs as water migrates to the bean core (Bolles *et al.*, 1982).

1.4.3.2.3. Visual appearance

There are different methods of sensory evaluation for the assessing for cooked dry bean flavour namely the flavour profile analysis (FPA), category scaling (CS), magnitude estimation (ME), and quantitative descriptive analysis (QDA). These methods vary somewhat in how the sensory characteristics are chosen and defined, in the number and training of panelists, although all are highly trained, and in scaling technique used to measure intensities of characteristics. McTigue, Koehler and Silbernagel (1989) found that in general these methods evaluated the bean cultivars similarly, but different levels of flavour intensity. These methods detected differences between beans in some characteristics but not in others. Therefore, choice of method or technique should depend on the type, amount and depth of sensory information required by the project and test objectives.

Large amounts of samples in a breeding program limited the time and financial aspects of trained panelists for the micro-canning method.

1.5. Chemical analysis: Environmental influence and correlation with quality parameters

Differences among bean classes and environmental factors influence variability. Quenzer *et al.* (1978) reported that the mineral composition of pinto beans is of importance to the food processor as well as the nutritionist. They found that firmness of pinto beans was related to calcium and magnesium contents since calcium content was positively correlated with shear and magnesium content. This substantiates earlier work done by other scientists. They found that calcium and magnesium contents were negatively correlated with imbibition. Analysis of variance indicated highly significant differences between cultivars and growing locations for calcium content. No difference was found for iron content between cultivars at different locations.

Koehler and Burke (1988) simulated a range of conditions found in commercial bean fields with *Fusaruim* infestation, *Fusarium* root rot, drought stress and irrigation as well as soil N. They found that the calcium and potassium levels differed significantly under different management and environmental conditions.

Leleji *et al.* (1972) found that yield and crude protein percentage were generally negatively correlated, that is, high-yielding segregates tended to be relatively low in protein percentage. However, they identified plants having both high seed yield and above average percentage of crude protein. Kelly and Bliss (1975) suggested using such bean strains in breeding programs to raise the nutritional contribution of beans, improving seed protein quality and quantity as well as seed yield.

Intriago-Ortega *et al.* (1996) undertook a field study to evaluate a new cultivar (Pinto villa) under diverse condition, with the aim of investigating the environmental effect on the biochemical and nutritional factors. The analysis of variance indicated highly significant differences for protein, moisture, fat, ash and carbohydrate content on various locations. A correlation analysis was conducted to determine the relationship between the amount of accumulated rainfall (separated into vegetative and reproductive phase) and the biochemical factors. Results indicated that percentage seed protein was negatively associated with the amount of rainfall accumulated during the reproductive phase (Intriago-Ortega *et al.*, 1996).

Seeds with the highest protein content were harvested from sites where less water was available to plants during seed filling period. On the contrary, percent carbohydrate was high for those bean seeds that were harvested from sites where more rainfall accumulated during the reproductive phase. The relationship between seed size and percent protein as well as carbohydrate content was not significant. Seed size was not determined by the availability of water during seed filling period. Intriago-Ortega *et al.* (1996) reported that cultivars from the semiarid highlands of Mexico were more affected by planting date on seed size, due to the sensitivity of these cultivars to photoperiod (Intriago-Ortega *et al.*, 1996).

2. Using GE (Genotype x environment) interactions for canning cultivar development

2.1. Breeding for canning quality

The breeder of dry beans must incorporate a selection scheme aimed at quality improvement into his breeding program to be assured of having achieved or maintained an acceptable level of canning and nutritional quality in potential new cultivars. This is necessary because of the importance of quality in variety acceptance by the industry and consumer (Hosfield, Uebersax and Isleib, 1984). The canning cultivar evaluations used by the breeder in making selections for canning quality must simulate commercial processing practices (Hosfield, 1991). There are a number of physical and chemical properties of canned beans that are nutritionally important and influence consumer preferences (Hosfield *et al.*, 1984).

A bean breeder must incorporate quality factors into high yielding, stress tolerant and pest resistant varieties. Therefore, modern technology has provided the means by which canning evaluations may be conducted rapidly, on small amounts of seed, and at a reasonable cost, while

maintaining the precision required in simulating a commercial processing operation.

A successful small white dry bean cultivar must possess various desired traits - high economic yield, desired canning quality, and resistance-tolerance to various environmental stresses and pests (Kang, 1998).

Objective canning quality assessments are used in other programs for screening large numbers of entries with accuracy, and excellent breeding progress has been achieved. Satisfactory evaluations could not be obtained with partial processing on small seed samples, hence, the complete canning procedure was required (Redden *et al.*, 1993).

The multiplicities of characteristics that consumers and processors use to determine whether or not beans are preferred and acceptable determine the characteristics measured for improving the canning quality of cultivars. Dry bean canning quality is more or less conceptual because its definition depends on a multiplicity of variables of which no single one adequately describes the properties preferred and required. It is therefore necessary to define canning quality in such a way that a few precise measurements can be taken and used as the

basis for discriminating among test samples (Hosfield and Uebersax, 1980).

A multiplicity of traits to ascertain the genetic worth of a crop presents a problem to a breeder who must limit the number of determining tests because of the large number of samples in a program among which differences need to be elucidated. It would be helpful for the breeder to know to what extent the available tests are measuring the same or similar basic components.

2.2. Genetic variability

Hosfield (1991) stated that gene control of trait expression is either qualitative or quantitative. The function of qualitative and quantitative genes differ. Genes that function qualitatively divide individuals into discrete groupings with little or no connection by intermediates. Qualitative gene function is studied by counting and observing ratios. In contrast, phenotypic expression due to quantitative genes is continuous through a range, with ratios of particular groups not observed. Moreover, quantitative gene expression is most often modified by non-genetic causes.

Genetic variability arises from differences in the assemblage of genes among varieties. Genetic variability is the ingredient that the breeder uses as the basis to select new and more desirable forms. Selection efficiency measures the degree of success in moving the average value of a trait in the population toward a desirable end point. The selection efficiency should be high.

Stability in plant breeding sense refers to a lack of responsiveness to environmental change. Hence the selection of cultivars with a high or favourable mean performance is the best way for the breeder to counter

genotype x environmental interactions (Hosfield and Uebersax, 1980; Walters *et al.*, 1995). Characterisation of genotypes as stable or unstable across environments through statistical methodologies could only treat the symptoms and not the causes of the problem (Kang, 1998).

Basford and Cooper (1998) defined a genotype as the set of genes possessed by individuals that is important for the expression of the trait(s) under investigation. The environment is defined as all things non-genetic that influence the expression of the trait(s). These environmental influences could therefore be water, nutrition, temperature or diseases that influence the growth and development of the individuals and thereby influence the expression of the trait(s). Genotype and environment interactions indicates a significant difference in the relative performance of the genotypes when they are grown in different environments and this will occur when the expression of the genes regulating the trait differ among environments. These interactions are detected statistically, as significant patterns of differential response among the genotypes across environments.

GE interactions are called collectively, differential genotypic responses to different environments. Kang

(1998) stated that GE interaction is primarily a crop breeding issue since crop breeders are interested in knowing how much of the selection progress achieved in one environment can be carried over to another environment.

Since GE interactions complicate selection for broad adaptation, their nature and causes need to be understood to utilise and exploit them in selection for specific adaptation. Progress in dealing with GE interactions can be made since several assessments of other crops have been reported in the literature (Basford and Cooper, 1998).

Variation among genotypes associated with GE interactions introduces a degree of uncertainty into the measure of overall superiority of any genotype and thus complicates selection for broad adaptation (Kang and Miller, 1984). This uncertainty increases with the magnitude and complexity of the responses contributing to GE interaction variation. The larger the relative size of the interaction component, the more complex the problem of identifying broadly adapted genotypes (Basford and Cooper, 1998).

The effects of GE interactions must be taken into account when selecting for performance within various environments. Breeding methodologies, that reduces the uncertainty associated with the interactions, should result in more rapid genetic improvement (Basford and Cooper, 1998; Hosfield, 1991).

A detailed understanding of the causes of GE interactions is rarely achieved. The level of understanding that can be achieved will depend on the repeatability of the interactions within the genotype-environment system. The data sets generated from multi-environment trials (MET) presents patterns of performance for quality traits that are a consequence of a mixture of interactions of undefined causes (Basford and Cooper, 1998).

2.3. Heritability

The concept of heritability (H^2) is important to understand how to successfully change the characteristics of populations. Thus, the H^2 of a metric character is one of its most important properties. Heritability in its broad sense is the proportion of the phenotypic expression of a trait that is due to genetic causes and is defined as H^2 = genotypic variance/phenotypic variance (Hosfield, 1991).

Since H^2 is that proportion of the total variation in a trait's expression attributable to the average effects of genes, it has a major impact on the methods chosen for population improvement. For this reason, H^2 enters into most formulas concerned with plant breeding theory and methods, and in the practical sense, its magnitude determines the effectiveness of improvement strategies (Hosfield, 1991).

The way a trait is inherited is synonymous with mating design and this knowledge is fundamental to efficient use of the genetic variability extant in a breeding population. The use of statistics is important to ascertain whether the variability noted within a population is due to the effects of genes or merely

chance. Statistical knowledge also helps one to assess if and how much a gene's expression is modified by the environment (Hosfield, 1991).

Wassimi *et al.*, (1986) reported the results of a full diallel cross among four diverse homozygous strains of dry beans that were evaluated for yield, protein content, and culinary quality traits in the F2 and F3 generations in two locations. Data from two generations were combined into a single analysis and the relative contributions of additive and dominance genetic effects to general (GCA) and specific (SCA) combining abilities were quantified. GCA was found to arise from three potential sources: additive effects, dominance interactions at homozygous loci, and average dominance interactions in hybrids involving the parent in question. SCA was found to be a function solely of dominance. Additive effects were the primary determinant of GCA and were highly significant. Specific dominance interactions were significant for seed yield, cooked bean moisture, and texture but not for protein content. Texture was the only trait for which the additive-dominance model failed to provide an adequate fit to the data, suggesting that texture are significantly affected by epistatic interaction. One cross ('Brazil-2' x 'Sanilac') was identified that exhibited a large heterotic effect for seed yield

although the parent additive effects were non-significant. Such a "nicking" effect was attributed to complementation between the two parents.

Wassimi *et al.*, (1990) reported results from a diallel cross with eight parents to estimate the combining ability of parents and determine the inheritance of nine culinary quality traits important to processors and consumers. Genetic variability among the eight parents, 56 F2, and 56 F3 progenies was confirmed by significant mean squares from analysis of variance. Significant variability detected between F2 and F3 progenies for soaked bean weight (SBWT), soaked bean water content (SBWC), and clumps (CLMP) was due to inbreeding effects. General combining ability (GCA) components were highly significant and overshadowed specific combining ability (SCA) components in the F2 and F3 for SBWT, SBWC, split beans (SPLT), and the washed-drained coefficient (WDWTR), indicating that additive variance predominated.

Ratios of GCA:SCA components were equal to or less than unity for bean clumping in the can (CLMP), washed-drained weight(WDWT), and texture(TEXT), indicating that both additive and non-additive effects contribute to trait expression. Significant SCA effect variances were noted for some parents for WDWT and TEXT, implying that progeny

from crosses of these parents had higher or lower mean values for the traits than the average expected on the basis of GCA. Graphs of the regression of V_r on W_r showed that genes controlling WDWT and TEXT were completely dominant in most cases. Recurrent selection, which seeks to concentrate favourable alleles with additive effects in populations, may be an effective breeding procedure to improve the culinary quality of dry beans. It is not feasible to breed for TEXT and WDWT simultaneously because of a negative correlation between the traits (Hosfield, 1991).

2.4. Strategy for improvement

Selection in segregating generations following hybridisation is a current practice to make genetic advances for traits in beans. Quality evaluations of dry beans for colour, size, and shape are carried out in early generations following hybridisation (F3 and F4 seeds). The traits mentioned will pose few serious problems to a bean breeder because they are highly heritable and easily recovered. Assessment of soaking and cooking properties, on the other hand, is delayed to more advanced generations (F4 and F5) after preliminary testing for yield and other agronomic features. The necessity for large seed samples and the costs associated with the tests are the basis for the delay.

Backcrossing to an adapted cultivar as a recurrent parent is an efficient way to recover highly heritable traits. Traits that are under complex (quantitative) genetic control and display predominantly additive effects may be improved through recurrent selection (pedigree selection). Recurrent selection seeks to concentrate favourable alleles in a population and is accomplished by intermating parents with the most favourable mean values for the traits of interest in each selection cycle. Although South African breeders that work with self-

pollinated crops (M.T. Labuschagnè-Personal communication) more commonly use pedigree selection, selection methods like single seed descent on soybeans and recurrent selection on dry beans for disease resistance are used. Significant non-additive variation can also be exploited. In this case the breeder will wish to restrict recombination, and practise selection only among a few crosses from bulk inbred populations.

It may be difficult to improve TEXT and WDWT simultaneously through selective breeding because of a negative correlation between the traits (Nordstrom and Sistrunk, 1977; Hosfield *et al.*, 1984). This obstacle may be overcome, however, because in some instances the values are small. It should be possible to make progress in breeding for optimum levels of both traits.

3. Statistical analysis of multilocation trails

Crossa (1990) defined data collected in multilocation trials as intrinsically complex with three fundamental aspects:

1. structural patterns
2. non-structural noise
3. relationship among genotypes, environments and genotypes and environments considered jointly.

There exist two basic options for the problems with genotype-by-environment interaction; one aimed at the genotypes, and the other at the environments. One option is to seek a high-yielding, widely adapted genotype that wins throughout the growing region of interest. The other option, particularly relevant when the first fails, is to subdivide the growing region into several relatively homogeneous macro-environments (with little interaction within each macro-environment) and then breed and recommend varieties for each (Gauch and Zobel, 1996). One may have difficulty breeding dry beans for wide adaptation. This may hold for other self-pollinating plant species (G.L. Hosfield-personal communication).

3.1. Conventional analysis of variance

Conventional analysis of variance of multilocation trials is used to measure genetic variability and to estimate the heritability and predicted gain of a trait under selection. This is done by estimating variance components related to different sources of variation, including genotypes and genotype-environment interaction. One of the main deficiencies of the combined analysis of variance of multilocation yield trials is that it does not explore the underlying structure within genotype-environment interaction and fails to determine the pattern of response of genotypes and environments (Crossa, 1990).

Peterson *et al.* (1992) determined relative contributions of genotype, environment, and GE interaction to variation in quality characteristics of hard red winter wheat. According to these results, environmental influences on end-use quality attributes should be an important consideration in cultivar improvement efforts toward enhancing marketing quality of hard red winter wheat.

3.2. Principal factor analysis (PFA)

PFA is a statistical procedure that reduces a series of traits, measured on a sample, into a small, common set of influences or factors (Crossa, 1990). It works by reducing the dimensions of a data set so that intercorrelated traits are treated as multivariate structures and not simply as independent entities. PFA would be helpful in a research area where little is known concerning the sources of common variation in a set of traits. First of all, it would tell which tests are measuring similar basic components and secondly, it could point out the number and nature of underlying casual influences on which more intensive research can be concentrated (Hosfield *et al.*, 1984).

PFA was used to interpret canning quality in beans and measurements made on 15 traits were restructured into a smaller number of interpretable and useful patterns of influences characterising the particular test groupings. Four major patterns influence (factors) emerged from restructuring the 15 measured traits (Hosfield and Uebersax, 1990). Factor I was viewed by Hosfield and Uebersax (1990) as the soaked bean factor. Since factor III was characterised by the washed drained weight (WDWT) and texture traits characteriastics of cooked beans.

Factor III was known as the thermal factor of bean culinary quality. Factors II and IV were identified as bean colour constructs. Cooked bean colour variables identified Factor II and surface colour for beans in the dry state characterised factor IV.

3.3. Principal component analysis

The aim of principal component analysis is to transform the data from one set of co-ordinate axes to another, which preserves, as much as possible, the original configuration of the set of points and concentrates most of the data structure in the first principal components axes. This analysis effectively reduces the structure of a two-way genotype-environment data matrix with G (genotypes) in E (environments) dimensions in a subspace of fewer dimensions (Crossa, 1990).

Ghaderi *et al.* (1984) reported that principal component analyses provided more evidence as to the independence of navy and pinto bean quality traits. PC-I was identified as a soaking property. Independence of dry and processed bean colour was established by PCA since the colour components loaded in different PCs. Seed size in this study was not related to quality traits. Weight of the soaked beans measured both the weight of the water and weight of the total solids whereas the hydration ratio is related by a common numerator, thus leading to a large correlation between them although they are perceived as 2 separate traits. Clumps and splits in navy beans were highly correlated and both loaded heavily on PC-II. The relationship seems to be one of cause and effect where

the exudate (consisting of a matrix of protein and starch), produced from the breakage of the beans, led to their clumping and packing. Texture affects the perceived physical stimulus for chewing and influences the degree of consumer acceptance. An inverse but moderate relationship was observed between texture and washed, drained weight, suggesting that firmer textured beans produce lower washed drained weights.

In examining environmental effects on yield and bread-making quality, cereal researchers measure yield and a complex of biochemical and rheological traits to try to develop relationships with associated environmental variables. An effort to identify a single variable representative of the complex of traits by using univariate analysis are inadequate and has proved to provide redundant information (Lezzoni and Pritts, 1991).

Van Lill *et al.* (1995a) used principal-component analysis to estimate the magnitude of the effects of environment, cultivar and cultivar-by-environment interaction on yield and quality attributes of winter wheats, and to determine the underlying source of variability in their bread-making quality. Van Lill *et al.* (1995a) indicated that multivariate statistical techniques are best suited to evaluate the magnitude and contribution of several

factors to variation in bread-making quality.

Hazen and Ward (1997) reported results on variation in soft winter wheat characteristics analysed by using the principal component analysis method with success. Hazen *et al.* (1997) also used principal component analysis with success to analyze the variation in soft wheat grain samples for traditional and non-traditional (mixograph and wire-cut formulation cookie test) quality characteristics.

3.4. Canonical correlation analysis

Canonical correlation analysis (CANCOR) finds linear combinations of two sets of variables for the sites, such that the linear combinations (canonical variates) have maximal correlation. In this manner the combination of biochemical variables could be identified that best correlate with combinations of quality variables, so that quality variability may be predicted for biochemical variation on site.

Graybosch *et al.* (1993) used canonical correlation analysis to ascertain the extent to which a set of biochemical measurements was related to a set of quality measurements, and also, to determine the particular components that have been responsible for these correlations. Osborne *et al.* (1993) employed canonical variate analyzes for discrimination between quality types in breeding material, where differences between groups are of more significance than differences between individual breeding lines.

Van Lill *et al.* (1995b) reported that they calculated simple correlations to test significance of relationships among and between yield, quality and biochemical attributes. A canonical correlation (CANCOR) analysis was

conducted to examine whether a set of biochemical variables could significantly account for the observed variation in a second set of quality variables for bread-making quality of winter wheats. Van Lill *et al.* (1995b) also classified environmental variables into groups according to climate, crop history and soil type. Canonical variate analysis was then used to determine whether groups of this classification differed significantly from each other over yield and quality attributes. They obtained excellent results with these methods.

3.5. Canonical variate analysis

Canonical variate analysis (CVA), better known as linear discriminant analysis, is used when there is more interest in differences between groups than between individuals. The variability in a large number of variates is first reduced to a smaller set of variates that account for most of the variability in the data set. The new sets of variates, called canonical variates, are linear combinations of the original measurements. With this approach a set of directions are obtained in such a way that the ratio of between group variability to within group variability in each direction is maximised. The scores found for each of the canonical variates are then correlated with the original variates to find those that are the most important in discriminating between the groups.

The method used by Van Lill and Smith (1997) enable quality assessors to objectively compare differences among independent data sets.

3.6. AMMI analysis

The additive main effect and multiplicative interaction (AMMI) method integrates analysis of variance and principal component analysis into a unified approach to analyse multilocation trials. AMMI analysis first fits the additive main effect of genotypes and environments by the usual analysis of variance and then describes the non-additive part, genotype-environment interaction, by principal component analysis (Crossa, 1990). The AMMI analyses proved useful for understanding complex genotype-environment interactions (Gauch and Zobel, 1996). The results can be graphed in a very informative biplot that shows both main and interaction effects for both genotypes and environments. Through the use of AMMI one can partition the data into a pattern-rich model and discard the noise-rich residual to gain accuracy (Gauch and Zobel, 1996).

Nachit *et al.* (1992) determined that the AMMI model was more effective in partitioning the sum of squares of GE interaction than a linear regression technique using data from a durum wheat program. Steyn, Visser, Smith, and Schoeman (1993) also reported use of the evaluation and selection of new potato cultivars in the National Cultivar trials, to evaluate the use of the AMMI model

against the existing Finlay-Wilkenson regression technique. They found that the AMMI model was suitable for determining the reaction of cultivars/lines in an environment. They recommend that the AMMI model be the first model to be fitted, with others being explored for possible improvement in efficiency, or used for testing specific hypotheses about the underlying interaction patterns.

CHAPTER 2

MICRO TESTING PROCEDURES FOR SMALL SEEDED WHITE BEANS (*PHASEOLUS VULGARIS* L.)

2.1 Introduction

The acceptance of a new dry bean cultivar by the industry, consumers and the producers in South Africa is important. Therefore the dry bean breeder at the Grain Crops Institute (GCI), Potchefstroom has to incorporate a selection scheme based on quality criteria as early as the F4 generations. At this stage there is only a small amount of seed of each selection available but many lines of varying quality have to be evaluated. There is a need for a micro-canning testing procedure which is accurate, repeatable, cost effective and time saving to ensure that only the lines with the best agronomic characteristics and canning quality are evaluated in further trials. The genotype choices resulting from such a procedure should agree with that of commercial processors.

Cultivar, production area, bean quality at harvest, handling, food processing methodology and storage conditions have been reported as factors affecting bean quality (Bolles *et al*, 1990; Chang, 1988; Davies, 1976; Hosfield and Uebersax, 1980; Machiortatti *et al.*, 1987). Uebersax and Bedford (1980)

showed that the level of hardness of soak water significantly altered cooked bean texture. Firmness and colour of canned beans can initially be improved by the addition of calcium to the canning medium but excess calcium could result in increased bean firmness (Wang *et al.*, 1988).

Various workers have also reported on soak methods, soak temperatures, soak times and soak additives (Uebersax and Bedford, 1980; Uebersax *et al.*, 1981). There has been a tendency to use high-temperature soak treatments of 85-90°C for approximately 30 min. The main disadvantage with this process is that the product is not as tender as slowly (room temperatures) hydrated beans (Priestly, 1978).

Priestley (1978) reports that the National Canners Association of America recommends that navy beans in 410g cans must be cooked for 50 min at 121°C. The industry normally uses an agitating retort. Rotation increases the rate of heat transfer, allowing a reduction in process time and reduces the gelation tendency of the sauce.

Processors prefer beans that expand rapidly and uniformly in the can during processing, leave no sludge at the bottom of the container and have acceptable drained masses and textures (Hosfield, 1991). Consumer preferences include colour, appearance, and ease of preparation and texture. Criteria for

consumer and processor acceptability are therefore water absorption, texture and visual appearance. Redden *et al.* (1993) founded that integrated scores for appearance, water absorption and texture were repeatable and useful for screening many new bean selections resulting in excellent breeding progress.

Hosfield and Uebersax (1979) stated that the major characteristics responsible for desirable canning quality are as follows:

A. **Physical characteristics of the seed:**

1. Seed size
2. Soak mass (Hydration ratio)

B. **Processing and cooking characteristics:**

1. Drained mass (g)
2. Texture (shearing force and total shear force)
3. Sensory evaluation or visual appearance of the beans.

C. **Chemical composition of grains:**

1. Protein content
2. Fibre content

Standardisation of the processing techniques is necessary to insure that possible variation is due to genetic and

environmental variation and not because of external factors influencing processing, measuring or evaluation.

There is a need to calibrate the results of the micro-canning method with the commercial processing practices in order to maintain an acceptable standard of quality in selecting the best performing breeding lines and to evaluate the various cultivars entered in the National Cultivar Trials. The complete canning procedure, therefore, evaluation of all the different parameters, is required for an objective assessment of the overall canning quality.

The objectives of the work in this chapter were to:

1) Develop micro-canning techniques to assess the canning quality of a large number of bean selections and cultivars,

2) Determine the effect of water quality on the results of the micro-canning technique,

3) Insure that the micro-canning results correlate with those in use in industrial assessments.

2.2 Materials and Methods

Breeding lines and cultivars (hereafter called genotypes) were kept in cool storage at 4°C and a relative humidity of 60% as these conditions were reported as the ideal storage conditions for canning beans (Jones and Boulter, 1983).

2.2.1. Processing procedures

Since small white beans are traditionally canned in tomato sauce, a standard bean factory canning process was simulated using a static vertical retort. The number of seeds per 30g was determined for each sample. Hundred gram (100g) of each genotype was placed in a nylon mesh bag and soaked for 40 min at 88°C. After soaking, beans were instantly cooled under cold tap water and drained for two minutes on a 500 µm mesh sieve positioned at a 15° angle. Water uptake was measured by determining the mass gain in grams of the soaked beans (SBM).

Ingredients used for the tomato sauce were the same (tomato puree, white sugar, brown sugar and salt) as those used by the industry in order to compare results. Two hundred and ten grams of blanched beans were filled into 410g plain-bodied cans, with sulphur resistant lacquered ends and 200g prepared

tomato sauce at boiling point was added. Cans were sealed and then sterilised in a static retort for 50 min at 121°C, followed by immediate water cooling to 32-38°C. A storage period of two weeks after processing was allowed in order to permit canned beans to completely equilibrate with water before objective and visual assessment. Washed drained mass (WDM) of processed beans was determined in the same way as the SBM.

Potential external factors affecting canning quality, such as processing procedure and additives were not investigated.

2.2.2. Quality assessments

2.2.2.1. Water absorption

Water absorption was determined after soaking as the SBM and again after the canned beans were evaluated, washed and drained as WDM.

2.2.2.2. Visual appearance

Canned samples of breeding lines and cultivars were assessed for visual appearance. The equilibrated cans were opened and the contents poured into soup bowls. Two persons evaluated the overall bean appearance for the suitability of beans for commercial processing. Criteria included examining beans for

loose or free seed coats, individual bean integrity, sauce consistency and colour. Intact beans, with a minimum of pieces of skin, and medium sauce viscosity were rated acceptable. Discoloured beans, cloudy sauce, low hydration of beans and sticky beans (solid pack) were defects resulting in down graded appearance scores. A score from 0-7 (Table 2.1) was used in the overall evaluation with nil as the poorest and seven as the best quality.

Table 2.1. Visual observation of processed small white beans

Rating	Description of rating
0	Bean breakdown (70-100%) Mushy, free skins and splits. Dull bean surfaces. (Unacceptable)
1	Bean breakdown (50-70%) Mushy, free skins and splits. Dull bean surfaces. Uneven colour and seed sizes. (Unacceptable).
2	Bean breakdown (10-50%). Free skins and splits. Dull bean surfaces. Uneven seed sizes. (Unacceptable).
3	Soft beans, bean breakdown (-10%). Splits (Free skins) Uneven seed sizes. (Acceptable).
4	Soft beans, broken beans with seed integrity still maintained. No free skins. Uneven seed sizes and colour.
5	Soft beans, shiny bean surfaces. Intact broken beans, but no splits. Uniform seed size and colour.
6	Firm intact beans. Shiny bean surfaces. Uneven colour and seed sizes.
7	Firm intact beans (No broken beans). Light, bright, shiny surfaces. Uniform colour and seed sizes. (Excellent visual appearance)

2.2.2.3 Texture

Texture was determined by means of a Texture Press System (Model TP-1A) fitted with a standard multi blade shear compression cell. One hundred grams of washed processed beans were placed in the compression cell and force was applied until the blades passed through the bean sample.

Data were stored electronically at 0,1 second intervals for 12 seconds. The texture data measures two different parameters: the peak of the curve indicates the shear resistance peak and the total shear resistance are estimated by the total area underneath the curve.

2.2.3. Experiment 1 Standardisation of the texture press system

Due to initial mechanical problems, a load cell was installed and connected to a personal computer with the help of the Electronics Department at the University of Potchefstroom.

A large homogenous sample of cooked beans that were divided into ten subsamples was used. The texture was determined as two different parameters namely the shear resistance peak and the total shear resistance.

2.2.4. Experiment 2: Sensory evaluation and comparison of the micro-testing procedures with the industrial canning procedures of the navy beans

The National Cultivar Trials (NCT) are conducted at 30 localities in South Africa. Cultivars from various seed companies and the GCI (Grain Crops Institute) are entered for agronomic and canning quality evaluation.

Seed of each cultivar, grown at different localities within each of four different production areas, was evaluated. This resulted in four samples per cultivar. Two people undertook a visual appearance evaluation of the beans on a 0-7 point scale with nil as unacceptable and seven as acceptable (Table 2.1). The criteria included the uniformity of the beans regarding the size, form, colour, stickiness, loose seed coats and bean integrity.

Duplicate dry bean samples were canned and evaluated at GCI and the Langeberg experimental laboratories in Bellville, Western Cape, for suitability to commercial processing. This laboratory did not use the same parameters since they did not have an objective texture measurement system but they have a trained sensory panel in place to do a sensory evaluation. The ratings of the visual appearance were not the same, since they

only used a sensory evaluation. The criteria for the visual appearance of the processed beans evaluated were, however, the same namely uniformity of the beans regarding the size, form, colour, stickiness, loose seed coats and bean integrity.

The results were compared at a Dry Bean Cultivar Evaluation Meeting. Reserve cans of the entries were retained to resolve differences between the evaluations by a joint evaluation panel.

2.2.5. Experiment 3: Determination of the effect of water quality on the canning quality evaluations

A large sample of the cultivar Helderberg was divided in 100g sub-samples. Three replicates of each treatment were canned. Soaking was done for 40 minutes in distilled water with various levels of $CaCl_2$ and $CaSO_2$ (Table 2.2) added. Since $CaCO_3$ cannot be dissolved in water, tap water was used and diluted with distilled water to different levels of $CaCO_3$. Levels of the water hardness were chosen according to the classification of the US Geological Survey (Uebersax *et al.*, 1987). Distilled water was also included in the treatment as a control. Since the effect of the quality of the soak water has a more significant influence on the canning quality (Larson *et al.*, 1988), than the water used in the preparation of the

cover sauce, distilled water was used for this purpose in all treatments.

Table 2.2 Treatments with water hardening elements

Water	Soft (ppm)	Medium (ppm)	Hard (ppm)
$CaCl_2$	24	48	72
$CaSO_2$	24	50	72
$CaCO_3$	82	131	197

Quality assessments were done as described above with water absorption, visual appearance and texture as parameters.

2.3. Results and Discussion

2.3.1. Experiment 1: Standardisation of the modified texture press system

Standardisation of the texture press system was necessary to insure that measured variation was due to genetic and environmental effects and not due to experimental error. Coefficients of variance (Table 2.3) for shear force and total shear force respectively, indicated that the standard of the texture press is reliable.

Uebersax *et al.* (1988) suggested that the most typical force curve, which qualitatively indicates textural characteristics of texture of processed beans, is primarily a compression of

cotyledons (compression force (kg) of 100g over 12 seconds) and shearing of the compressed bean mass and seed coats (shearing force (kg) of 100g). Binder and Rockland (1964) reported compression-type curves for cooked lima beans when seed coats were removed and curves with large shear components when bean coats were intact.

Table 2.3 Texture as measured with the upgraded texture press system.

REPLICATES	SHEAR FORCE (kg 100 g^{-1})	TOTAL SHEAR FORCE (Area underneath the curve)
1	206.1	627.2
2	172	578.4
3	181.4	579.4
4	194.3	757.6
5	182.9	539.6
6	196.8	624.5
7	194.6	582.2
8	188.7	572.7
9	203.3	599.8
10	199.6	585.8
Mean	191.97	604.7
CV (%)	1.7	1.3

2.3.2. Experiment 2: Comparison of the micro-canning method to the industrial canning procedures.

Although GCI and Langeberg did not test overall canning quality with the same parameters, the conclusions about the canning quality were the same (Table 2.4). Cultivars evaluated

as choice grade, standard grade and unacceptable were in the same categories. Figures 1-6 are the photos of the different cultivars used in the NCT as in Table 2.4.

Table 2.4. Summary of the results of the canning evaluation of the navy bean cultivars in the National cultivar trials (Sept 1996) of GCI and Langeberg

Evaluation	**GCI**	**Langeberg**
Choice grade	Teebus	Teebus
	Kosi	Kosi
Standard grade	PAN 122	PAN 122
	Helderberg	Helderberg
	Arctic	Arctic
Unacceptable	Kamberg	Kamberg

The assessment of canning quality of navy beans with a micro-technique is necessary to maintain acceptable standards. These standards have to be the same as those used by the commercial processing industry in order to select acceptable cultivars for both the producers and the processors.

Rapid water uptake is an important attribute of dry beans used for food. The hilum and micropylar areas usually admit water readily, but seed coats differ strikingly in water permeability.

Fig. 2.1. A Photo of a choice grade cultivar; Teebus.

Fig. 2.2. A Photo of a choice grade cultivar; Kosi.

Fig. 2.3. A Photo of a standard grade cultivar; Helderberg.

Fig. 2.4. A Photo of a standard grade cultivar; Arctic.

Fig. 2.5. A Photo of a standard grade cultivar; PAN 122.

Fig. 2.6. A Photo of an unacceptable cultivar; Kamberg.

Water absorption is an important factor for commercial processing, since an elevated soak mass adds to a financial benefit for the industry. If the water absorption of beans in the can during processing and equilibration is too low, their final weight in the cans could be too low to be acceptable for commercial marketing, and therefore also leading to a financial loss.

A single integrated assessment for visual appearance is a subjective but more useful selection tool than a breakdown of component attributes (Redden *et al.*, 1993). A cultivar normally accepted by the industry as a canning cultivar with acceptable canning quality is used as a standard and the other genotypes evaluated against this cultivar for visual appearance.

The textural characteristics of processed beans can be readily evaluated with the texture press system (Deshpande and Cheryan, 1986). Texture is a primary canning quality characteristic because it simulates the perception of chewing which influence consumer acceptance of food products to a large extent. The variation in texture noted among genotype suggested that heritable differences existed for factors influencing softening of the cotyledonary matrix during cooking (Wassimi *et al.*, 1990). Texture of the beans can be

an objective measurement of the bean breakdown and softening of the cotyledonary matrix.

2.3.3. Experiment 3: Determination of the effect of water quality on the canning quality evaluations

A positive correlation was found between increasing concentrations of salts and bean firmness (Fig 2.7 and 2.8) as well as imbibition of water during the canning process (Fig 2.10) and a negative correlation with imbibition of water during the soak period (Fig 2.9). An increase in the salt concentration enhanced the visual appearance of canned beans (Fig 2.11). A decision was made to use the water quality of the municipal water system because the infrastructure for distilled water with added $CaCl_2$ was not possible.

This results substantiates earlier work by Quenzer *et al.* (1978) and Uebersax *et al.* (1987) demonstrating that calcium concentration was positively correlated with shear and negatively correlated with imbibition.

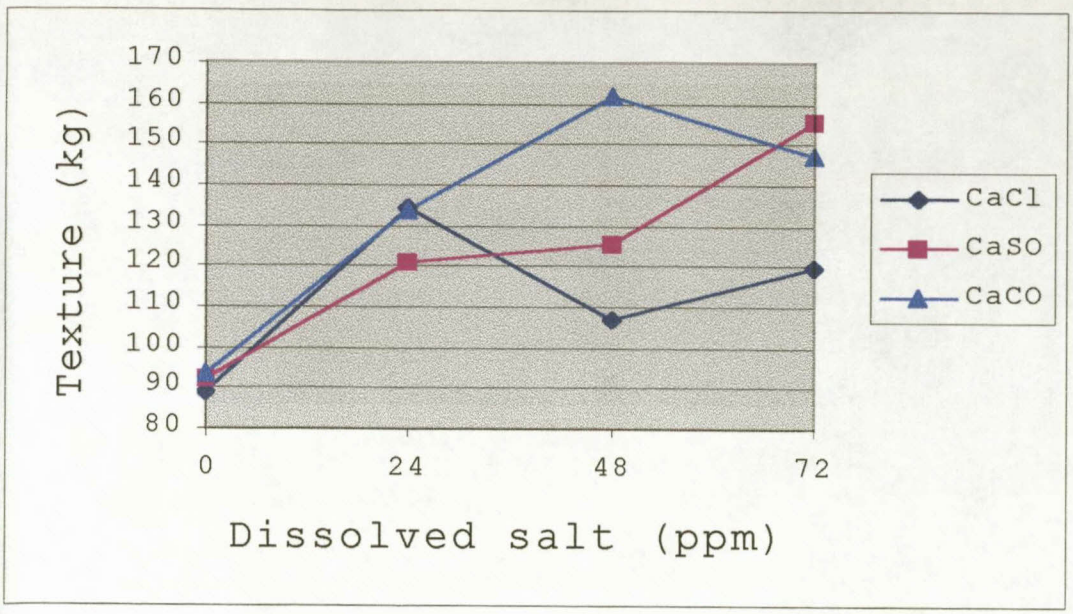


Fig. 2.7. Effect of water hardness on texture (Kg).

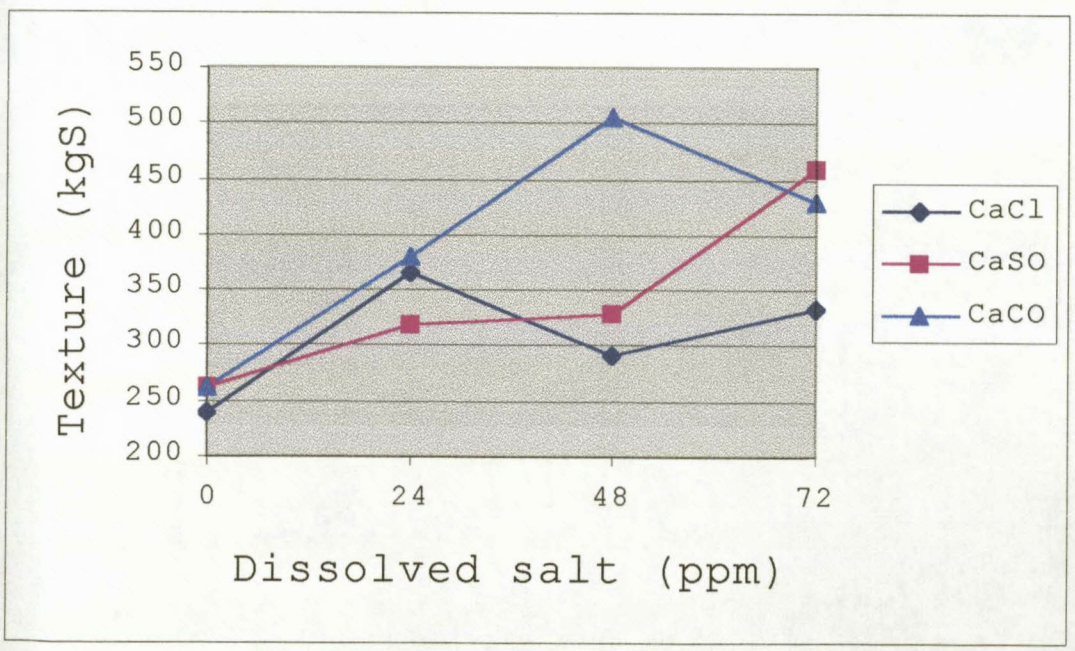


Fig. 2.8. Effect of water hardness on texture (KgS).

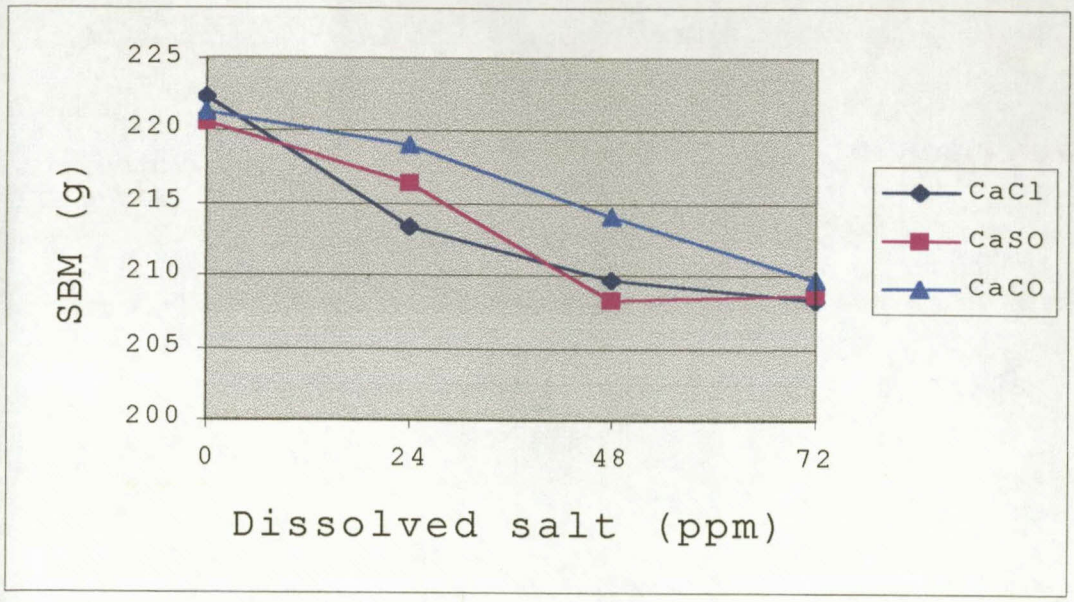


Fig. 2.9. Effect of water hardness on SBM (Soaked bean mass).

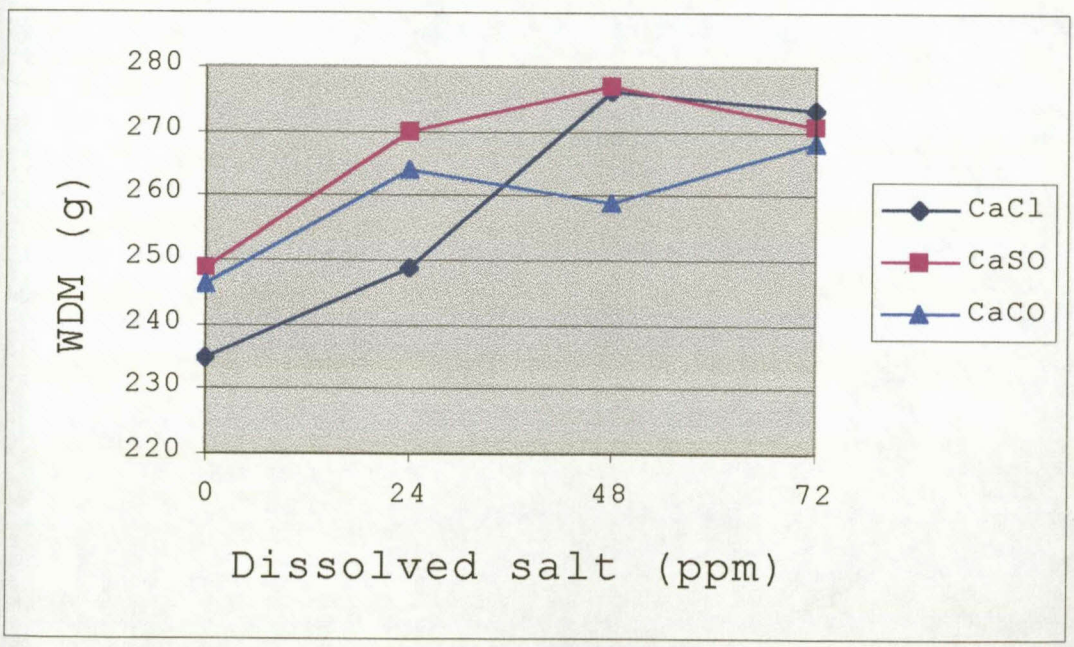


Fig. 2.10. Effect of water hardness on WDM (Washed drain mass).

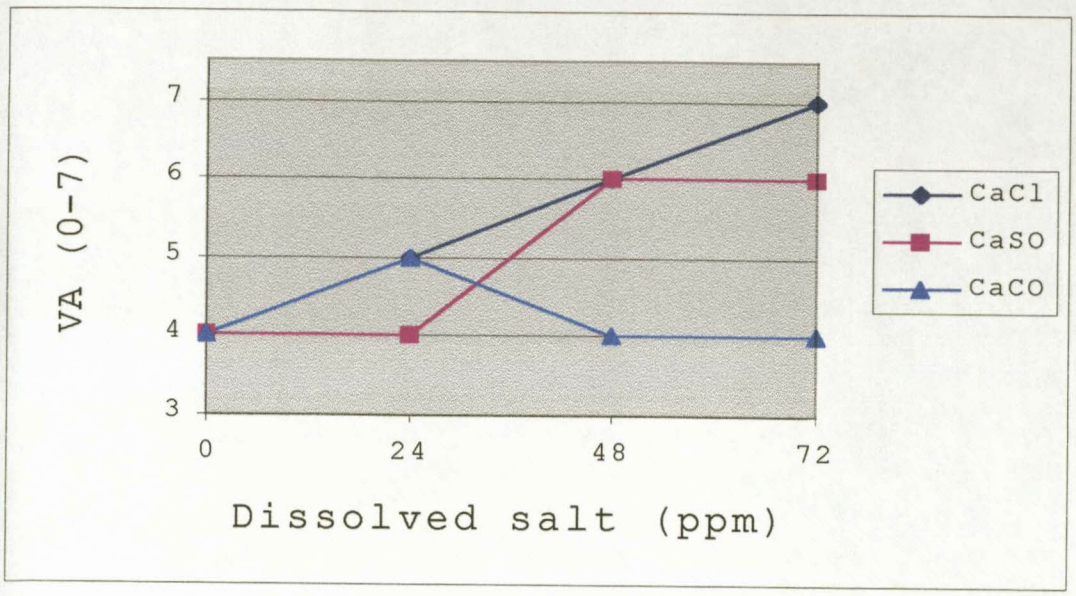


Fig. 2.11. Effect of water hardness on VA (Visual Appearance).

The characteristics of the cell wall and middle lamella of plant tissues and the changes in these components during thermal processing have a significant influence on the texture and consumer acceptability. Integrity of plant tissues are maintained by the intact cells and firm molecular bonding between constituents of cell walls (Uebersax, 1987). The pectic substances are extensively involved in structure stabilisation through cross-linking of their free carboxyl groups with polyvalent cations such as Ca^{2+} and Mg^{2+}. This increases firmness through enhanced cross-linking and the formation of relatively insoluble calcium pectate (Uebersax, 1987). The addition of calcium ions resulted also in a reduced splitting of the bean seed coat and therefore enhanced the

visual appearance of the canned beans that Larsen *et al.* (1988) also described.

2.4. Conclusions

Suitable screening methods are necessary for the incorporation of the aspect of quality improvement into a bean breeding program. This places an additional heavy burden on the breeder to develop efficient selection criteria. To maximise time and resources, the breeder must possess certain knowledge of the range of variability and the nature of gene action for food quality traits among the segregating lines.

Rapid assessment of canning quality, on small amounts of seed, and at a reasonable cost, with the precision required to simulate a commercial processing operation are therefore necessary. Van Wyk *et al.* (1982) published the standards for these specific parameters that have been used in developing the micro-canning method described in this study.

A micro-canning technique consisting of soaking and processing procedures was developed. The results of the comparison to the commercial processing practices were favourable and an acceptable standard of quality maintained in evaluation of the various genotypes to help progress towards improved canning quality. Therefore, this micro-canning technique and

evaluation should be useful for further research to achieve industry competitiveness. Thus, enabling local produce to compete on both price and quality when processed.

If the dry bean breeder wants to incorporate quality improvements in the selection program using this micro-canning technique, the canning quality of small white, carioca and haricot beans, must be determined to make effective selections for parents of the different crosses. Small white, carioca and haricot beans are the most important market classes in South Africa.

This micro-canning method is also necessary to investigate the different characteristics to be measured. It is also necessary to investigate the genotype, environment and GE interaction.

CHAPTER 3

VARIABILITY IN CANNING QUALITY PROPERTIES OF SMALL WHITE, CARIOCA AND YELLOW HARICOT GERMPLASM

3.1. Introduction

Incorporating the dimension of quality improvement into a bean-breeding program, the breeder should have suitable screening methods. This is necessary for the breeder to ensure an efficient selection strategy to choose the most favourable genotypes. In a bean breeding programme with a major objective to improve food quality characteristics, the breeder must know what the range of variability and the nature of gene action for food-quality traits are to maximise time and resources (Hosfield and Uebersax, 1980). Suitable screening methods for drybeans using small quantities of seed have been developed (Chapter 2) that simulate commercial processing practices.

The canning industry has established a definite set of acceptability standards for dry beans that are adhered to when a cultivar is considered for processing.

The objectives of this study were to:

1) evaluate and compare the genotypic, environmental, and genotype x environmental variability among the cultivars of small white canning beans and coloured beans namely yellow haricot and carioca beans,
2) to ascertain the potential of coloured genotypes as a source of variation in the germplasm for a dry bean breeding programme.

3.2. Materials and Methods

Dry beans used in this study were grown on eight different localities. The cultivars used were five small white cultivars: Kamberg, Teebus, Kosi, PAN 122 and Arctic. The coloured group of five cultivars included four carioca cultivars (Patrys, Mkuzi, Zambezi and Nandi) and the yellow haricot variety, Katberg. These dry beans were grown in the summers of 1994-95 and 1995-96. The trials were planted with a self-driven planter into four row plots. The rows were 5m long and spaced 750mm between rows and 75mm in the rows. Small white beans, yellow haricot, and carioca genotypes were planted in randomised blocks. Standard practices for herbicide and fertiliser applications were followed. Samples were harvested manually from the middle two rows of individual plots in late April 1995 and 1996.

The cultivars evaluated for canning quality, were cultivars from different companies enrolled in the national cultivar trials. Canning methods and evaluations of quality parameters were described in Chapter 2.2.2.

All data were subjected to an analysis of variance appropriate to a nested design. Contrasts between the small white canning beans and the coloured beans were calculated using Genstat 5 Release 3.1.

3.3. Results and discussion

3.3.1. Seed size

The main effect of years on seed size was non-significant (Table 3.1). The main effects for the other traits and all interactions except (W vs C) x Y x L were highly significant (Table 3.1). The cultivar x locality x year (CLY) interaction indicates that cultivars respond differently to localities and years. This is an indication that environmental parameters like rainfall, temperature and soil vary among localities and years in an inconsistent manner. As an example, consider localities Bapsfontein (3) and Ermelo (4) and cultivars Teebus and PAN 122 (Table 3.2). In 1994/95 the seed size based on the number of seed/30g of Teebus was significantly larger than in

1995/96 at Bapsfontein. The opposite was true at Ermelo. PAN 122 reacted differently since there was no significant difference between years at Ermelo.

Table 3.1. Anova of two groups with five small white cultivars and five coloured cultivars.

	Seed size (Seeds/30g)	SBM (g)	WDM (g)	Texture (kg/100g)	Texture (kg /100g /12 sec)	Visual appearance (0-7)
Year	NS	101.96**	298.1**	65.5**	40.2**	27.0**
Locality	21.3**	9.4**	5.9**	12.7**	9.0**	17.2**
Year x Locality	4.5**	9.2**	7.8**	11.5**	12.1**	2.3**
Cultivar	120.0**	5.1**	46.7**	124.7**	139.7**	461.6**
White vs coloured (WvsC)	345.1**	(NS)	159.7**	707.8**	856.6**	3184.0**
Cultivar x Year	8.4**	9.3**	9.1**	14.9**	10.8**	31.9**
(WvsC)x Year	50.6**	47.9**	32**	100.3**	64.3**	190.0**
Cultivar x Locality	4.1**	1.9**	2.8**	3.6**	2.7**	2.4**
(WvsC) x Locality	6.0**	8.2**	4.6**	15.0**	6.5**	5.4**
Cult x Year x Loc	2.5**	1.5**	1.8**	2.1**	1.5*	1.7*
(WvsC) x Year x Loc	3.5**	4.6**	3.1**	4.4**	2.6*	NS

Table 3.2. Seed size of 10 dry bean cultivars at eight localities over two years (Seeds per 30g).

Cultivar	Year	Potch 1	Potch 2	Bapsfon	Ermelo	Reitz	Ficks	Beth SS	Kokstad
Kamberg	1*	176.98	178.00	181.27	190.22	173.33	153.00	158.33	152.33
	2**	199.33	158.11	204.14	188.00	180.67	167.00	142.00	150.00
Teebus	1	162.33	114.67	125.08	160.00	123.67	109.35	114.00	125.67
	2	153.67	131.67	148.00	129.00	122.67	121.33	113.33	141.33
Kosi	1	159.00	102.52	99.67	115.33	121.00	108.00	114.00	171.67
	2	152.67	146.72	147.31	124.67	117.00	120.33	116.00	155.85
Katberg	1	163.67	155.33	125.70	150.67	161.67	150.00	141.00	150.00
	2	130.33	132.33	166.33	153.67	139.41	139.33	124.67	161.33
Helderberg	1	195.00	184.37	174.70	143.00	187.00	177.67	175.33	175.00
	2	202.00	175.67	213.55	192.00	192.00	176.00	159.67	156.67
Patrys	1	124.00	106.00	146.67	152.33	133.67	114.00	118.67	104.00
	2	121.33	94.98	136.00	124.00	123.33	113.33	110.00	110.67
PAN 122	1	160.67	147.52	137.67	183.00	154.33	138.33	144.00	127.33
	2	171.33	145.00	182.33	174.67	163.33	155.00	142.67	130.67
Nandi	1	140.67	127.37	168.33	146.33	135.65	128.67	123.00	126.67
	2	116.67	109.33	132.67	122.33	125.00	122.43	109.33	110.00
Mkuzi	1	159.00	159.67	136.00	145.67	150.00	136.00	131.33	109.00
	2	139.67	133.00	157.33	155.67	155.33	135.00	124.84	127.00
Zambezi	1	130.00	96.33	140.33	175.67	117.65	116.05	129.33	94.00
	2	100.00	95.30	122.00	115.00	103.33	92.00	95.33	97.00

* Year 1 - 1994/95
** Year 2 - 1995/96

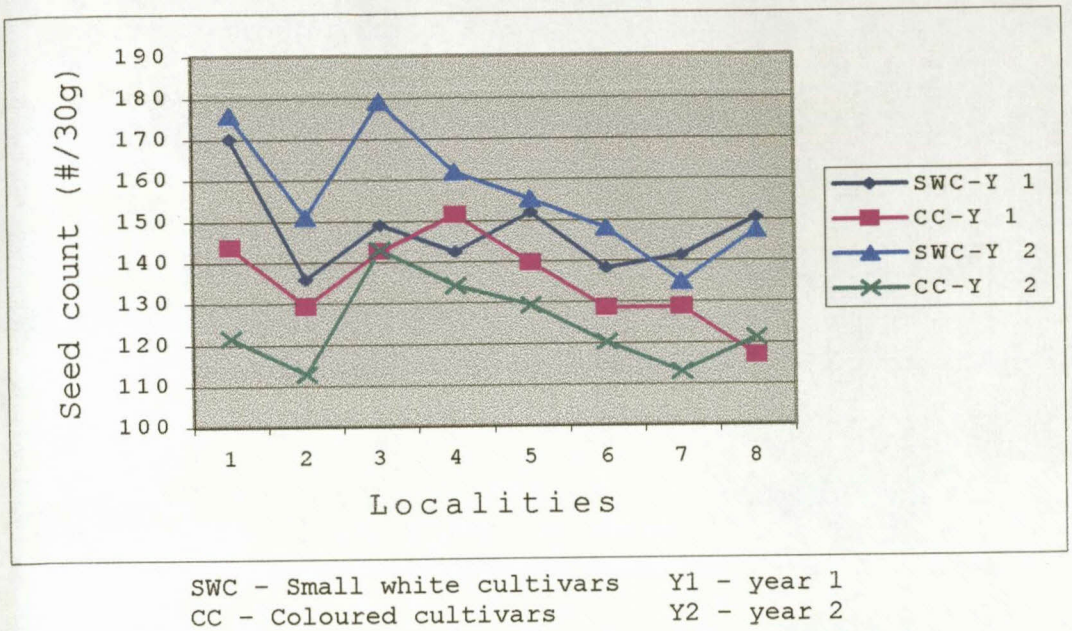


Fig 3.1. Seed count for two years of white and coloured cultivars.

Comparing white to coloured beans by means of contrasts also resulted in all effects being highly significant (Table 3.1). The (white vs coloured) x year x locality (CLY) interaction indicates that the two groups of cultivars did not respond to different localities and years in the same manner. From Fig.3.1 it is, however, clear that in general the white beans have a smaller seed size than the coloured beans.

The correlation between seed size and other parameters were not significant although Sefa-Dedeh and Stanley (1979) demonstrated that seed coat thickness, seed volume, and hilum size along with protein content were all factors in regulating

water imbibition. These results could be the effect of the significant interactions with the environment, although Intriago-Ortega *et al.* (1996) found that seed size of pinto seeds was not determined by the availability of water during the seed filling period. Ghaderi *et al.* (1984) reported that correlation and principal component analysis suggested that seed size was not related to canning quality.

3.3.2. Soak bean mass (SBM)

The main effects and all interactions of SBM were highly significant as indicated in Table 3.1 except the CLY interaction was only significant. Cultivars respond differently to localities and years as a result of different environmental parameters that vary over years and localities in an inconsistent manner (Fig. 3.2). An example of the interaction is the mean SBM of Teebus at Bethlehem SS (Table 3.3) which were 172.05g for 1994/95 and 186.66g for 1995/96. Teebus reacted differently at Reitz, because there were no significant differences between the two years at this location. PAN 122 on Potchefstroom 1 was 181.89g for 1994/95 and 196.67g for 1995/96.

Teebus had a SBM of 187.6 (1995/96) at Reitz but only a SBM of 172.05 (1995/96) at Bethlehem SS. It has been reported by other investigators that the environmental conditions

influences canning quality significantly (Hosfield *et al.*, 1984; Wassimi *et al.*, 1990).

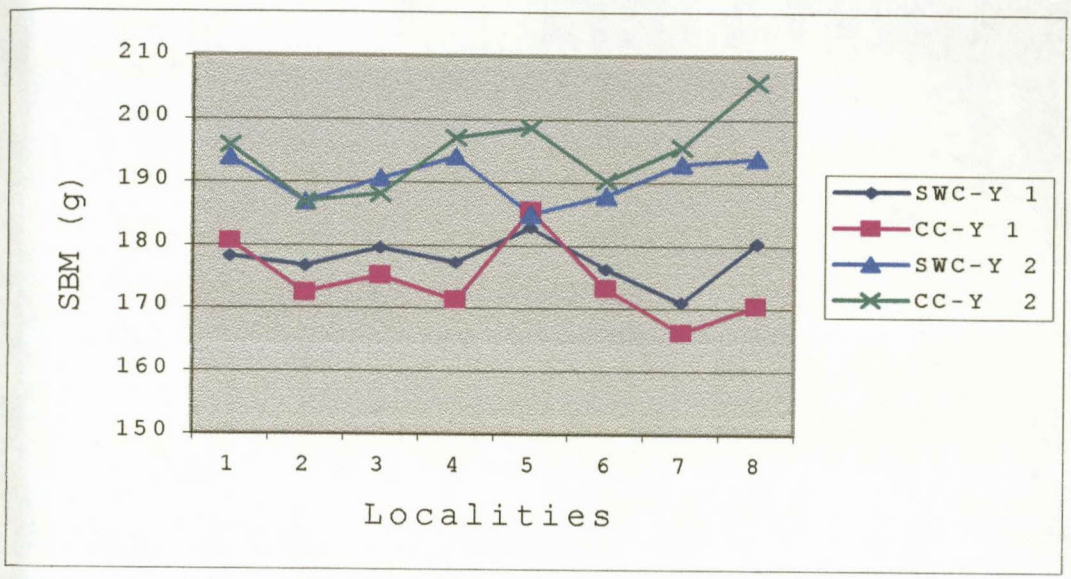


Fig 3.2. Soak bean mass for two years of white and coloured cultivars.

Table 3.3. Soak bean mass (SBM,g) of 10 dry bean cultivars at eight localities over two years.

Cultivar	Year	Potch 1	Potch 2	Bapsfon	Ermelo	Reitz	Ficks	Beth SS	Kokstad
Kamberg	1*	187.75	189.34	189.26	184.23	192.68	182.84	179.67	192.36
	2**	192.73	183.79	193.80	197.27	189.70	185.46	185.76	189.09
Teebus	1	186.65	187.60	179.20	186.01	187.60	179.92	172.05	185.70
	2	192.43	184.85	187.27	193.64	186.97	186.67	186.66	193.94
Kosi	1	185.38	189.10	179.98	187.61	188.87	178.40	174.27	187.60
	2	194.85	187.95	186.27	190.00	186.97	188.18	210.30	197.93
Katberg	1	194.27	183.16	175.25	192.36	201.25	182.52	180.93	181.25
	2	196.36	186.97	186.06	199.39	199.93	194.54	201.51	212.12
Helderberg	1	190.14	192.29	183.82	186.97	191.73	192.68	185.06	191.41
	2	192.12	189.39	189.47	194.24	163.94	186.67	188.49	191.21
Patrys	1	182.84	176.18	162.84	179.99	192.05	172.05	167.60	173.95
	2	194.24	187.81	188.48	196.36	199.39	192.12	194.85	205.46
PAN 122	1	181.89	196.24	195.22	190.14	196.49	189.19	184.43	186.97
	2	196.67	187.27	195.76	194.54	196.66	192.12	193.03	196.06
Nandi	1	188.24	185.63	177.44	191.09	193.28	184.75	172.36	180.30
	2	197.88	183.03	187.57	197.27	196.36	188.00	194.55	203.64
Mkuzi	1	189.19	184.11	178.72	194.27	192.68	183.16	169.83	179.67
	2	198.18	188.48	190.61	196.06	199.09	186.67	199.53	206.36
Zambezi	1	181.10	174.27	170.15	191.10	192.33	184.06	179.67	177.13
	2	192.42	185.18	187.27	196.06	195.75	188.18	192.12	202.12

* Year 1 - 1994/95
** Year 2 - 1995/96

When the accessions were broken down into subgroups according to their seed colour, the small white canning beans did not differ significantly from the coloured beans for the SBM. From Fig. 3.2 it is clear that the SBM of the second year (1995/96) of both the small white and coloured groups were significantly higher than the first year (1994/95). Hosfield (1978) reported a genetic difference between subgroups of tropical non-black and -black beans and domestic white beans and found that the coloured seed coat could have no effect on the water absorption during the soaking period, but influenced the cooking properties namely the WDM, texture and overall appearance. Del Valle *et al.* (1992) indicated that dark-coloured seed coats are less permeable to water than light-coloured ones as a result of oxidative reactions of phenolic substrates resulting in hydrophobic substances. Soaking is the first step in bean processing during which, uncooked beans generally undergo a minimum of 80% increase in weight due to water imbibition and attain a moisture level between 53 and 57% (Hosfield and Uebersax, 1980). Therefore, commercially a minimum weight gain of 1.8 times the original weight, is desired.

The correlation coefficients (Table 3.8) revealed that soaking properties were not associated with textural differences that were noted among the different subgroups and within the subgroups (Table 3.3). This finding is in agreement with that

of Hosfield and Uebersax (1980) who studied the effect of hydration rate on the texture for different bean cultivars and found that the degree of hydration of the beans had no effect on the texture.

3.3.3. Washed drain mass

There were considerable variations among genotypes, localities and year (Table 3.4). The WDM was significantly influenced by the GLY interactions. Helderberg, as an example, differed significantly at Potchefstroom 1, Bapsfontein, Ficksburg and Bethlehem SS and between the two years but the difference between the two years for the other localities were non-significant (Table 3.4). Teebus differed significantly between Potchefstroom 1 and Reitz in the 1995/96 season but the difference was non-significant for the 1994/95 season while Helderberg had almost the same texture for both the planting seasons on Potchefstroom 1 and Reitz (Table 3.4).

Both the small white and coloured subgroups for washed drained mass (WDM) of processed beans differ significantly for the CLY interactions (Table 3.4). It is obvious from Fig. 3.3 that the WDM was higher for the second year for both groups on most of the locations except Kokstad were there was only a small difference between the two years and between the two groups.

This could be a result of the rain fall which differed on the various localities.

Drained mass of processed beans is the mass of beans after the sauce (or starch) is washed away. After thermal processing, cooked beans continue to increase in weight as they equilibrate with water in the canning medium until they reach a endpoint moisture content of about 65% (Hosfield and Uebersax, 1980). Uebersax and Ruengsakulrach (1989) noted that starch functional property like swelling, solubility, and other factors, influencing process yield and therefore the WDM. Percent carbohydrate was significantly influenced by environmental influences with a high correlation between the percentage of carbohydrate and more rainfall accumulated during the reproductive phase (Intriago-Ortega *et al.*, 1996). Therefore it is possible that the environment can influence the WDM significantly.

Table 3.4. Washed drain mass (WDM) of 10 dry bean cultivars at eight localities over two years (g).

Cultivar	Year	Potch 1	Potch 2	Bapsfon	Ermelo	Reitz	Ficks	Beth SS	Kokstad
Kamberg	1*	244.07	236.00	229.08	241.94	244.67	250.00	209.67	236.33
	2**	262.27	257.50	246.86	253.47	257.93	261.47	249.87	240.43
Teebus	1	251.67	271.00	256.10	253.00	257.33	245.46	254.00	254.33
	2	259.53	272.33	271.03	271.70	270.00	275.73	276.50	261.27
Kosi	1	258.00	266.94	261.33	252.00	245.33	241.33	252.67	263.00
	2	261.40	271.00	265.24	271.03	276.33	270.97	281.63	266.95
Katberg	1	246.00	241.33	252.50	238.33	232.67	258.67	247.33	248.67
	2	248.03	259.00	255.60	238.50	239.12	255.00	248.53	235.23
Helderberg	1	247.00	260.51	253.50	247.00	252.33	244.67	249.67	248.33
	2	265.93	271.57	270.25	273.67	265.40	274.73	274.47	263.80
Patrys	1	241.33	249.00	243.33	244.33	240.00	248.33	248.67	250.00
	2	253.90	255.63	253.27	246.50	248.87	253.63	251.70	246.27
PAN 122	1	254.67	261.94	236.33	252.00	255.33	244.33	246.33	263.33
	2	267.63	279.97	267.00	262.70	262.03	266.40	270.30	261.97
Nandi	1	245.00	246.51	251.67	242.33	246.06	249.33	242.67	248.33
	2	250.03	262.63	266.13	252.53	249.90	258.15	252.30	244.90
Mkuzi	1	247.00	246.00	252.67	240.00	241.33	230.67	236.00	248.67
	2	254.07	258.70	253.10	252.63	247.00	262.80	252.91	242.50
Zambezi	1	255.00	242.67	246.67	245.00	249.06	239.40	246.00	243.33
	2	268.07	272.00	267.93	264.77	266.40	270.53	267.90	250.47

* Year 1 - 1994/95
** Year 2 - 1995/96

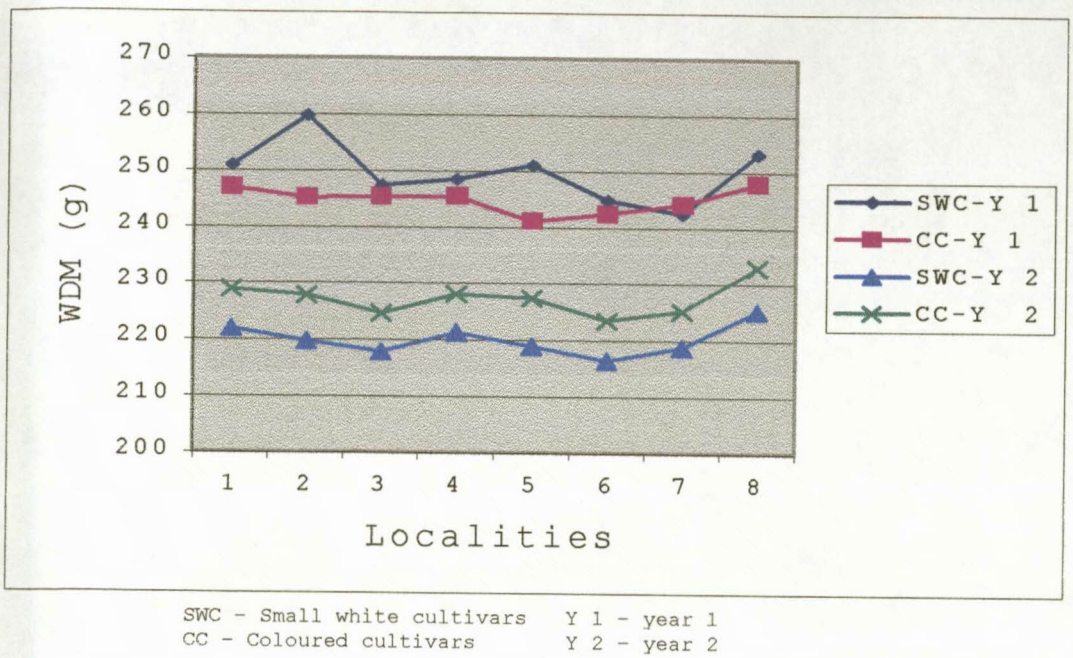
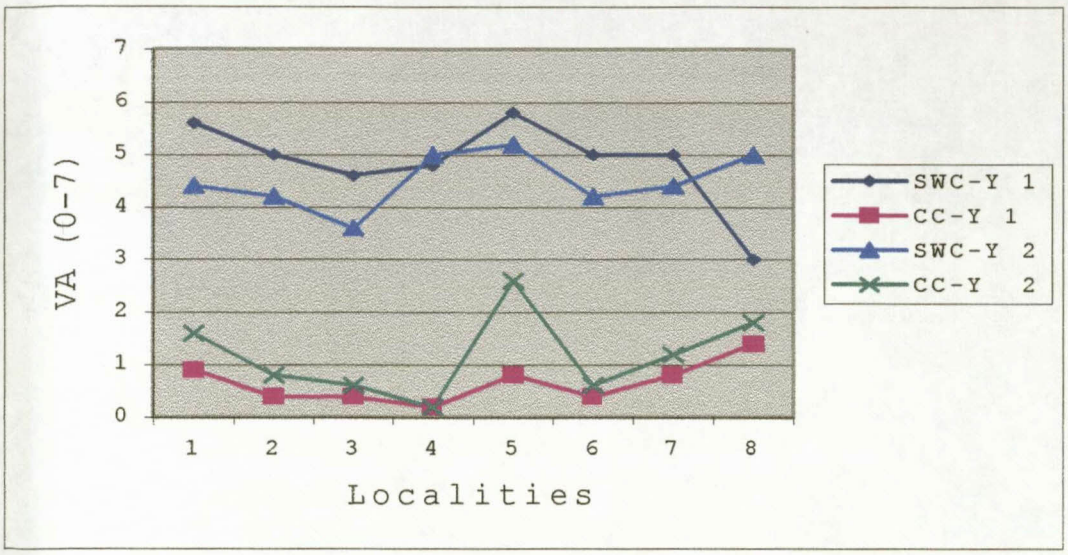


Fig. 3.3. Washed drain mass for two years of white and coloured cultivars.

3.3.4. Visual appearance

Table 3.1 shows the year x locality interaction to be highly significant. The cultivar x year x localilty interaction is significant but the (W x C) x year x locality is not significant (Table 3.1). Like all the other parameters measured the cultivar x locality interaction was inconsistent over years (Fig 3.5a).



SWC - Small white cultivars Y 1 - year 1
CC - Coloured cultivars Y 2 - year 2

Fig. 3.4. Visual appearance for two years for white and coloured cultivars.

Table 3.5a Visual appearance mean scores for two years (0-7)

Year	1994/95	1995/96	Mean
White	4.8	4.5	4.7
Coloured	0.7	1.2	0.9
Mean	2.7	2.8	2.8

Table 3.5b Visual appearance mean scores for eight localities (0-7).

Locality	Potch1	Potch2	Bapsfontein	Ermelo	Reitz	Ficksburg	Bethlehem SS	Kokstad	Mean
White	5	4.6	4.1	4.9	5.5	4.6	4.7	4	4.7
Coloured	1.3	0.6	0.5	0.2	1.7	0.5	1	1.3	0.9
Mean	3.1	2.6	2.3	2.6	3.6	2.6	2.9	2.7	2.8

When comparing white beans to coloured beans by means of contrasts (Table 3.1) the following effects were highly significant: White vs coloured, white vs coloured x year and white vs coloured x locality. The white vs coloured x year x locality interaction was non-significant. It is clear that, although the interaction is highly significant, the white beans were superior to the brown beans in both years. The white vs coloured x locality interaction is shown in Table 3.5b. White beans had greater visual appearance scores at all locations and were, thus, preferred over the coloured beans.

There was a significant negative correlation between the visual appearance and the shearing- and compression force, r=-0.3001** and r=-0.363** respectively (Table 3.8). Soft textured beans had higher visual appearance scores than more firm beans, but, although the correlations are significant, the values are low. This could be the effect of the coloured bean cultivars included, since these cultivars tend to be to hard. There is also a significant positive correlation between the WDM and the visual appearance (r=0.3934**). Beans that are to soft or to hard, have lower WDM since there is a loss of solids when excessive bean breakdown during cooking occur when the beans are to soft or else these cultivars did not imbibe water during the thermal processing. Beans must soften during processing yet still maintain their individual integrity. It is assumed that the intact beans undergo little

loss of solids during processing while excessive bean breakdown during cooking would result in starch exudation into the canning medium and may lead to broken beans, graininess and clumping of individual beans and therefore, the visual appearance would be unacceptable.

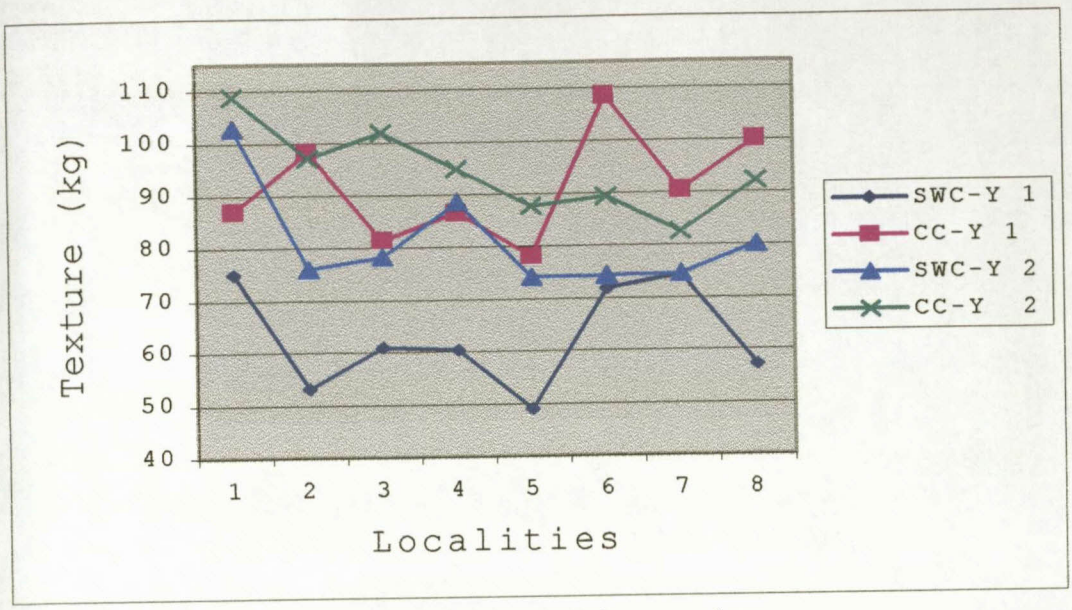
3.3.5. Texture (Shearing force, kg/100g)

All main effects and interactions were highly significant (Table 3.1). The significant cultivar x locality x year interaction showed that all the cultivars differed at various localities (Fig. 3.6) and this interaction was inconsistent over years. The variance ratios (Table 3.1) showed that the variance is mainly due to the difference between the cultivars and to a lesser degree to the difference between years (Table 3.1). Kamberg and Teebus for example, were significantly firmer at most of the localities, except on Bethlehem SS, for the season 1995/96 than for 1994/95 (Table 3.6).

The difference between most of the cultivars for the two years were non-significant at Bethlehem SS. This finding is not surprising because the environments in South Africa differ widely in minimum- and maximum temperatures, rainfall, soil pH and soil fertilisation. Texture is a primary canning-quality

characteristic, because texture influences to a large degree a consumer acceptance of a food product.

The main effects and interactions as well as the white vs coloured x year x locality interaction were significant. The interactions between years is clearly due to the coloured cultivars in Fig. 3.5, since the second year's shearing force was higher at all the localities than the first year for the small white cultivars. The mean shearing force of the coloured beans were higher (82.9kg force/100g) than that of the white beans (69.3kg force/100g). The coloured cultivars were firmer than the small white cultivars for both years. Textural properties of processed beans must fall within prescribed acceptability limits and deviations from the range of acceptance, reduces bean quality and may lead to cultivar rejection. Beans may be unacceptable, as they are too firm or too soft after cooking (Hosfield and Uebersax, 1980).



SWC - Small white cultivars Y 1 - year 1
CC - Coloured cultivars Y 2 - year 2

Fig 3.5. Texture peak (Kg) for two years for white and coloured cultivars.

Table 3.6 Texture (kg force/100g) of 10 dry bean cultivars at eight localities over two years

Cultivar	Year	Potch 1	Potch 2	Bapsfon	Ermelo	Reitz	Ficks	Beth SS	Kokstad
Kamberg	1*	78.42	51.70	35.62	58.42	42.77	60.53	62.07	41.57
	2**	87.30	61.34	71.83	85.67	61.73	57.20	65.37	71.77
Teebus	1	74.37	51.63	30.33	63.30	45.77	60.02	79.50	62.90
	2	106.17	79.17	75.40	87.53	76.83	81.77	79.30	83.63
Kosi	1	88.37	60.18	52.17	82.90	59.30	79.40	70.43	71.80
	2	116.10	85.23	92.55	98.77	71.70	82.90	80.50	95.60
Katberg	1	102.03	121.00	84.16	116.23	86.17	124.97	96.20	128.47
	2	131.07	126.90	125.37	119.80	102.41	110.37	86.80	121.77
Helderberg	1	71.83	55.38	52.11	65.60	52.50	81.23	80.57	49.10
	2	102.30	70.83	65.47	77.90	76.77	72.73	70.40	69.07
Patrys	1	80.50	98.13	73.70	94.93	105.33	113.83	90.30	98.67
	2	106.20	94.37	110.10	91.90	79.03	81.47	84.37	84.87
PAN 122	1	73.90	47.33	50.40	65.73	44.63	73.97	78.93	59.83
	2	101.93	78.17	85.53	92.70	83.17	76.33	76.50	78.53
Nandi	1	79.27	82.98	72.33	85.77	63.36	102.83	87.53	84.33
	2	107.47	83.43	85.80	79.33	73.60	90.94	78.03	82.77
Mkuzi	1	77.23	88.97	66.83	83.57	68.77	94.23	78.97	88.17
	2	101.03	93.27	98.57	87.83	98.13	80.40	80.44	77.50
Zambezi	1	95.20	100.20	72.37	85.90	62.96	110.12	99.30	100.27
	2	98.20	87.07	89.27	95.03	83.60	84.27	81.80	93.47

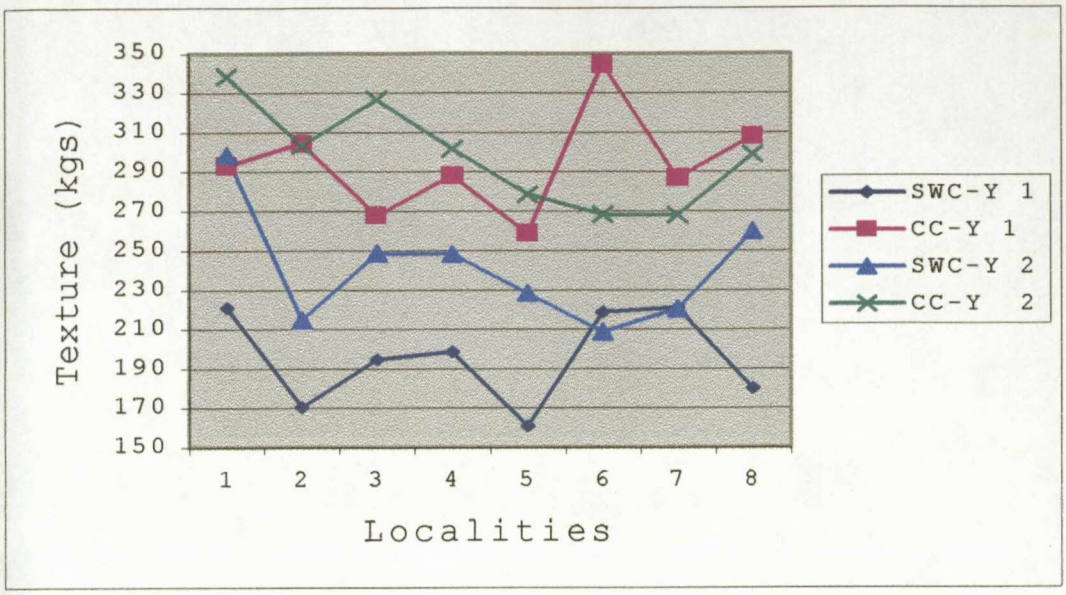
* Year 1 - 1994/95
** Year 2 - 1995/96

3.3.6. Texture (Compression force, kg/100g/sec)

The GLY interaction for the compression force (kg/100g/sec) was significant. For example, Kamberg differed significantly at three of the eight localities while PAN 122 differ significantly at five of the eight localities. There were no cultivars which differed between years at Bethlehem SS but at Ficksburg five of the ten cultivars differed between years (Table 3.7).

The white and coloured bean groups differed significantly for the texture measurement (Table 3.7). The mean compression force of the coloured beans (262.3kg force/100g/12sec) differed from that of the white beans (213.9kg force/100g/12sec). The coloured beans were therefore firmer than the small white beans.

Examination of fig. 3.6 indicates that the small white cultivars were for both years softer than the coloured cultivars at all the localities and in both growing years.



SWC - Small white cultivars Y 1 - year 1
CC - Coloured cultivars Y 2 - year 2

Fig. 3.6. Texture (KgS) for two years for white and coloured cultivars

Table 3.7 Texture (kg force/100g/sec) of 10 dry bean cultivars at eight localities over two years

Cultivar	Year	Potch 1	Potch 2	Bapsfon	Ermelo	Reitz	Ficks	Beth SS	Kokstad
Kamberg	1*	213.3	158.1	119.1	187.9	136.7	181.0	163.6	130.9
	2**	231.9	154.6	219.0	230.4	206.1	157.6	194.1	211.7
Teebus	1	213.0	168.9	108.0	202.7	158.8	188.4	252.3	179.1
	2	325.7	233.4	236.4	247.0	218.8	228.0	232.5	291.9
Kosi	1	266.1	184.1	185.0	258.6	182.5	235.4	192.5	233.7
	2	356.5	245.7	294.6	279.6	215.9	228.7	232.9	316.1
Katberg	1	344.6	385.8	277.0	378.3	292.1	403.6	301.1	393.7
	2	409.4	395.2	402.8	374.5	326.3	333.7	288.0	160.1
Helderberg	1	210.2	185.8	168.0	216.1	165.8	240.3	259.2	213.2
	2	284.3	214.4	222.2	212.6	236.8	203.4	209.0	310.6
Patrys	1	274.7	296.8	255.2	315.3	340.0	361.1	282.0	287.5
	2	346.6	284.8	360.1	305.1	268.7	270.2	261.9	194.2
PAN 122	1	220.7	159.8	182.6	211.5	159.5	235.2	235.8	260.8
	2	292.3	216.4	268.6	270.4	261.5	223.9	232.2	268.8
Nandi	1	280.9	257.3	241.0	281.9	216.9	336.7	286.0	282.4
	2	344.9	273.1	282.2	272.3	253.6	277.8	264.0	273.7
Mkuzi	1	254.3	290.6	229.8	275.8	234.0	295.1	258.5	252.6
	2	320.3	295.5	314.0	282.1	301.0	251.1	272.7	282.0
Zambezi	1	309.0	291.8	242.3	273.0	203.3	340.2	305.7	278.3
	2	270.8	265.3	274.6	273.6	240.2	215.7	252.0	

* Year 1 - 1994/95
** Year 2 - 1995/96

Table 3.8. Correlation Coefficients of 10 small white, carioca and yellow haricot cultivars planted with three replicates on eight localities over two years

Canning quality characteristic	Seed size (Seeds /30g)	Soak bean mass (SBM) (g)	Washed drained mass (WDM) (g)	Visual appearance (0-7)	Texture (kg force /100g)
Seed size (Seeds/30g)	---				
Soak bean mass (SBM) g	0.09	---			
Washed drained mass (WDM) g	-0.04	0.07	---		
Visual appearance (0-7)	0.17	0.14	0.39**	---	
Texture (kg force/100g)	-0.10	0.07	-0.07	-0.30**	---
Texture (kg force/100g/12sec)	-0.12	0.07	-0.15	-0.36**	0.95**

3.4. Conclusions

Processing quality of most small white bean cultivars is associated with various seed characteristics that appear to be significantly influenced by the environment. The environments differ strikingly in South Africa in relation to minimum- and maximum temperatures, rainfall, soil pH, micro- and macro elements in the soil, and fertilisation. Hosfield and Uebersax (1980) and Walters *et al.* (1995) found that the canning quality of the navy beans in Michigan, appeared to be moderately to highly heritable. This could be a result of

more homogenous production areas in Michigan in comparison to the variety of environments in South Africa. Less variabilility in genetic background of cultivars and more stability bred into cultivars could also be reasons, but it needs further investigation. This study includes most of the small white canning and yellow haricot as well as carioca cultivars presently produced in SA. The cultivar x year x locality interactions were significant for most of the canning quality parameters indicating that the genotype x locality interaction varies from year to year.

Hosfield and Uebersax (1980) indicated that it might be possible to transfer genes for important morphological and physiological traits that many of the tropical bean genotypes possess, into the small white canning beans, while simultaneously breeding for protein content. Tropical beans may therefore be useful, as parent in domestic dry bean breeding programs, to transfer desired agronomic characteristics. Indications in this study are that coloured beans in South Africa cannot be used as a parent in the breeding programme to enhance canning quality but can be used to improve agronomic traits. On the basis of the material evaluated in this study, preliminary indications are that reduction in quality could be expected from using coloured beans in the small white canning bean breeding programme if one of the parents used are not a small white canning bean

with excellent canning quality. The breeder should pay special attention to the monitoring of quality characteristics of the progeny of small white x coloured bean crosses, especially, for appearance traits which are important to the canning industry.

Carioca and yellow haricot beans are not usually canned in South Africa and the canning quality of coloured beans is usually lower than those of the white beans. Therefore, it was decided that only the small white beans would be used in further investigations of the interrelationships between the different parameters as well as the investigation of the genotype, environment and GE interactions.

CHAPTER 4

SEASONAL AND GENOTYPIC EFFECTS ON SEED CHARACTERISTICS RELATED TO CANNING QUALITY OF SMALL WHITE CANNING BEANS IN SOUTH AFRICA AND THE COMPONENT INTERRELATIONSHIPS OF THE TESTS USED TO MEASURE CANNING QUALITY (PHASEOLUS VULGARIS L.).

4.1. Introduction

Since the small white beans are traditionally canned in tomato sauce in South Africa as "baked" beans and the coloured beans e.g. carioca and yellow haricot beans are marketed as dry packed beans, the further investigations will be done with small white beans.

There exist no single objective evaluation method to determine the overall acceptability of the canned product for the consumer. Subjective evaluations were employed to differentiate one sample from another and determine consumer acceptability (Redden, *et al.*, 1993).

Seed size has also been exploited to determine the variation in seed size of the dry seeds and the density of the different seed sizes in relation to the water absorption during soaking as well as during processing.

This was done in order to determine objective evaluations of the different parameters instead of the subjective evaluations.

The quality of the processed beans depends on the genetic architecture of cultivars, over which breeders could exert major control, and on unpredictable environmental factors (Ghaderi *et al.*, 1984).

It is necessary to evaluate genetic materials for improved canning quality, in addition to yield and other agronomic features since an unacceptable cultivar with poor canning quality may be rejected by consumers regardless of how agronomically superior it is (Hosfield, 1991). While the micro-canning method provides a suitable screening technique for the food scientist to differentiate the quality of different samples, the utility of the method in plant breeding depends on the extent of genetic variation for the measured traits (Ghaderi *et al.* 1984).

Principal factor analysis (PFA) is a statistical procedure that yields a description of trait measurements as a pattern of components relative to a small, common set of influences or factors. Factor analysis extracts principal components for variables of interest from the

correlation matrix. It is similar to the principal component procedure, except that the system scales factor weights so their sum of squares is equal to the associated eigenvalue and so is related to the total variance explained by that factor.

Principal factor analysis works by reducing the dimensions of a data set so that inter correlated traits are treated as multivariate structures and not simply as independent entities. PFA would tell which tests are measuring similar basic components and it could point out the number and nature of underlying causal influences on which more intensive research can be concentrated. Since it is not known whether any of the multiplicity of test properties of canning quality routinely measured are repeatable, the resolution to this question could be obtained through PFA analysis (Hosfield et al., 1983).

The objectives of this research chapter were to:

1. Determine whether canning quality factors can be described in terms of a few test properties
2. Ascertain the patterns of interrelationship among the canning quality traits
3. Evaluate the genotypic, environmental and genotype x environmental variability for the evaluations.

4.2. Materials and Methods

Small white canning beans (6 cultivars) were grown at five locations in South Africa in the 1995/96 season. These trials were planted with a self-driven planter into four row plots. The rows were 5m long and spaced 750mm between rows and plant spacing within rows was 75mm. The small white beans were planted in randomised blocks. Standard practices for herbicide and fertiliser applications were followed. Samples were harvested manually from the middle two rows of individual plots in late April 1996. Three replications were used for quality evaluations.

The cultivars evaluated for canning quality, were cultivars from different companies enrolled in the National Cultivar Trials namely Teebus, Kamberg, Helderberg, Arctic, Kosi and PAN 122. The canning method used were the same as described in Chapter 2.

4.2.1. Quality assessment

The three replications were assessed for quality traits at dried, soaked and cooked stages of processing.

Initially 29 traits were measured; however, after elimination of redundant traits, 22 traits were retained for subsequent statistical analyses.

The 22 traits (Table 4.1) were measured as follows:

1. Seed mass was measured by counting the number of seeds in 30g samples.
2. Seed size was also determined as the percentage of seeds under a 4mm sieve, above the 4mm sieve, above the 5mm sieve as well as the percentage above the 6mm sieve.
3. Three components of surface colour of the dry seeds and processed seeds were measured with a Hunter lab, Model D25 (L, white to black; a_L, red to green; b_L, yellow to blue and an index of whiteness as WIE313 (Chung *et al.*, 1995).
4. Mass of soaked beans was determined after soaking.
5. Washed, drained weight was determined by weighing rinsed, cooked beans drained for 2 min on a 500µm sieve.
6. Colour, broken and split beans, and uniform seed size was scored subjectively on a 1-5 scale to represent the minimum and the maximum expression of the characters, respectively.
7. Texture was objectively determined with a Texture Press System (Model TP-1A) fitted with a standard multi-blade

shear compression cell. A 100g sample of washed processed beans was placed in the compression cell and force was applied until blades passed through the bean sample (12sec).

8. Dry weight of solids after texture determinations was determined by drying of 100 g in a 60°C oven for 24 hours. This could also be an estimate of the processed bean moisture when subtracted from 100.
9. Overall bean appearance was evaluated (0-7) to measure the suitability of beans for commercial processing. Criteria included loose or free coats, individual bean integrity, and colour of the beans and the uniform bean size after processing.

4.2.2. Statistical procedures

Analyses of variance were performed on Genstat 5 statistical analysis package (GENSTAT 5 Committee, 1978) and used to test the significance of cultivar, location, and cultivar x location interactions for the measured traits. Correlation coefficients between pairs of traits were calculated on Statgraphics 6 statistical analysis package.

Principal factor analysis was performed on the data using the Statgraphics 6 statistical analysis package. The

means for the 23 quality traits were used to calculate the product-moment correlation matrix for the traits. The number of factors with eigenvalues (total variance accounted for by individual factors) equal to or greater than one are extracted. After factor extraction, the matrix of factor loadings was submitted to a Varimax orthogonal rotation. This improved the opportunity of achieving a meaningful interpretation of each factor. A factor can be viewed as a construct delineated by a particular axis protruding through a multidimensional space. The variables that cluster (load) about the axis are highly correlated with it and identify that axis from all others. In this regard, the decision is rather arbitrary as to what magnitude of loading should possess to be considered important (Hosfield, 1983). Traits with loadings between 0.50 and 0.99 were considered major.

4.3. Results and Discussion

4.3.1. Genotype x environment interaction

The main effects as well as the interaction between genotype and environment were either significant or highly significant for seed size, dry bean surface colour, soaked and processed bean characteristics. The

processed bean colour (a_L, b_L and WI313) was not significant (Table 4.1). This could be a result of the tomato sauce colour that probably masked any genotype and environmental effects. Ghaderi *et al.* (1984) also found that the processed bean colour for navy beans did not have significant interactions.

The subjective evaluation of the colour, splits and uniform bean evaluation did not differ significantly between localities (Table 4.2). The evaluation scale was only 1-5 and the subjectivity associated with measuring colour, splits and uniform bean size could have inflated experimental error. Ghaderi *et al.* (1984) found that the GE interaction of the colour components for dry beans differed significantly. They also found that for the L, a, and b components of processed beans, the interaction effects did not differ significantly for navy beans while these trails were planted on two localities. In South Africa, the production areas differ strikingly in temperature, rainfall and other environmental factors.

Correlation coefficients between traits are described in Table 4.3. The different measurements of seed size (SC, Under 4mm, above 4mm, above 5mm and above 6mm sieves) were significantly correlated since it is only different portions of a 100g seed sample, except for the seed

count. The calculated whiteness index was also highly correlated with the other components of surface colour (L, a_L and b_L) since each of these components was used in the calculation of the index. The subjective evaluation were significantly correlated with the processed bean colour namely L (r=0.49**), b_L (r=0.5**) and WIE313 (r=0.49**) measurements and not the a_L component (r=0.08NS) due to the red colour of the tomato sauce. The dry seed colour and the processed colour were not correlated. This could be due to the red colour but Hosfield *et al.* (1983) reported that for navy beans canned in brine, the dry seed colour and the processed colour was not significantly correlated. The surface colour of beans in the dry state is not a determinant of cooked bean colour (Hosfield *et al.*, 1983).

Table 4.1. Mean squares, means, minimum-maximum values for different quality characters of small white beans grown at five locations.

Trait	Cultivar	Location	Cultivar x location	Mean	Min-Max
Dry characteristics					
Seed count(30g)	38.62**	4.268*	6.58**	170.5	107 -227
%Under 4 mm sieve	4.635**	11.61**	0.638**	1.81	0-9.27
%Above 4 mm sieve	63.03**	10.68**	12.32**	56.76	5.15-98.6
%Above 5 mm sieve	56.39**	9.396**	7.82**	39.21	0.42-91.5
%Above 6 mm sieve[1]	---	---	---	1.164	0-16.9
Surface color					
L	34.22**	9.9**	3.65**	63	58-67
A_L	9.36**	10.43**	3.67**	2.121	1.15-3.2
B_L	15.41**	5.92**	3.2**	11.9	10.2-13.9
WI313	20.61**	8.41**	4.12**	-5.2	-15.3-3.0
Soaking characters					
SBM	11.97**	7.87**	2.39*	215.5	190-236
Cooking characters					
Color	7.41**	2.88(NS)	2.53*	3.33	2-5
Splits	66.05**	2.79(NS)	1.76(NS)	2.94	1-4
Uniform beans	26.17**	4.6*	1.51(NS)	3	1-4
VA	91.89**	19.33**	1.4 (NS)	6.795	3.5-8
WDM	4.05**	5.83**	1.72(10%)	283.4	253-309
Texture (Kg)	51.81**	35.94**	2.44*	72.22	42.2-98.9
Texture (KgS)	40.67**	9.94**	1.89(10%)	212.9	141.7-319.6
Processed bean moisture	7.94**	16.49**	1.47**	37.19	31.6-46.5
Surface color					
L	4.92**	5.196**	1.21**	39.83	35.8-43.2
A_L	1.22(NS)	10.84**	2.25*	10.32	9.2-11.3
B_L	2.03(NS)	3.09(NS)	0.92(NS)	16.63	15.3-17.9
WI313	1.94(NS)	3.066(NS)	0.97(NS)	-25.6	-29.7- -21.7

*p=0.05; **p=0.01

The visual appearance evaluation was significantly correlated with each of the subjective evaluations of splits (r=0.788**) and uniform bean size (r=0.809**). The visual appearance (VA) was also correlated with the WDM (r=0.426*). Beans with low WDM indicated an excessive loss of solids during processing and would therefore be "mushy".

Table 4.2. Correlation coefficients indicating the relationships among 22 quality traits of small white beans.

	U4MM	A4MM	A5MM	A6MM	L	A_L	B_L	WI313	SBM	WDM	CO-LOUR	SPLITS	UNI-FORM	VA	KG	KGS	PBM	L	A_L	B_L	WI313
SC	0.7**	0.8**	-0.8	-0.3	-0.5*	0.36	0.7**	-0.7**	0.5*	-0.2	0.07	-0.5**	-0.1	-0.3	-0.3	-0.3	-0.2	0.04	-0.02	0.2	-0.1
U4MM	1.00	0.7**	-0.81	-0.19	-0.3	0.1	0.5**	-0.5**	0.3	-0.3	-0.1	-0.6**	-0.3	-0.4	-0.2	-0.2	-0.06	0.07	-0.1	0.2	-0.2
A4MM		1.00	-0.9	-0.4*	-0.2	0.2	0.5**	-0.57	0.2	-0.2	0.1	-0.5**	-0.2	-0.2	-0.1	-0.1	-0.1	0.08	0.05	0.3	-0.2
A5MM			1.00	0.05	0.4	-0.04	-0.4*	0.4*	-0.3	0.1	-0.4	0.5**	0.2	-0.3	0.1	0.09	0.03	-0.1	0.09	-0.2	0.2
A6MM				1.00	-0.2	-0.4*	-0.6**	0.4*	-0.2	0.2	-0.01	0.3	-0.03	0.1	0.06	0.08	0.2	-0.1	-0.09	-0.3	0.2
L					1.00	-0.4*	-0.4*	0.7**	-0.5**	0.2	-0.05	0.5**	0.5*	0.6**	0.4*	0.6**	0.5*	-0.1	-0.1	-0.1	0.1
A_L						1.00	0.9**	-0.8**	0.3	-0.4	-0.04	-0.5**	-0.5**	-0.6**	-0.3	-0.4*	-0.5*	-0.03	0.2	0.05	-0.05
B_L							1.00	-0.9**	0.4	-0.4	-0.05	-0.7**	-0.4	-0.5**	-0.4	-0.5*	-0.4*	-0.03	0.1	0.1	-0.09
WI313								1.00	-0.5**	0.4*	0.02	0.7**	0.4	0.6**	0.4*	0.5**	0.5**	0.00	-0.1	-0.1	0.1
SBM									1.00	-0.6**	-0.1	-0.3	-0.2	-0.1	-0.3	-0.4	-0.5**	-0.02	-0.1	0.01	-0.01
WDM										1.00	0.06	0.4*	0.4*	0.4*	0.05	0.2	0.3	0.0	0.2	0.02	-0.01
COLOR											1.00	-0.04	0.1	0.1	0.5**	0.3	0.2	0.5**	0.1	0.5**	-0.5**
SPLIT												1.00	0.7**	0.8**	0.4*	0.6**	0.4	-0.3	-0.4	-0.4*	0.4*
UNIF.													1.00	0.8**	0.3	0.4*	0.4*	-0.1	-0.4*	-0.3	0.3
VA														1.00	0.3	0.5*	0.4*	-0.3	-0.3	-0.3	0.3
KG															1.00	0.9**	0.4*	0.3	-0.4*	0.2	-0.2
KGS																1.00	0.5**	0.07	-0.4*	-0.03	0.04
PBM																	1.00	0.2	-0.2	0.1	-0.2
L																		1.00	-0.2	0.9**	-1**
A_L																			1.00	0.01	0.01
B_L																				1.00	-1**
WI313																					1.00

* Significant (p=0.05), ** Highly significant (p=0.01)

U4MM, A4MM, A5MM, A6MM = seed count under 4mm sieve, above 4mm, 5mm and 6mm sieve; L, AL,BL ,WI313=colour of dry beans; SBM = soak bean mass; WDM = washed drain mass; VA=visual appearance; KG = texture (kg); KGS=texture (kgs); PBM=processed bean mass; L, AL,BL ,WI313=colour of processed beans.

The two texture measurements, namely Kg and Kgs, were significantly correlated since the one is the peak of the texture curve and the other is the area beneath the texture curve. There was a highly significant correlation (r=0.58**) between the evaluation of the percentage of splits and the Kgs texture measurement. The kg measurement was significantly correlated (r=0.43*) with the splits. Softer beans can result in more splits. The processed bean moisture was also highly significantly correlated with the Kgs. Beans with a higher processed bean moisture could result in softer textures. The remaining correlation coefficients ranged from small to moderate with positive and negative signs (Ghaderi *et al.*, 1984).

4.3.2. Factor analysis

This analysis gave a good separation of traits into seven orthogonal factors. Major traits did not appear in more than one factor in the analysis.

The different components of seed size (SC, under 4mm-, above 4mm-, above 5mm- and above 6mm sieves) constituted factor I (Table 4.3). These traits were measured

independently to determine if it is possible to correlate different seed sizes of the dry seeds with uniform seed size of the processed beans. The correlation coefficients were low and therefore it is accepted that different seed sizes of the dry seeds were not related to the uniform seed size of the processed beans.

Table 4.3. Loadings of 22 sensory and physico-chemical traits on the first seven principal factors after rotation from five entries of small white canning beans

Variable	I	II	III	IV	V	VI	VII	VIII
Dry Characteristics								
Seed count(30g)	-0.85							
%Under 4 mm sieve	-0.65							
%Above 4 mm sieve	-0.90							
%Above 5 mm sieve	0.92							
%Above 6 mm sieve	0.6						0.55	
Surface colour								
L		0.58						0.52
A_L		-0.86						
B_L		-0.91						
WI313		1.9						
Soaking characters								
SBM						-0.78		
Cooking characters								
Colour			0.63	0.50				
Splits				0.66				
Uniform beans				0.71				
VA				0.79				
WDM						0.81		
Texture (Kg)					0.9			
Texture (KgS)					0.89			
Processed bean moisture								0.68
Surface colour								
L			0.9					
A_L							-0.85	
B_L			0.96					
WI313			-0.97					

There is a significant (r=0.449*) correlation between the seed size (SC) and the SBM. Larger seeds absorb more water than smaller seeds since hard-shelled beans are not related to seed size (Del Valle *et al.*, 1992).

Dry seed surface colour (L, a_L, b_L and WIE313) showed a high positive and negative loading on factor II and characterised this construct as dry bean colour while factor III was the construct of the processed bean colour (L, b_L, WIE313 and the subjective colour evaluation). The aL component of the processed colour was not included in this factor since the red colour of the tomato sauce influenced the a_L (red to green) components of the colour measurement. The loadings of the subjective colour evaluations with factor III (Processed bean colour) indicated that it could be possible to detect the colour differences visually.

The subjective visual appearance (VA, colour, splits and uniform bean size evaluations) showed high positive loadings on factor IV. Since the VA is an evaluation of the overall appearance of the beans consisting of criteria which included loose or free coats, individual bean integrity, colour of the beans and the uniform bean size after processing.

Texture measurements were the traits that gave high positive loadings on Factor V. The texture did not load significantly in a processed bean factor. This indicated

the independence of the texture measurements although Ghaderi *et al.* (1984) found that texture and washed drained mass (WDM) loaded on the same factor for both navy and pinto data and these constructs changed from year to year. The texture of food is important to consumers because it affects the perceived stimulus of chewing. Beans may be unacceptable it they are too firm or too soft after cooking.

Water absorption during soaking and processing load with positive and negative loadings for WDM and SBM, respectively. The SBM and WDM were significantly correlated (r=-0.55**). Two variables in a given factor with high loading but opposite in direction can be expected to exhibit a negative correlation (Hosfield *et al.*, 1984). This indicates an inverse relationship between SBM and WDM.

Factor seven consisted of a high negative loading for the processed colour (a_L component) due to the tomato sauce used as canning medium. The percentage of seeds above the 6mm sieve also loaded a significant score on factor VII. This could be a result of larger seeds that absorb smaller quantities of sauce during processing although there were no significant correlation (r=-0.18 NS)

between seed size and WDM.

4.4. Conclusions

Cultivars responded differently to localities as a result of different environmental parameters at each locality. It has been reported by other investigators that the environment influences canning quality significantly (Hosfield, 1991).

Principal factor analysis results will depend to a considerable extent upon the genetic composition of the cultivars evaluated and upon the particular canning quality tests conducted on these cultivars. The principal factor analysis restructured multivariate data into a smaller number of interpretable and useful patterns of influence characterising the particular test groupings into seven factors.

Tests that measure aspects of dry and cooked beans would be of interest to food scientist and plant breeders. New cultivars falling below certain industry standards and consumer expectations for canned bean quality may be rejected regardless of how agronomically superior they are. For example, knowledge of the WDM aids industry in

complying with labelling regulations. Bean products with a relatively low WDM may indicate an excessive loss of solids during processing and characterise a nutrient deficient product. On the other hand, texture measured the force required to bring cooked beans to a yield point and, thus, served as an estimate of texture.

The processed colour of the beans canned in tomato sauce is not a factor in South Africa since most of the small white beans are presently marketed as "baked" beans. In the presence of the heat and colour agents like tomato sauce, beans underwent pigment changes distinguishing the canned product from the dry product (Hosfield et al., 1983) and masked the natural colour of the beans. Visual selection for seed-coat colour is therefore efficient and intensive colour analysis with a Hunter lab not necessary. Ghaderi *et al.* (1984) reported that colour of the processed beans, within a given class, depends to a large extent on the type of canning media used.

Canning quality of dry beans is laborious and expensive to measure. It necessitates large samples and therefore prohibits testing on F1-F3 generations. Quality evaluations of dry beans for dry bean colour, size and shape could be carried out quite conveniently in early

generations (F1-F3).

Assessment of soaking and canning properties could be started at F4 generations when disease resistance-tolerance has already been tested and ample seed is available for the canning tests. Testing of canning quality at F4 generation level at 3-5 localities ensure that the lines falling beyond the undesirable end(s) of the range will be discarded. Bean lines carrying a single, undesirable feature, despite superiority in other quality attributes is not acceptable to consumers or processors. A selection index could be constructed to ensure that only the best lines would be selected for testing in further multi environment trials.

The canned bean quality of dry beans in a tomato sauce medium can be determined by four characteristics. These characteristics consisting mainly of the seed size, water absorption during soaking and canning, the texture and the visual appearance will be used for further investigations of the genotype, environment and genotype x environment interactions on the canning quality.

CHAPTER 5

MULTIVARIATE ASSESSMENT OF CANNING QUALITY, CHEMICAL CHARACTERISTICS AND YIELD OF SMALL WHITE CANNING BEANS (*Phaseolus vulgaris* L.) IN SOUTH AFRICA.

5.1. Introduction

The canning quality is an aggregate of traits that determine consumer acceptability although the previous chapter showed that six different traits described canning quality of navy beans in tomato sauce. Several tests are suitable for assessing the canning quality of dry and cooked beans (Hosfield and Uebersax, 1980). The multiplicity of tests available to measure dry bean quality presents a problem for the researcher who is restricted to a limited number of tests because of the large number of samples among which differences generally need to be elucidated. There is a need for information about the basic underlying influences or dimensions that best characterize the canning quality (Hosfield *et al.*, 1984).

Research and quality evaluations of the breeding program are directed to provide a consistent cultivar, possessing acceptable canning quality characteristics as well as

acceptable agronomic features (Kang, 1998). A micro-canning method enables the dry bean breeder to improve the canning quality of the new cultivars through effective selection. The evaluation of genetic materials for improved canning quality is necessary since a bean cultivar with poor canning quality may be rejected by the processors regardless of how agronomically superior it is (Hosfield, 1991).

A single variable, representative of the complex of traits, is inadequate. Univariate analysis has proved to provide redundant information (Crossa, 1990; Lezzoni and Pritts, 1991). Van Lill *et al.* (1995a) used multivariate analysis namely principal-component analysis, canonical correlation and canonical variate analysis to determine the environmental effects on the yield, biochemical and bread-making characteristics of hard red winter wheat.

The quality of processed beans depends on the attributes of the seeds at harvest and handling, storage, and processing procedures (Hosfield *et al.*, 1984; Nordstrom and Sistrunk, 1977). The characteristics of beans at harvest depend on the genetic architecture of cultivars and on environmental factors. Breeders exert control over the genetic make-up, but they cannot control the unpredictable environmental factors (Hosfield *et al.*,

1984). However, it is easier to predict location effects than year effects. The relative contributions of cultivar, environment and their interaction as sources to the variation remained unclear.

A better understanding of the magnitude and nature of environmental variance could potentially guide the dry bean breeders in the developing of cultivars with more stable quality attributes (Adams and Uebersax, 1984; Basford and Cooper, 1998). Differences among dry bean cultivars in yield and quality attributes arise from a multitude of genetic factors (Walters *et al.*, 1995).

In this chapter on the canning quality of small white canning bean cultivars, the objectives were to:

1) Evaluate the different quality parameters used for canning quality evaluations and the genotypic and environmental influences and interactions on these quality parameters.

2) Ascertain the patterns of interrelationships among the canning quality traits and the chemical analysis.

3) To attain a better understanding of those variates discriminating the most effectively between the six cultivars studied for canning quality, by means of multivariate analysis and therefore between unacceptable, standard and choice grade cultivars.

5.2. Materials and methods

Small white canning beans were grown at 11 locations in South Africa in the 1995/96 growing season. Six different small white cultivars were planted with three replicates. These trials were planted in the same way as described in the previous chapter.

5.2.1. Quality assessment

The canning methods and the quality assessment methods were the same as described in Chapter 2.

5.2.2. Determination of nutrient composition of raw beans

Dry bean seed was ground in a Wiley mill to pass through a 60 mesh screen. Total nitrogen content (Kjeldahl) was determined according to procedures of the Association of Official Analytical Chemists (AOAC) (Horwitz, 1975).

Calcium (Ca) and potassium (K) were determined on dilutions of dry-ashed samples by atomic absorption employing a Varian Spectra A10 instrument.

5.2.3. Statistical procedures

Canonical correlation analysis was performed using the Statgraphics version 6 data analysis package. Canonical variate and analysis of variance analyses were performed using the GENSTAT 5 statistical analysis package (GENSTAT 5 Committee, 1978). Analysis of variance was used to test the significance of cultivar, location, and cultivar x location interactions for the measured traits. Expected mean squares were used to compare the relative magnitude of main effects and interaction variances.

5.3. Results and Discussion

5.3.1. Analysis of variance

The impact of the environment and cultivar contributed to significant variation in all attributes (Table 5.1). Wide ranges (Table 5.1) in each of the variates were observed. Hosfield *et al.* (1984) confirmed these results for the canning quality traits, yield and protein contents in the black seeded bean cultivars. There is no information on the significant variability for %Ca and %K and locality

effects for small white canning bean cultivars in the literature.

Table 5.1. Mean squares of the different variates for canning quality, biochemical analysis and yield of six cultivars planted on 11 localities.

Identifier	Minimum	Mean	Maximum	Environment	Genetic	G x E
D.f.				10	5	50
%N	2.8	3.3	4.4	42.5**	51**	1.9*
%CA	0.1	0.2	0.3	4.9**	24.1**	1.4(NS)
%K	1.3	1.5	1.9	18.4**	62.4**	1.3(NS)
SC	98	147.7	227	32.6**	200.1**	4.5**
SBM	180	189.7	202.7	22.9**	37.5**	2.1**
WDM	232.5	269.8	286.4	3.3(NS)	41.2**	1.5(NS)
VA	4.5	6.9	8	15.8**	444.7**	3.5**
SPLITS	4	6.7	8	14.2**	247.7**	2.5**
KG	49.7	79.4	127.9	33.4**	109.6**	2.5**
KGS	146.6	232.3	393.6	35.9**	135.8**	4.7**
YIELD	0.2	3.4	8.6	40.5**	2.1(NS)	1.3(NS)

* P≤ 0.01
** P≤ 0.05
NS Not significant

Table 5.1 indicated that for differences existed between the six dry bean cultivars and between localities for each variate separately.

The interaction between cultivar and locality was significant for most of the variates except for the %Ca, %K, SBM and the yield. Hosfield (1991) mentioned that one of the formidable roadblocks to success in the genetic improvement of a trait is the unpredictable consequence of the environment. The consequences of GE interactions

lead to changes among genotypes that are grown at several places or over a number of seasons. The relative magnitude of cultivar importance of the variation for environment and their interaction is provided by the mean squares determined in the analysis of variance (Table 5.1). All the canning quality traits and chemical analyses were genetically determined with small environmental influences.

5.3.2. Linear correlation among canning quality, biochemical characteristics and yield.

Table 5.2 shows the correlations between the canning quality attributes, chemical characteristics and yield. As expected, VA and splits were highly related, as were the two texture measurements (Kg and Kgs). Protein content was not related to any of the canning quality attributes. Yield was significantly correlated to the texture and the percentage splits with correlation coefficients ranged from -0.2 to -0.3, indicating poor predictability. Hosfield *et al.* (1984) found in blackseeded dry beans that yield and protein content were independent of canning quality. The results of the current work agree with Hosfield et al. (1984) results in which small white canning beans were studied.

The texture was significantly correlated with SC, SBM,

WDM and VA (splits) although the correlation coefficients ranged from 0.27 to 0.40. This indicates that the canning quality attributes are related to each other but the low correlation coefficients for most of the pairs of traits indicated that selection for the measured traits could be carried out independently.

The %K content of the dry seeds was significantly and negatively correlated with the canning quality attributes but the low correlation coefficients ranging from 0.23 to 0.38 indicating poor predictability. These low linear correlation coefficients indicated that no single parameter could explain variation in the yield and canning quality attributes. These results are in agreement with previous findings for dry beans in various classes (Hosfield and Uebersax, 1980; Ghaderi *et al.*, 1984).

Most of the attributes were interrelated, but the largest amount of variation explained in a given quality parameter estimated by a single chemical component was 14 percent ($r=-0.38$, $r^2=0.14$; Table 5.2), this excluded the use of conventional multiple linear regression analysis. Therefore, canonical correlation analysis was used to explain the observed variation in quality attributes.

Table 5.2. Linear Correlation coefficients between the quality characteristics, the chemical seed analysis and yield.

	Prot	%Ca	%K	SC	SBM	WDM	VA	SPLITS	KG	KGS
%Ca	-0.2*	1								
%K	0.103	0.03	1							
SC	-0.04	0.29*	0.28**	1						
SBM	0.056	-0.003	-0.36**	0.15	1					
WDM	-0.07	-0.25**	-0.23**	-0.55**	-0.11	1				
VA	-0.04	-0.1	-0.37**	-0.39**	0.13	0.38**	1			
SPLITS	0.08	-0.09	-0.38**	-0.33**	0.09	0.34**	0.88**	1		
KG	0.07	0.26**	-0.27**	0.38**	0.38**	-0.40**	0.36**	0.34**	1	
KGS	0.09	0.18	-0.25**	0.39**	0.35**	-0.39**	0.37**	0.4**	0.95**	1
YIELD	0.05	0.099	0.37**	-0.7	-0.12	-0.02	-0.16	-0.19*	-0.20*	-0.3**

5.3.3. Canonical correlations between canning quality characteristics, chemical analysis and yield of six small white dry bean cultivars.

Canonical correlation analysis determines the relationship between two sets of variables. The procedure identifies linear combinations of variables in one set that are most highly correlated to linear combinations of the second set.

In this study the first set of variables is the canning quality as determined by the SBM, WDM, VA and texture (KgS). The second set of variables consisted of the total nitrogen contents (protein), calcium, potassium and the yield.

It is clear from Table 5.3 that the first two canonical correlations (CC) between the two sets are highly significant.

Table 5.3. Canonical correlations between the quality parameters and the chemical analysis and yield.

Number	Eigenvalue	Canonical correlation	Wilks Lambda	Chi-kwadraat	Degrees of freedom	F-value
1	0.288	0.537	0.595	69.8	16	0.001
2	0.152	0.39	0.836	24.11	9	0.004
3	0.011	0.106	0.986	1.91	4	0.752
4	0.0029	0.054	0.997	0.387	1	0.534

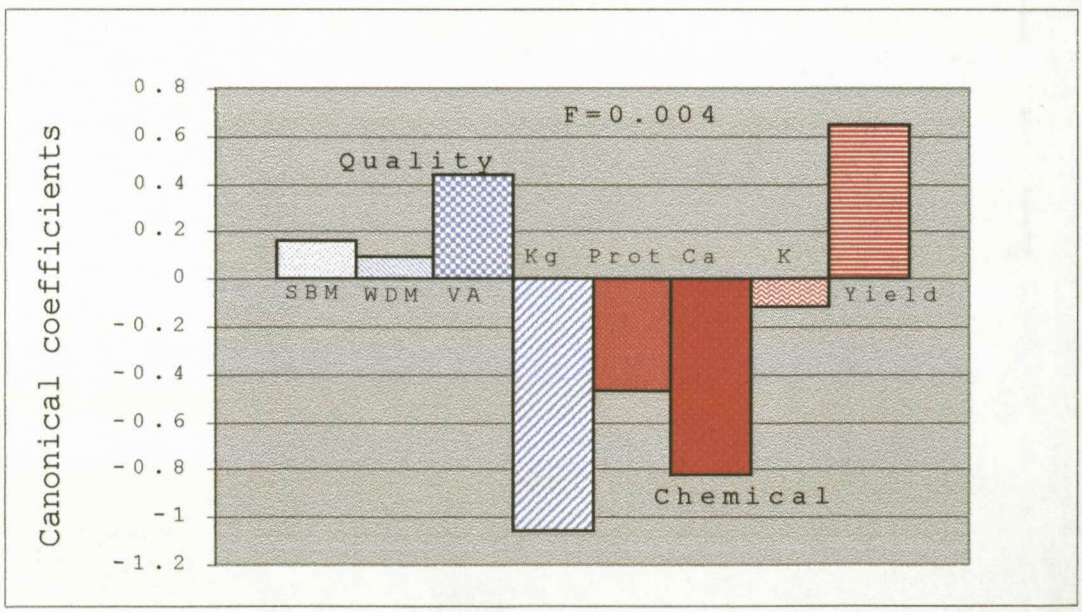


Fig 5.1. Canonical correlation analysis to show the relationship between a group of chemical and quality characteristics - First Canonical correlation.

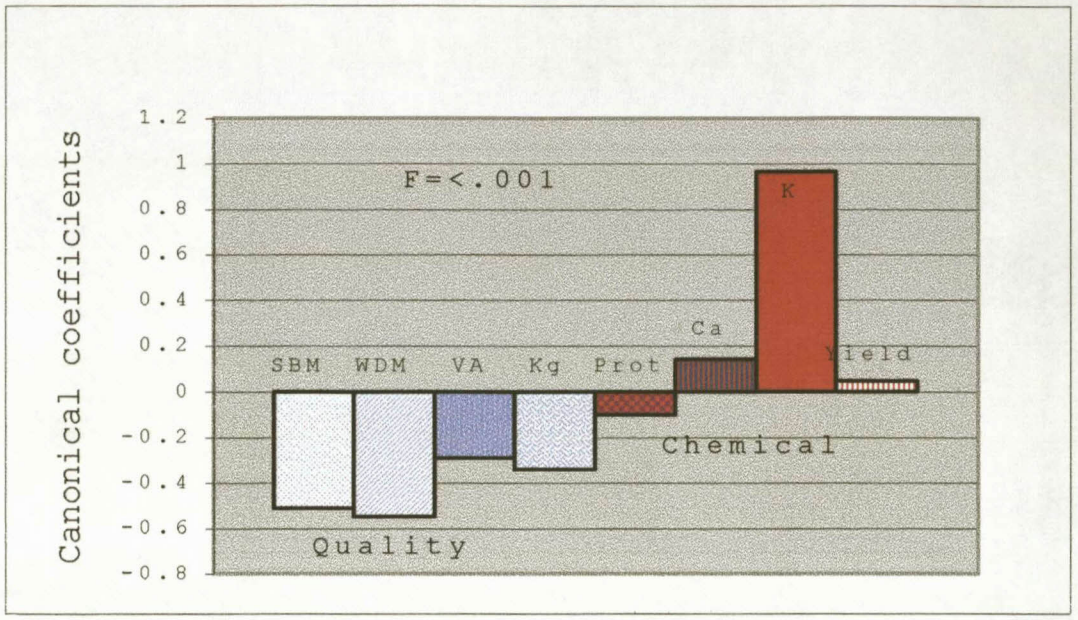


Fig 5.2. Canonical correlation analysis to show the relationship between a group of chemical and quality characteristics - Second Canonical correlation.

Table 5.4. Coefficients of canonical correlations.

Characteristics	CCA 1	CCA 2
Set 1		
SBM	-0.581	0.165
WDM	-0.549	0.097
VA	-0.29	0.442
Texture(Kg)	-0.3398	-1.055
Set 2		
Protein	-0.0996	-0.468
Calcium	0.145	-0.819
Potassium	0.968	-0.116
Yield	0.048	0.65

These significant relationships are shown in Figure 5.1.

The first canonical correlation described 69,8% (r=0.54)

of the variation between the canning quality traits and the chemical analysis.

The extent to which an individual trait contributed to a canonical variate is indicated by the magnitude of its canonical coefficient. The main contributing factor to the chemical data set was the %K (0.968) while there were two main traits contributing to the canning quality attributes namely SBM and WDM. These results indicated that the %K in the dry seeds influenced the canning quality traits and to a greater extent the water absorption of the dry beans. Since this is a negative correlation coefficient, lower levels of K would enhance the water absorption. Lower water absorption could result in a firmer texture and better visual appearance.

The second canonical correlation accounted for 24% (r=0.39) of the variation (Table 5.3). The canning quality traits influencing this response domain are mainly the texture (Kgs) with a canonical coefficient (cc) of -1.06 and the VA (cc=0.44). The inverse canonical coefficients between the texture and visual appearance could be the result a firmer bean with lesser percentage splits and beans that are too soft or "mushy". The chemical domain is mainly influenced by the %Ca (canonical coefficient (cc)=-0.82) and to a lesser extent

by the yield (cc=0.65) and %K (cc=0.047)(Fig 5.2). The influence of Ca is expected since pectic substances allow divalent cation cross-linking and thus, forming intercellular polyelectrolyte gels that significantly contribute to the textural quality (Uebersax and Ruengsakulrach, 1989). Therefore, the higher the %Ca in the beans the more the cation cross-linking and the firmer the texture.

5.3.4. Canonical variate analysis on factors affecting canning quality of dry beans.

The analysis of variance (ANOVA) is a univariate technique, whereby one can show statistical evidence for real differences between the six dry bean cultivars for each variate separately. There was strong evidence ($p < 0.01$) of differences between cultivars for all variates measured (Table 5.5). However, it does not give an indication of how they group, or which variate(s) are most important in discriminating between groups. Canonical variate analysis (CVA), better known as linear discriminant analysis, is used when it is of more interest to show differences between groups than between individuals. The variability in a large number of variates is first reduced to a smaller set of variates that account for most of the variability. The new sets of

variates, called canonical variates, are linear combinations of the original measurements. With this approach a set of directions are obtained in such a way that the ratio of between group variability to within group variability in each direction is maximised. The scores found for each of the canonical variates are then correlated with the original variates to find those that are the most important in discriminating between the groups.

In this study the variates were chemical analysis as well as quality characteristics and yield that were measured on each of six cultivars at 11 localities in one year. Those variates which were unimportant were then deleted from the analysis one-by-one until only those with reasonable correlation coefficients, $r > 0.4$, were retained. The variates excluded were %N (protein content), SBM and yield.

The first two canonical variates (CV1 and CV2) together accounted for 87.0% of the total variation among groups. The canonical variate mean scores and percentages for these two CVs are shown in Tables 5.5 and 5.6, respectively.

Table 5.5. Canonical variate percentage variation and mean scores of the first two canonical variates of the six cultivars.

Variates	CV1	CV2
	65.7%	20.3%
Kamberg	4.94	0.728
Teebus	-1.55	0.051
Helderberg	0.899	-2.353
PAN 122	-0.384	0.19
Kosi	-2.42	-0.559
Arctic	-1.353	2.079

It is already evident from Table 5.5 that Kamberg contrasts the most with the other cultivars (large negative CV1 score vs. positive or very small negative scores, and this horizontal separation accounted for nearly 66% of the total variation). A plot of the two canonical variates mean scores (Fig. 5.2) shows the grouping of the six cultivars more clearly. In such a plot, points closer together are similar and points further apart are dissimilar with respect to their general response to the variates that discriminate between them. As far as response to all the variates included in the final CVA, cultivars Teebus and Arctic (choice grade cultivars) were most similar, and cultivars Kamberg (unacceptable cultivar) and Kosi (choice grade cultivar) most dissimilar.

Table 5.6. Correlation coefficients of those variates retained in the final CVA with each other and the first two canonical variates.

	%Ca	%K	SC	WDM	VA	Splits	KG	KGS	WDM
%Ca	1								
%K	-0.019	1							
SC	0.237	0.417	1						
WDM	-0.135	-0.283	-0.493	1					
VA	0.025	-0.492	-0.472	0.44	1				
Split	0.036	-0.514	-0.455	0.418	0.907	1			
KG	0.265	-0.313	0.263	-0.337	0.359	0.342	1		
KGS	0.189	-0.296	0.262	-0.321	0.385	0.398	0.944	1	
SBM	-0.002	-0.251	0.339	-0.332	0.177	0.195	0.558	0.588	1
Yield	0.084	0.206	-0.193	0.036	-0.034	-0.044	-0.174	-0.24	-0.235
CV[1]	0.081	0.604	0.583	-0.474	-0.951	-0.911	-0.364	-0.44	0.075
CV[2]	-0.583	-0.312	-0.602	0.193	-0.215	-0.203	-0.511	-0.44	0.002

The variates which mainly discriminated between cultivars for CV1 (x-axis)(Fig 5.3) were visual appearance(r=0.97) and splits (r=0.92), and to a lesser extent %K (r=-0.57), as these correlated strongest, positive or negative, with the CV1 scores. Thus, generally Kamberg had low rating for visual appearance (mean=5.05; Table 5.7) and splits (mean=4.9; Table 5.7), but higher %K values (mean=1.65; Table 5.7) than the other five cultivars, which were either average, when close to the zero line (Fig 5.3), or higher for VA and splits.

The discrimination between Arctic and Helderberg on the vertical or y-axis was mainly due to seed count (r=-0,69) and %Ca (r=-0.60). Thus, for example, Kamberg (unacceptable cultivar) forms a unique group with low

visual appearance and splits score, high %K, but also a little above average seed count (mean=168.6) and %Ca (mean=0.16; Table 5.7). Helderberg was little below average for visual appearance and splits scores, but high for seed count and %Ca (Table 5.7). Helderberg is a standard grade cultivar with small seeds (SC=180). These variates, their simple correlation coefficients with the CV mean scores, as well as the relevant means of the groups are presented in Tables 5.6 and 5.7.

Table 5.7. Means of six dry bean cultivars for all variates considered in the canonical variate analysis.

	%Ca	%K	SC	WDM	VA	Splits	KG	KGS	Yield	SBM
CULT										
Kamberg	0.16	1.65	168.6	259.6	5.1	4.933	67.77	190.2	3.518	187.5
Teebus	0.18	1.45	132.4	271.2	7.4	7.08	86.07	251.7	3.35	188.7
Helderberg	0.18	1.64	179.7	271.5	6.9	6.734	78.93	226.7	3.737	189.2
PAN122	0.15	1.45	158.3	266.9	7.0	6.75	86.97	256.9	3.29	194.7
Kosi	0.16	1.52	133.6	268.4	7.8	7.5	93.85	278.2	3.555	190.7
Arctic	0.12	1.49	114	280.9	7.2	7	61.75	185.8	3.038	187.8
Mean	0.16	1.54	147.7	269.8	6.9	6.678	79.42	232.3	3.415	189.8

Graphical representation of the quality variation of genotypes is done in Fig. 5.3. Applying the model described in the two equations to independent data sets would result in co-ordinates that would represent the cultivars as choice grade, standard grade or unacceptable cultivars.

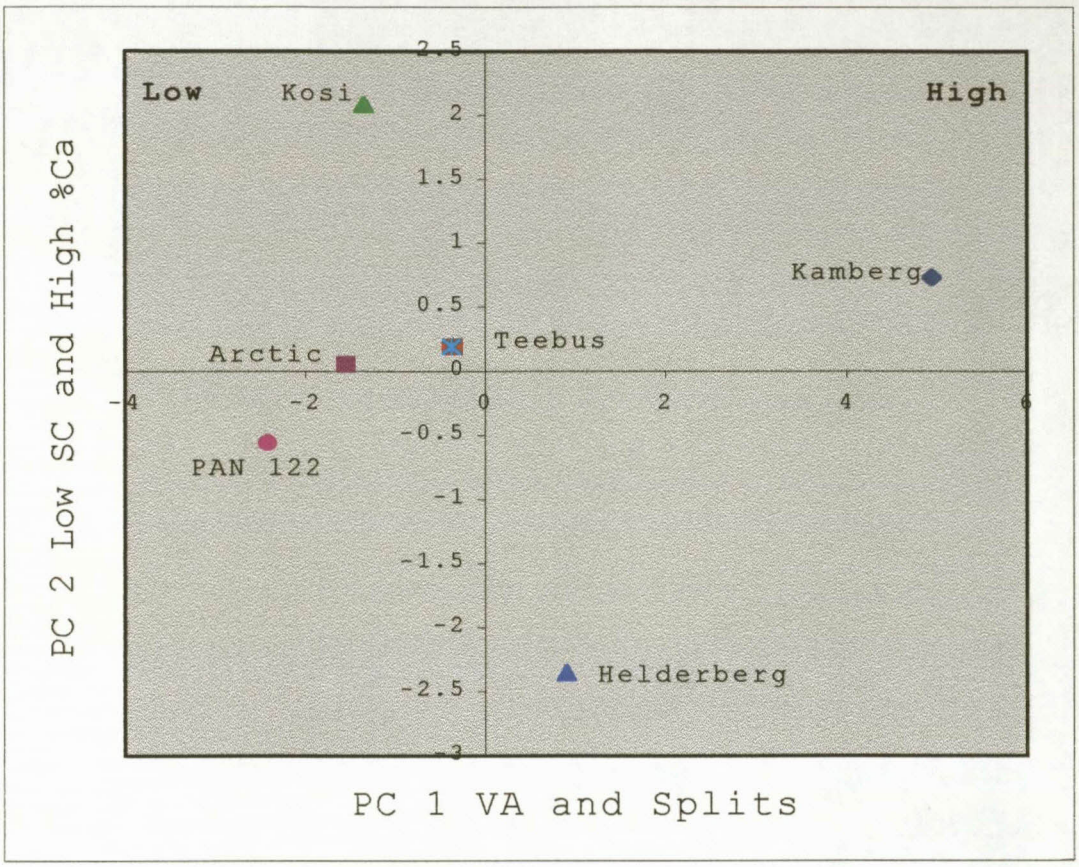


Fig. 5.3. Canonical variate one for each cultivar plotted against canonical variate two.

The discriminating equations obtained from this analysis were as follows:

CV_1= -3.095(**%Ca**) - 0.384(**%K**) - 0.018(**SC**) + 1.441(**VA**) + 0.395(**Splits**) + 0.016(**KgS**) -22.63

CV_2= -16.539(**%Ca**) - 5.449(**%K**) - 0.041(**SC**)- 0.755(**VA**) - 0.428(**Splits**) + 24.7

5.4. Conclusion

Our aim was to attain a better understanding of those variates discriminating most between the six cultivars studied for canning quality by means of multivariate analysis. Canonical variate analysis indicated that of all the measured variates for one year of this study, visual appearance, splits, %K, seed count and %Ca discriminated most effectively between cultivars (Fig 5.3). Kamberg was most different from all the others since Kamberg is a cultivar with an unacceptable canning quality. Kamberg has a soft "mushy" texture with more splits and smaller seed sizes than Teebus and Arctic (Table 5.7). CV1 discriminated most effectively between the choice grade, standard grade and unacceptable cultivars (Fig 5.3). According to the canonical correlation analysis, lower %Ca results in lower texture measurements and lower visual appearance scores. Inverse relationships between the %K and the water absorption (Fig.5.1) indicated that Kamberg with high %K content would have absorbed less water than Helderberg (standard grade).

CV2 discriminated more effectively between the choice grade and standard grade cultivars. Helderberg, PAN 122 and Arctic are standard grade cultivars according to the

processing industry. Although the cultivars do not all have smaller seeds, the Ca content of these cultivars resulted in standard grade cultivars.

These analyses therefore provided a procedure to determine the canning quality grade of new or unknown cultivars. This demonstrates the potential of this approach in enabling quality assessors to objectively compare differences among independent data sets.

There are indications that the genotype, environment as well as the GE interactions influence the quality. There is also a need to determine the effect of different seasons on the canning quality as well as a clustering of environments to enable the dry bean breeder to allocate resources effectively.

CHAPTER 6

EFFECTS ON SEED CHARACTERISTICS RELATED TO CANNING QUALITY OF SMALL WHITE CANNING BEANS (*Phaseolus vulgaris*. L) AND THE INTERRELATIONSHIPS OF CANNING QUALITY TRAITS IN SOUTH AFRICA.

6.1. Introduction

Increased and stabilised yield over a range of environmental conditions is generally a major goal of breeding programs since the year, environment, genotype and the different interactions influenced the canning quality as described in the previous chapter. The dry bean breeders are also interested in food quality improvements since beans that do not meet consumer expectations may be unacceptable to processors (Hosfield, Uebersax and Isleib, 1984).

Physical properties of dry and canned beans can influence consumer preferences and processor expectations. Objective criteria can be used to identify preference standards by using a series of tests that permit the measurement of specific and distinct sample traits (Hosfield and Uebersax, 1980; Ghaderi, Hosfield, Adams and Uebersax, 1984). The micro-canning method can be used for assessing canning quality of dry beans and can be conducted rapidly at a reasonable cost on small amounts of

seed with good precision. This method can therefore be used by breeders to evaluate canning quality of the breeding populations (Hosfield *et al.*, 1984).

Genotype-by-environment interaction (GE) is said to be present when different cultivars (genotypes) respond differently to different environments. The nature of gene action involved in trait expression and the degree to which the genes are influenced by environmental fluctuations are determinant factors in developing selection strategies in a breeding program (Hosfield *et al.*, 1984).

Assessing any breeding line or population for canning quality without including its interaction with the environment is incomplete and limits the accuracy of the micro-canning quality evaluation of different breeding lines and cultivars (Crossa, 1990; Kang, 1998).

Knowledge of the GE interaction variances provides insight into the amount of testing required characterising breeding lines and populations reliably. A detailed understanding of the causes of GE interactions is rarely achieved. The level of understanding that can be achieved will depend on the repeatability of the interactions within the GE system under investigation (Basford and Cooper, 1998).

The analysis of variance assumes a completely additive model and treats the interaction as a residual. One of the main deficiencies of the combined analysis of variance is that it does not explore any underlying structure within the residual (observed non-additivity). Valuable information contained in the non-additivity is practically wasted it no further analysis is done (Crossa, 1990).

Principal component analysis (PCA) was used to examine the data structure and reveal the relationship pattern among measured traits. PCA assumes a complete multiplicative model without any description of the main effects of genotypes and environments. The analysis consists of transformation of the original (correlated) traits into a new set of uncorrelated variables or principal components. PCA is a generalisation of linear regression giving more than one statistic and the scores on the principal component axes describe the response pattern of a genotype (Crossa, 1990).

The objectives of this chapter were to:

1. evaluate the genotypic, environmental, and genotype x environmental variability among the small white canning cultivars commonly grown in South Africa and
2. to ascertain the patterns of interrelationship among the canning quality traits through multivariate analysis.

6.2. Materials and Methods

Dry beans used in this study were grown at 16 different localities in 2 seasons. These dry beans were grown in the summers of 1995-96 and 1996-97. These trials were planted in the same manner as described in Chapter 2 and harvested manually from the middle 2 rows of individual plots in late April 1996 and 1997. The small white cultivars evaluated for canning quality, were cultivars from different companies enrolled in the National Cultivar Trials, namely, Teebus, Helderberg, PAN 122 and Kosi.

6.2.1. Quality evaluations

The canning methods and quality evaluations were the same as described in Chapter 2.

6.2.2. Statistical analysis

All data were subjected to an analysis of variance appropriate to a nested design. Analysis of variance and principal component analysis were done using Genstat 5 Release 3.1.

The combined analysis of variance removes the replicate effect from the data and the GE observations are partitioned into two sources: (a) additive main effects for genotypes and

environments and (b) nonadditive effects due to genotype-environment interaction (Crossa, 1990).

The aim of principal components analysis is to transform the data from one set of co-ordinate axis to another, which preserves, as much as possible, the original configuration of the set of points and concentrates most of the data structure in the first principal component axis (Crossa, 1990).

6.3. Results and discussion

6.3.1. Analysis of variance

The minimum, maximum and mean of each characteristic are listed in Table 6.1. The variance analyses were listed in the second table for each of the six characteristics, namely, seed count (SC), soaked bean mass (SBM), washed drain mass (WDM), visual appearance (VA), texture (kg) and texture (kgs).

Table 6.1. Mean, maximum and minimum values of two years and 16 localities for 4 cultivars.

Identifier	Minimum	Mean	Maximum
SC	92	153	253
SBM	170	203.1	311.1
WDM	239.8	274.1	305
VA	1	5.4	7
KG	47.9	81.17	136.1
KGS	163.3	257.3	437

Table 6.2. Analysis of variance of 2 years and 16 localities (4 Cultivars).

Source of variation	df	SC	SBM	WDM	VA	Texture (Kg)	Texture (KgS)
Year	1	81.0**	32.3**	22.6**	2.4(NB)	41.9**	43.3**
Cultivar	3	271.9**	70.6**	5.99**	86.9**	40.6**	46.5**
Locality	15	21.5**	14.05**	16.8**	11.4**	9.7**	13.5**
Year x Locality	15	14.9**	29.7**	14.7**	6.9**	34**	24.0**
Year x Locality x replicate	64	1.96(NB)	3.8(NB)	2.5(NB)	2.0(NB)	3.1(NB)	2.4(NB)
Cultivar x Year	3	2.1(NB)	0.9(NB)	5.5**	17.96**	2.5(NB)	5.3**
Cultivar x Locality	45	10.1**	3.2**	4.1**	3.0**	1.8**	2.5**
Cultivar x Locality x Year	45	3.03**	1.7**	1.3(NB)	2.8**	2.2**	2.1**
Residual	183(9)						

* p= 0.05

** p=0.01

Seed size

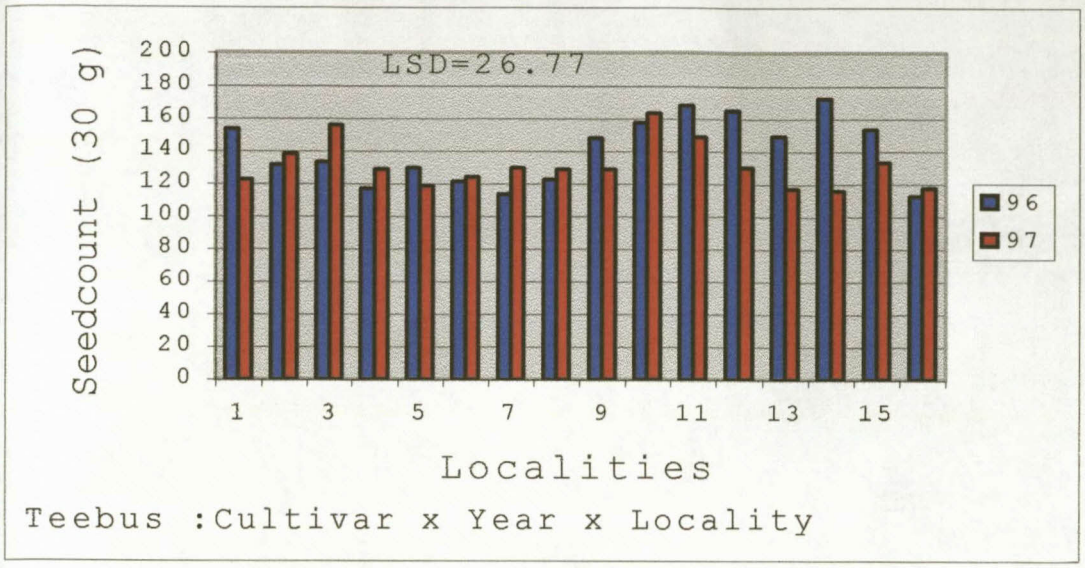
The main effects for year, cultivar and locality were significant for seedsize. For the SC trait the interaction for cultivar x locality (CxL) and CxLxY were highly significant as indicated in Table 6.2. The interaction for CxY was not significant. Cultivars respond differently to localities and years as a result of different environmental parameters that vary over localities in an inconsistent manner. For example consider localities 1(Potchefstroom 1) and 3 (Derby)(Fig 6.1a-d) for the four different cultivars (Table 6.3). The seed size of Teebus (Fig 6.1a) was larger in the 1996 season than in the 1997 season at Potchefstroom but at Derby the opposite was true. PAN 122 had almost the same seed

size at Potchefstroom 1 and Derby. Ghaderi *et al.*, (1984) reported that correlation and principal component analysis suggested that seed size was not related to canning quality. Intriago-Ortega *et al.* (1996) found that seed size of pinto seeds was not determined by the availability of water during the seed filling period.

Table 6.3. Locality names and numbers

Locality number	Locality names
1	Potchefstroom 1
2	Potchefstroom 2
3	Derby
4	Carletonville
5	Syferbult
6	Ficksburg
7	Bethlehem Sensako
8	Reitz
9	Bapsfontein
10	Greytown 1
11	Greytown 2
12	Cedara
13	Potchefstroom (LP)
14	Cedara (LP)
15	Bapsfontein (LP)
16	Syferbult (LP)

LP- Pilot trail



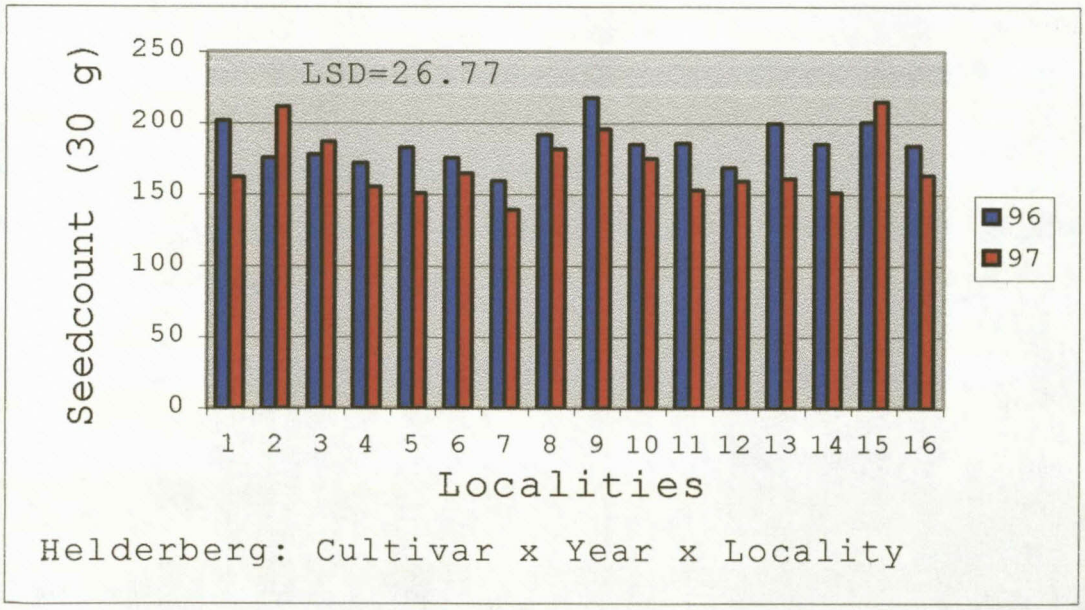
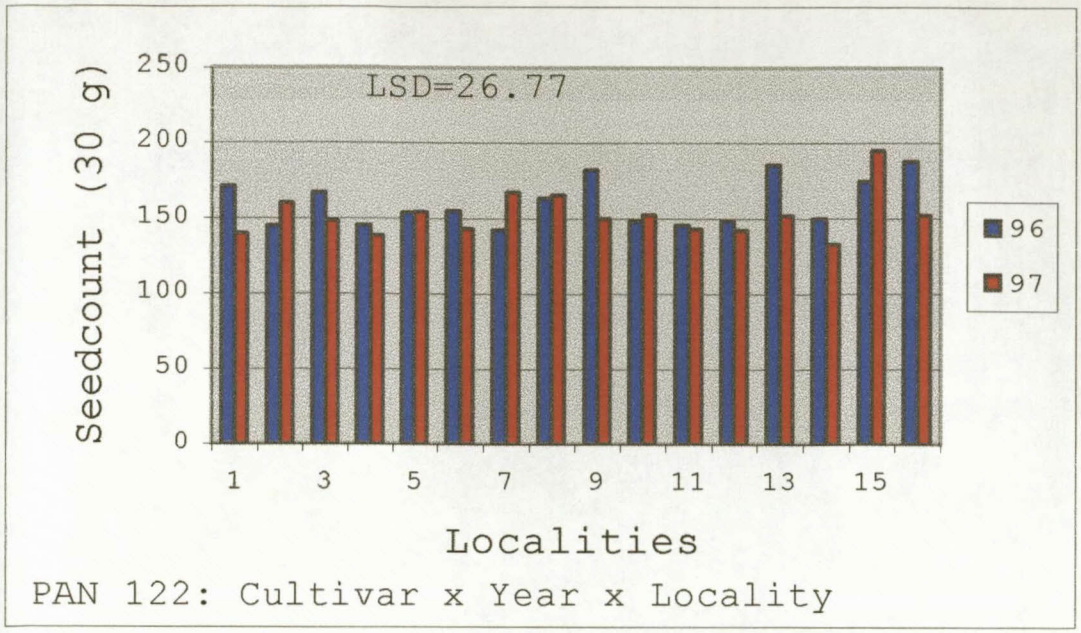


Fig. 6.1a & b. Effect of significant genotypic and environmental interactions over two years on the seed size of the individual cultivars.



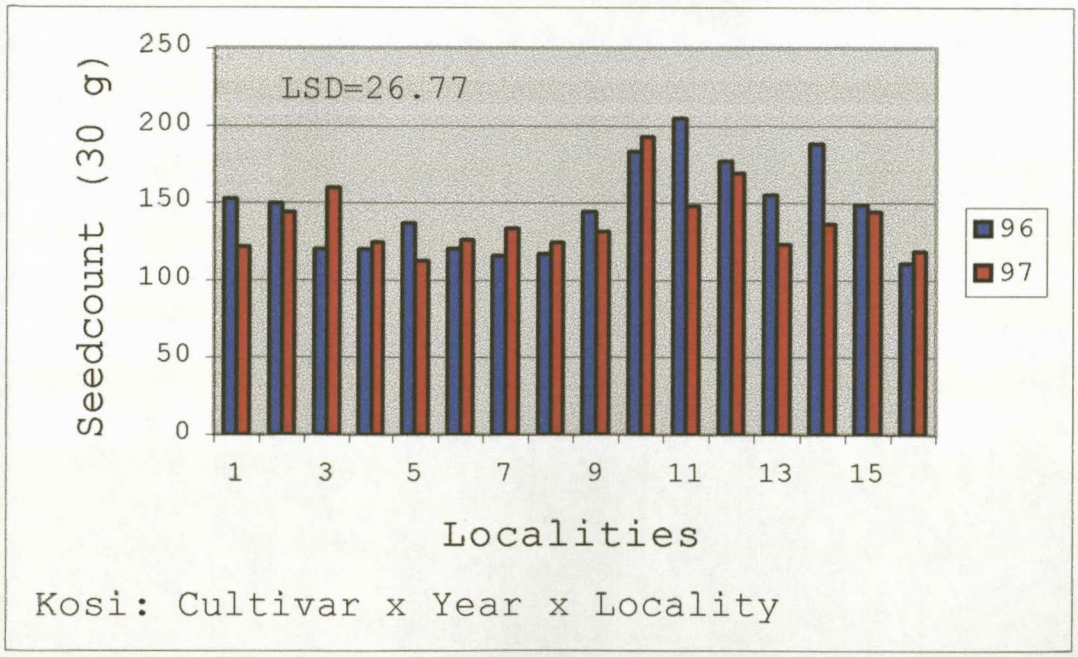
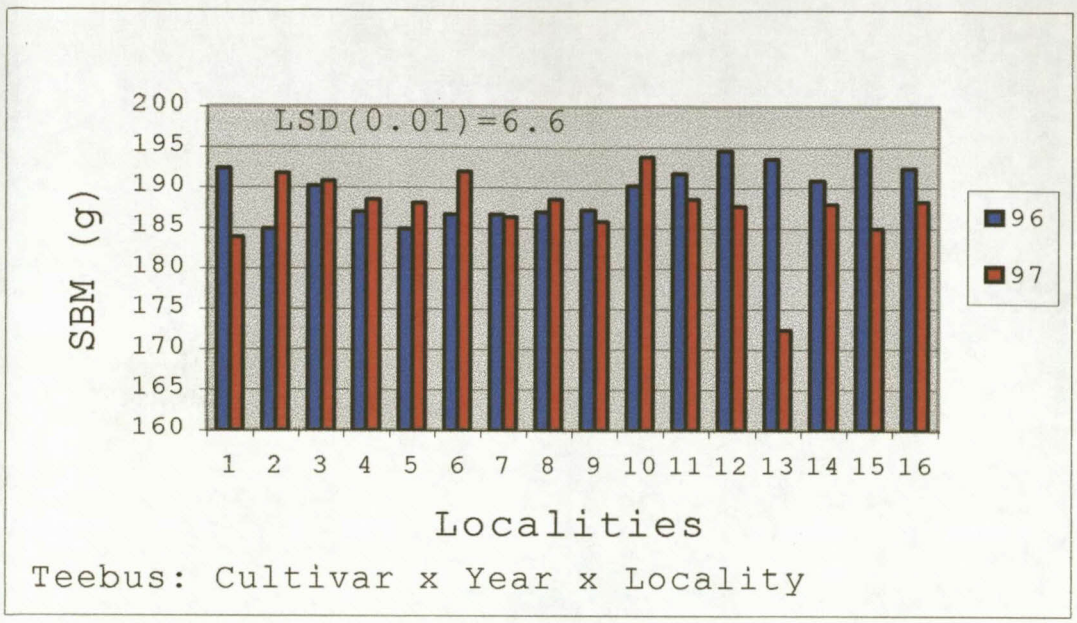


Fig. 6.1c & d. Effect of significant genotypic and environmental interactions over two years on the seed size of the individual cultivars.

Soak bean mass (SBM)

The main effects and all interactions of soak bean mass (SBM) were highly significant as indicated in Table 6.2, except the cultivar x year interaction. The CxLxY interaction means that cultivars respond differently to localities and years. This is an indication that environmental parameters like rainfall, temperature and soil vary among localities and years in an inconsistent manner. An example of the interaction is the means of Teebus, Kosi, Helderberg and PAN 122 on locality 10 and 11 (Greytown 1 and 2) for 1996-1997 (Fig 6.2a-d). Teebus and Helderberg have a higher SBM on Greytown 1 for 1997 than for 1996 while they have a higher SBM in the Greytown 2 trail for the 1996 than the 1997 season. PAN 122 and Kosi reacted differently at Greytown 1 and 2 with a lower SBM in the 1997 season than in the 1996 season in the Greytown 1 trail and the Greytown 2 trail. Other investigators have reported that the environment influences SBM significantly (Hosfield and Uebersax, 1980; Ghaderi *et al.* 1984).



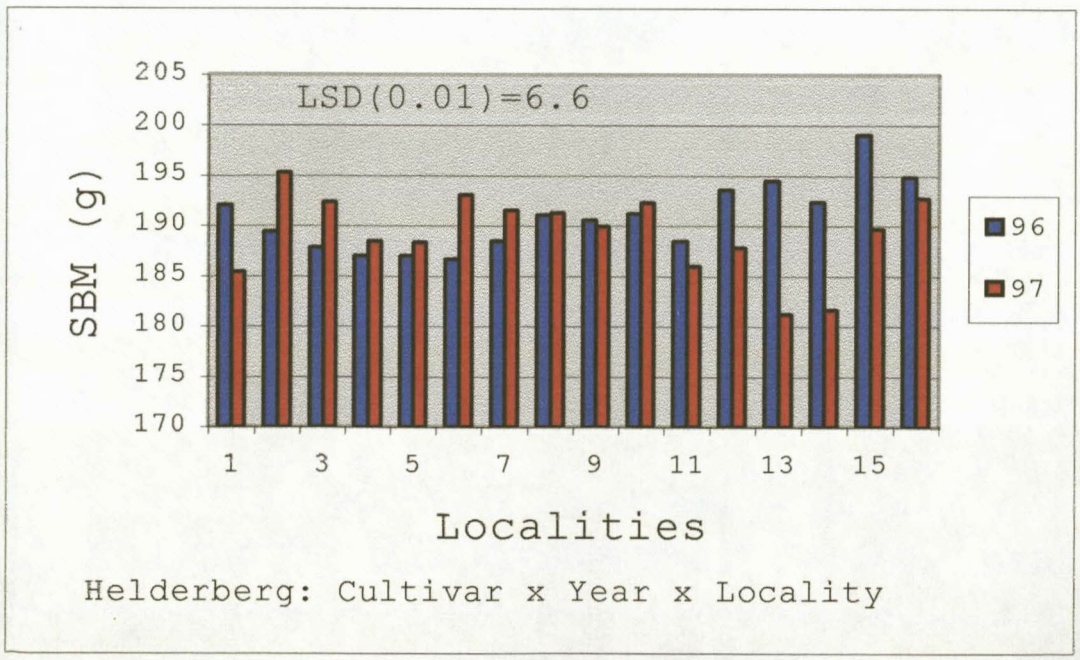
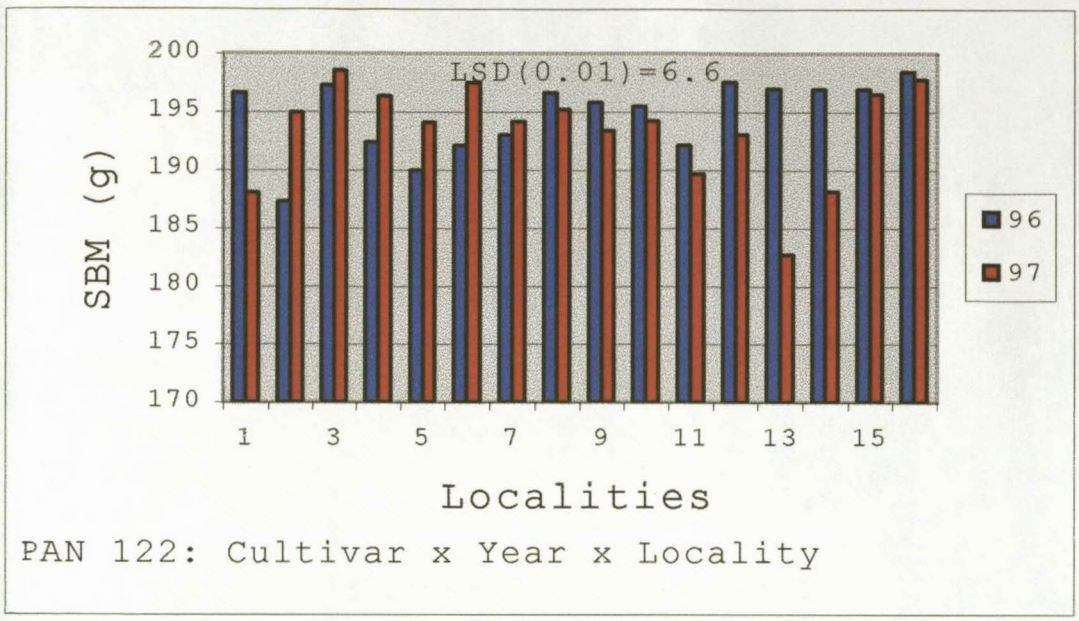


Fig. 6.2a & b. Effect of significant genotypic and environmental interactions over two years on the soak bean mass (SBM) of the individual cultivars.



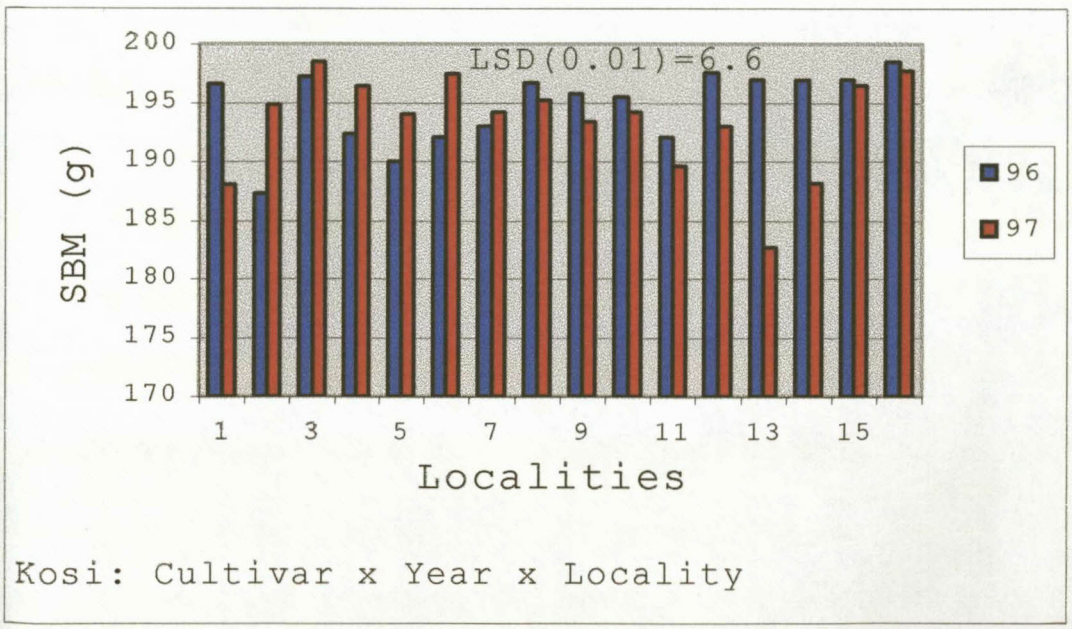


Fig. 6.2c & d. Effect of significant genotypic and environmental interactions over two years on the soak bean mass (SBM) of the individual cultivars.

Commercially a minimum weight gain of 1.8 is desired, since dry beans undergo a minimum of 80% increase during soaking and attain a moisture level between 53 and 57%(Hosfield and Uebersax, 1980). Sefa-Dedeh and Stanley (1979) demonstrated that seed coat thickness, seed volume, and hilum size along with protein content were all factors in regulating water imbibition.

Washed drain mass (WDM)

There were considerable variations among genotypes and localities. The washed drain mass (WDM) was not significantly influenced by the GxYxL interactions although the cultivar x year, the cultivar x locality and locality x year interactions were significant. Teebus, for example, had a significantly higher WDM for 1997 than 1996 (Fig 6.3a) while Helderberg had a higher WDM in the 1996 than 1997, although the difference is not significant.

The locality x year interaction was also significant as 10 localities had higher WDM for the 1997 season while 4 localities had higher WDM for the 1996 season than the 1997 season and 2 localities have almost the same WDM for both seasons (Fig. 6.3b). It is obvious from Fig. 6.3c that cultivars react differently on the 16 localities for the WDM.

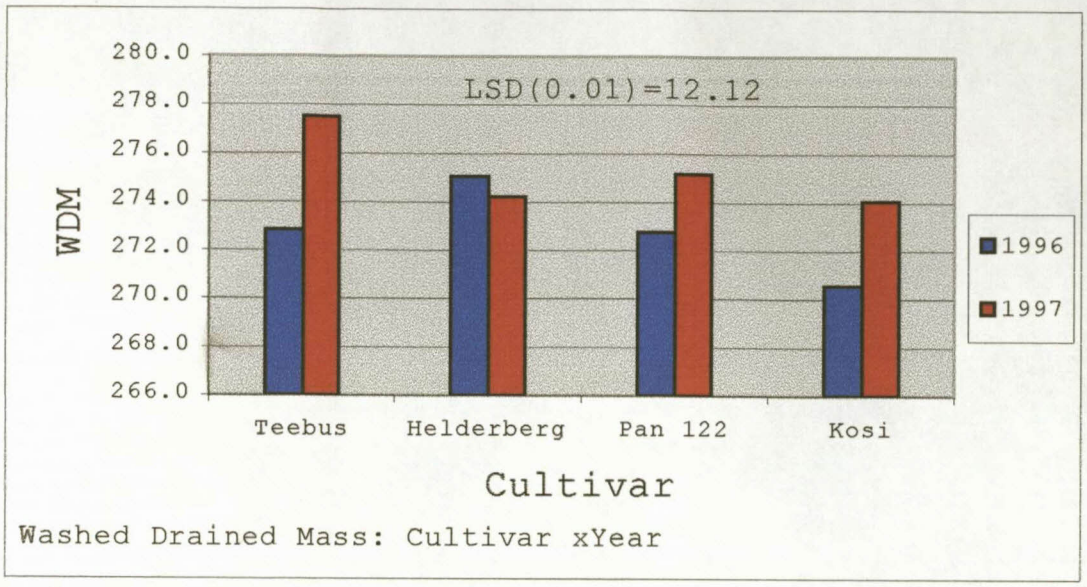


Fig 6.3a. Effect of significant genotypic and seasonal influences over two years on the washed drain mass (WDM).

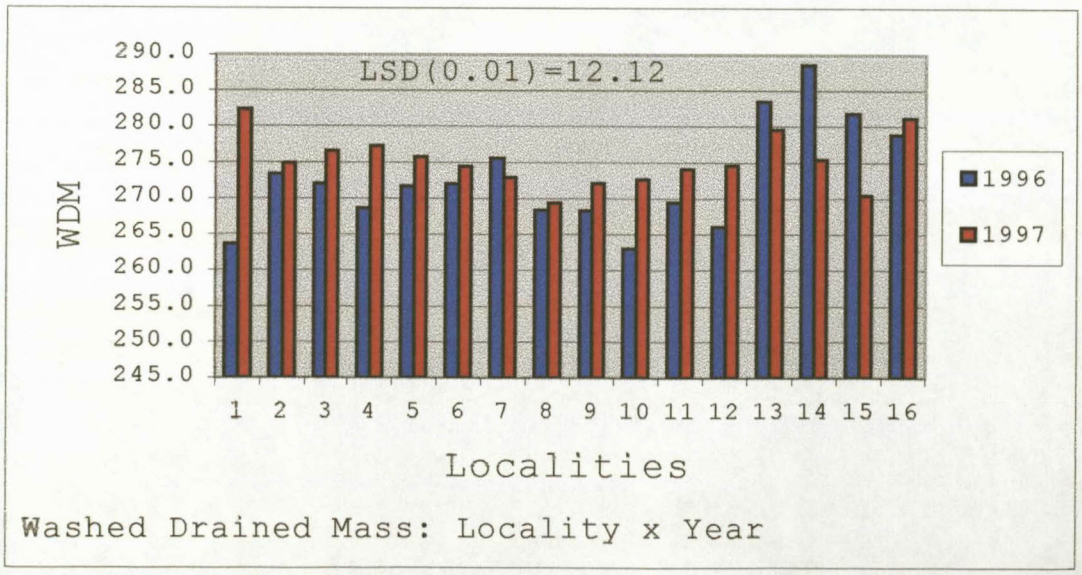


Fig 6.3b. Effect of significant seasonal and environmental influences over two years on the washed drain mass (WDM).

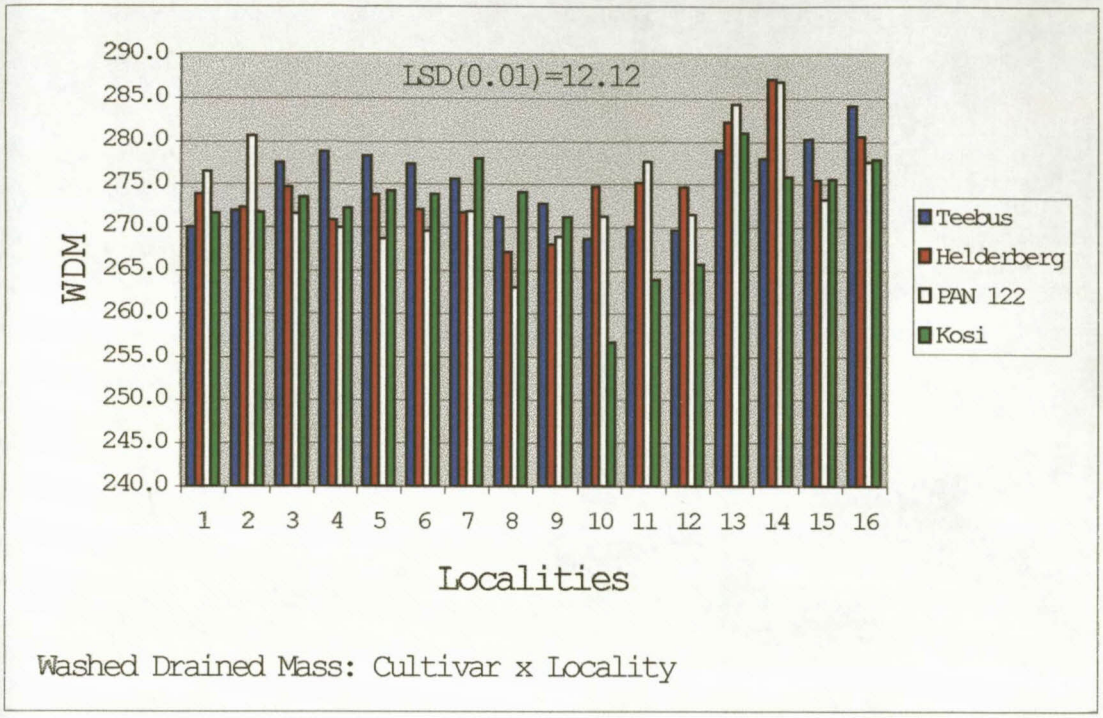


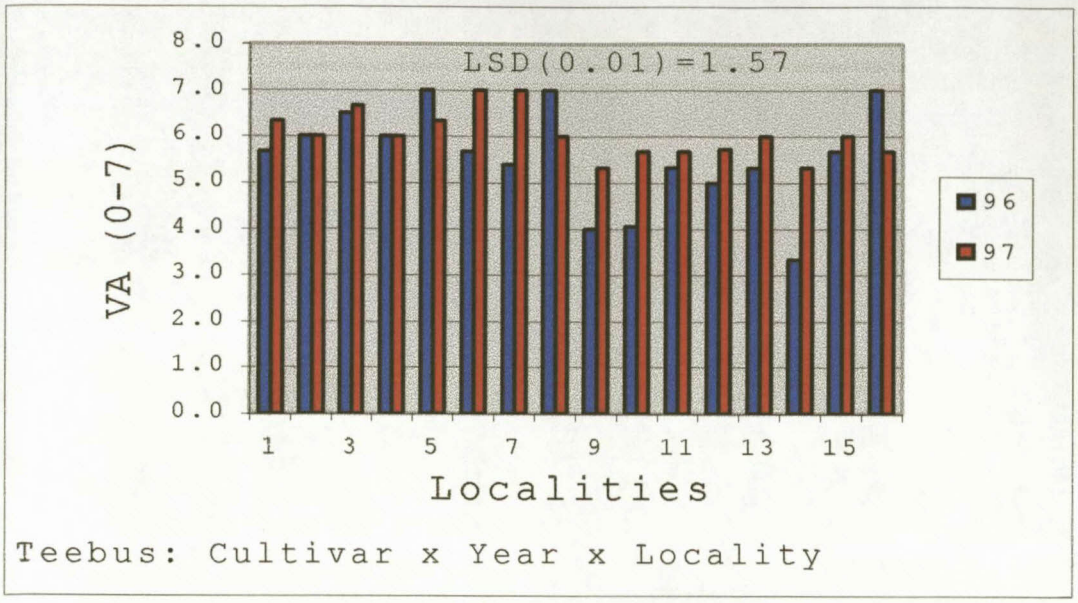
Fig 6.3c. Effect of significant genotypic and environmental influences at 16 localities on the washed drain mass (WDM).

Beans continue to increase in weight after processing as they equilibrate with water in the canning medium until they reach an end point moisture content of about 65 % (Hosfield and Uebersax, 1980). Starch functional properties like swelling, solubility, and other factors, influenced process yield and therefore the WDM (Uebersax and Ruengsakulrach, 1989). Percent carbohydrate was significantly influenced by environmental influences with a high correlation between the percentage of carbohydrate and more rainfall accumulated during the reproductive phase (Intriago-Ortega *et al.*, 1996). Therefore

it is possible that the environment can influence the WDM significantly.

Visual appearance (VA)

All main effects and interactions for visual appearance (VA) were highly significant. The cultivar x year x locality interaction for VA is depicted in Table 6.2. The cultivar means of the visual appearance differ between the two growing seasons on the 16 different localities (Fig 6.4 a-d). For example, Teebus (Fig 6.4 a) at Potchefstroom 1 (locality 1) has a better visual appearance in the 1997 than 1996 season. Helderberg has a better visual appearance (Fig. 4 b) in the 1996 season than the 1997 season at Potchefstroom 1 (locality 1). PAN 122 and Kosi (Fig. 4c and d) have almost the same visual appearance in both years at locality 1 (Potchefstroom 1).



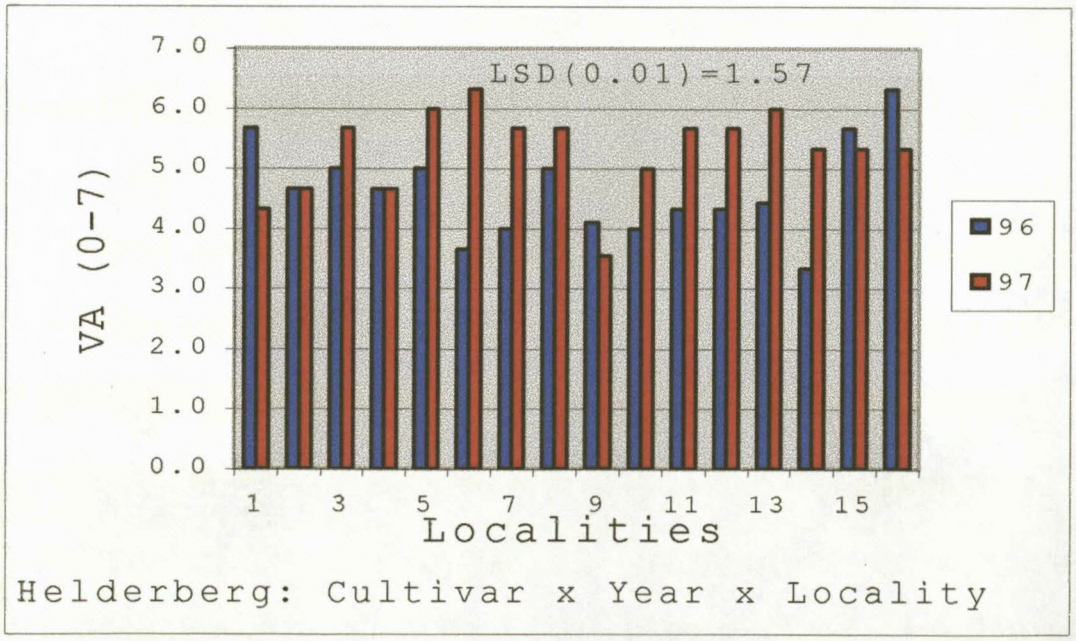
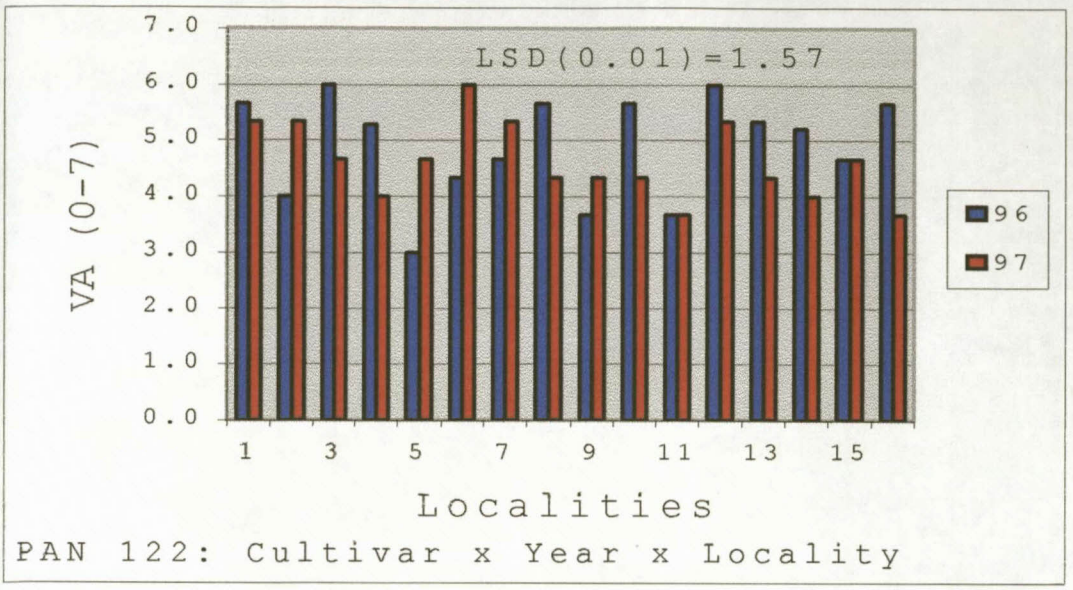


Fig 6.4a & b. Effect of significant genotypic and environmental influences over two years on the visual appearance (VA).



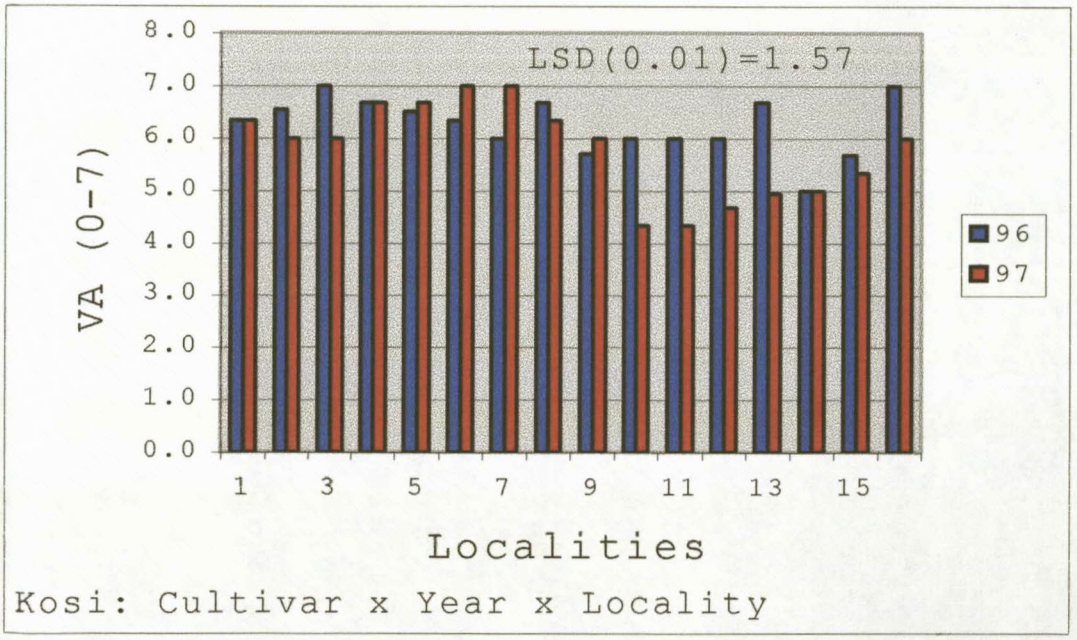
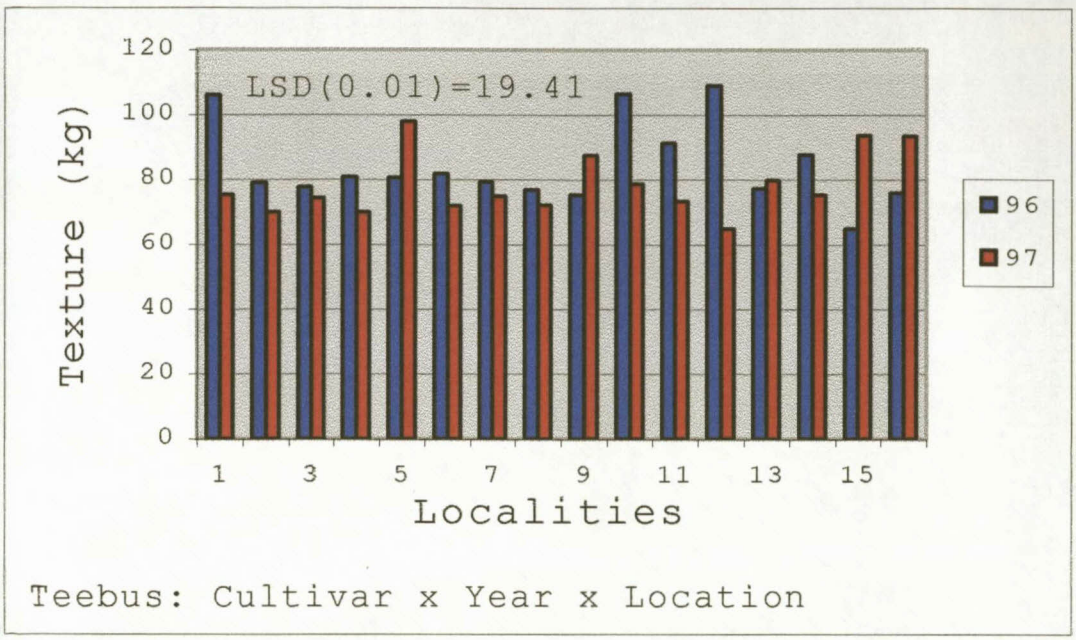


Fig 6.4c & d. Effect of significant genotypic and environmental influences over two years on the visual appearance (VA).

Texture (shearing force, kg/100g)

Beans must soften during processing yet still maintain their individual integrity. It is assumed that intact beans undergo little loss of solids during processing while excessive bean breakdown during cooking resulted in starch exudation into the canning medium which may lead to broken beans, graininess and clumping of individual beans. Beans may be unacceptable if they are too firm or too soft after canning (Hosfield and Uebersax, 1980).

All main effects for the texture (shearing force, kg/100g) were highly significant except the cultivar x year interaction (Table 6.2). For example (Fig 5a-d), all the cultivars differed significantly between 1996 and 1997 on most of the localities. The cultivars did not always react the same on every location. In 1996 PAN 122 was harder at the Potchefstroom 1 (locality 1) than in the 1997 season but softer on the Bapsfontein PT (locality 15) in 1996 than the 1997 season. This finding is not surprising because the environments in South Africa differ widely in minimum- and maximum temperatures, rainfall, soil pH and soil fertilization from year to year. Texture is a primary canning-quality character, because texture influences to a large degree a consumer acceptance of a food product (Hosfield *et al.*, 1984).



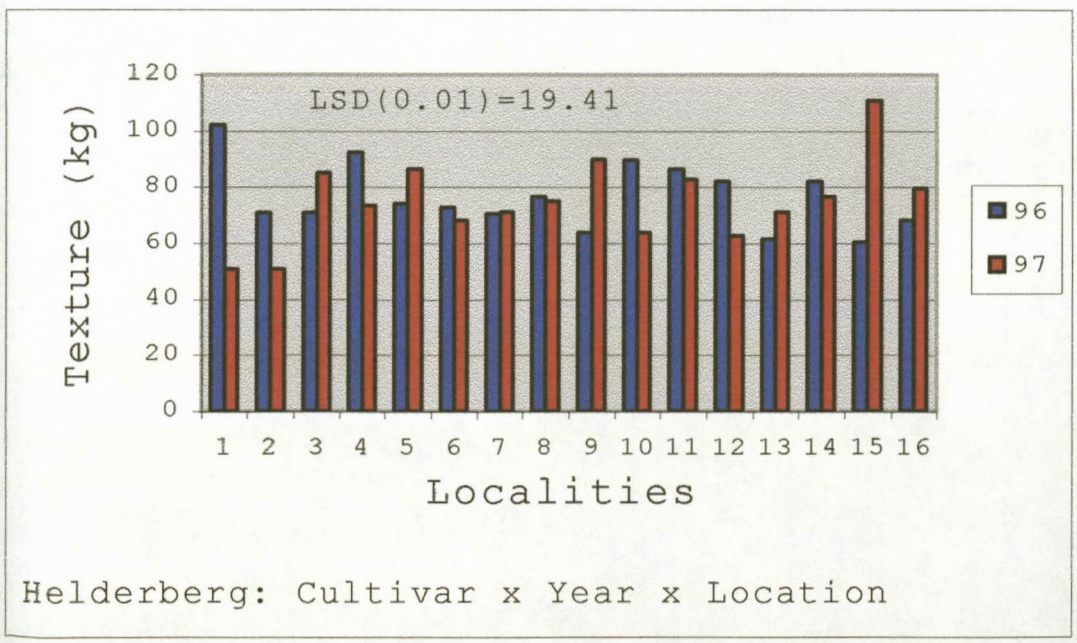
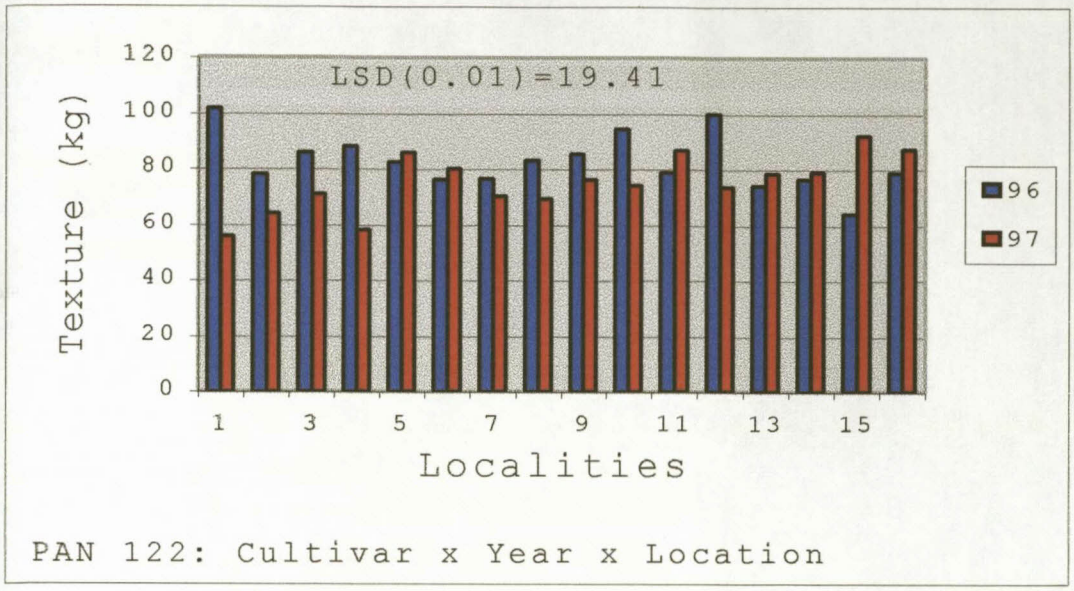


Fig 6.5a & b. Effect of significant genotypic and environmental influences over two years on the texture (Kg)



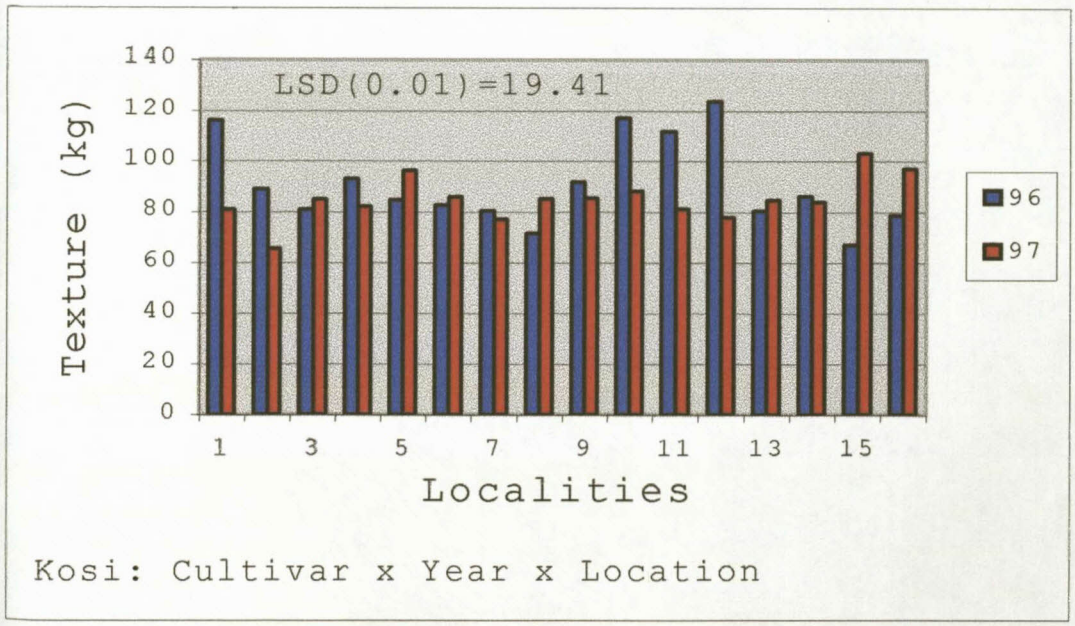
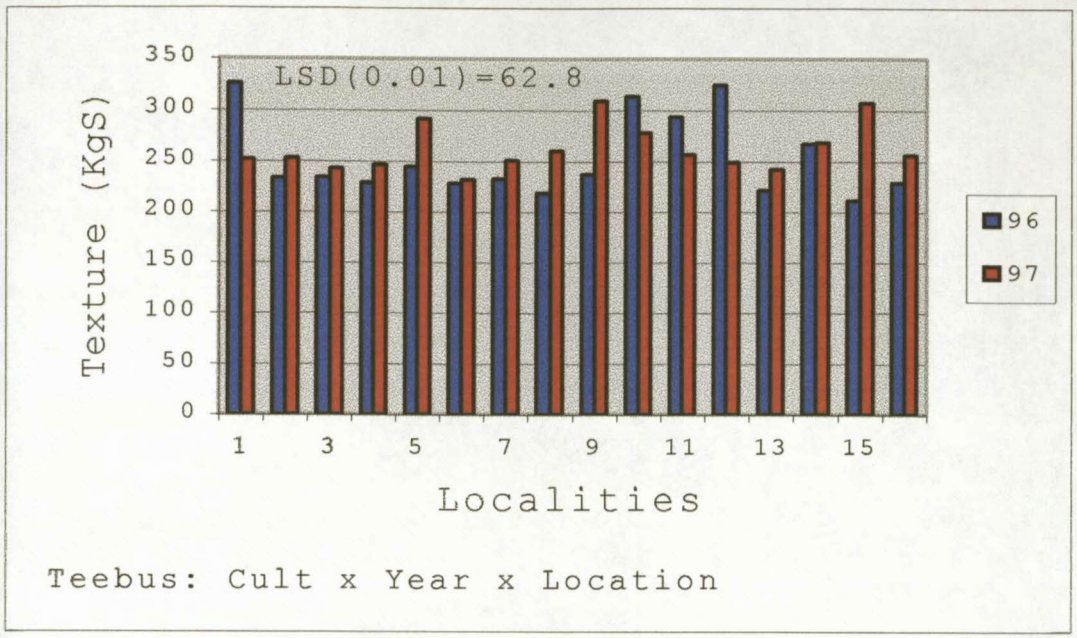


Fig 6.5c & d. Effect of significant genotypic and environmental influences over two years on the texture (Kg)

Texture kg/100g/sec

The main effects and all the interactions for texture (Compression force, kg/100g/sec) were highly significant for the compression force (kg/100g/sec). Helderberg and PAN 122 are an example (Fig 6.6b and c) since these two cultivars reacted differently according to the texture (Kgs) of Teebus and Kosi in 1996 and 1997 on the Kwa-ZuluNatal localities, Greytown 1 and 2 and Cedara (localities 10, 11 and 12). This could be a result of the environmental factors that influenced the texture of the cotyledon, which differ between seasons on various locations.



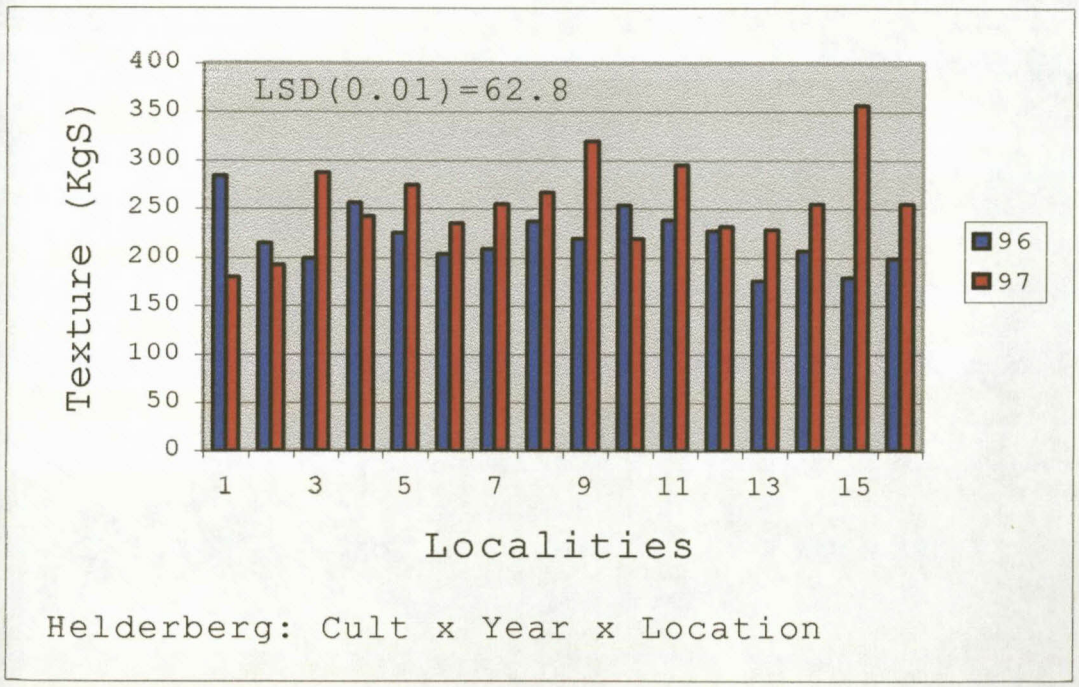
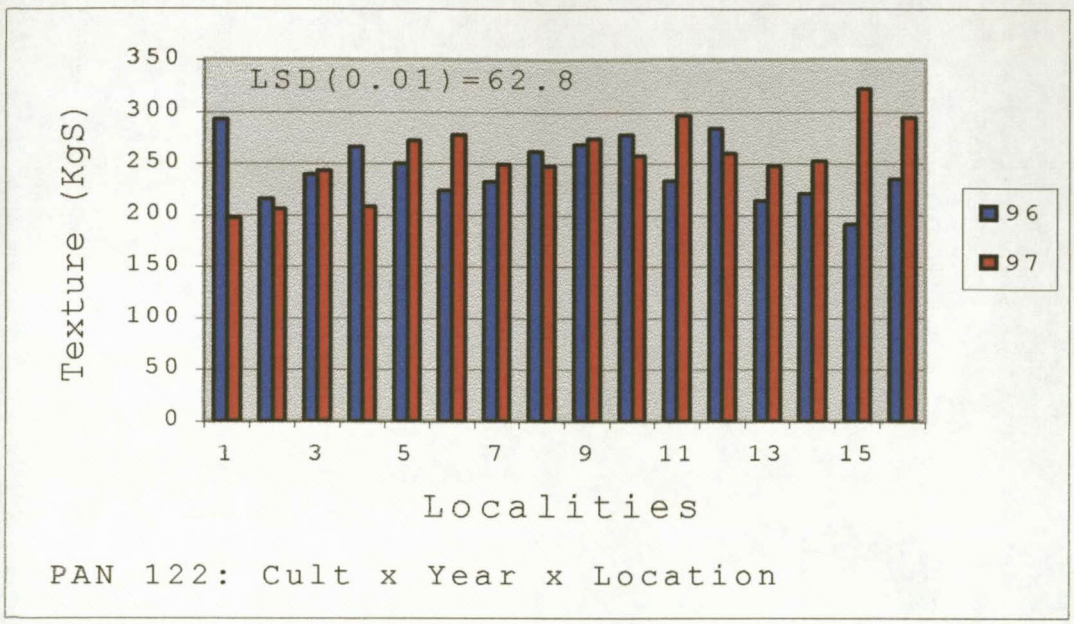


Fig 6.6a & b. Effect of significant genotypic and environmental influences over two years on the texture (kgs).



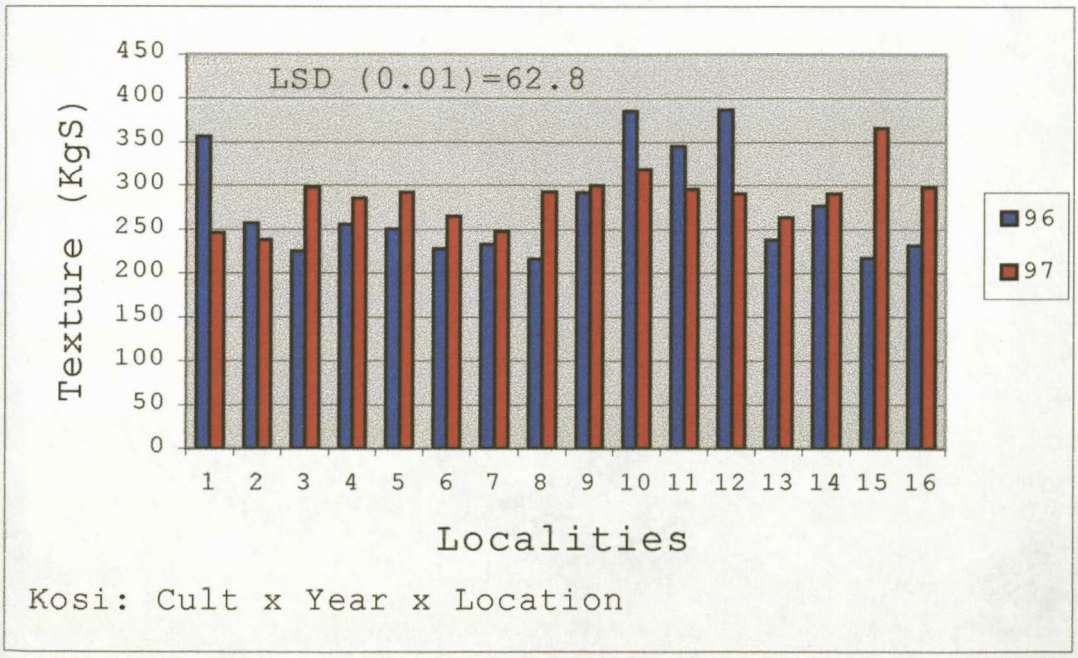


Fig 6.6c & d. Effect of significant genotypic and environmental influences over two years on the texture (kgs)

6.3.2. Principal Component Analysis (PCA)

The first PC accounted for 70.41 % of the variance while PC 2 accounted for 20.83% of the total variance.

Principal component analysis provided evidence as to the independence of the quality traits. PC-1 was identified as the texture and more specific the total compression force (kg/100g/sec). The order of importance for the remaining PC's representing different quality components. PC's 4 and 5 represented only 1.54 and 1.12 respectively of the total variation.

Table 6.3. Loadings of quality characteristics of small white canning beans planted at 16 localities for two years on 6 principal components.

	1	2	3	4	5	6
% variation	70.41	20.83	6.07	1.54	1.12	0.03
SC	0.061	0.996	0.026	-0.04	-0.04	0.02
SBM	0.004	0.033	-0.96	-0.06	0.27	-0.01
WDM	-0.09	-0.05	-0.12	-0.78	-0.6	0.02
VA	0.002	-0.02	-0.004	0.002	0.02	0.999
KG	0.269	-0.02	0.24	-0.61	0.71	-0.01
KGS	0.957	-0.06	-0.08	0.1	-0.25	0.003

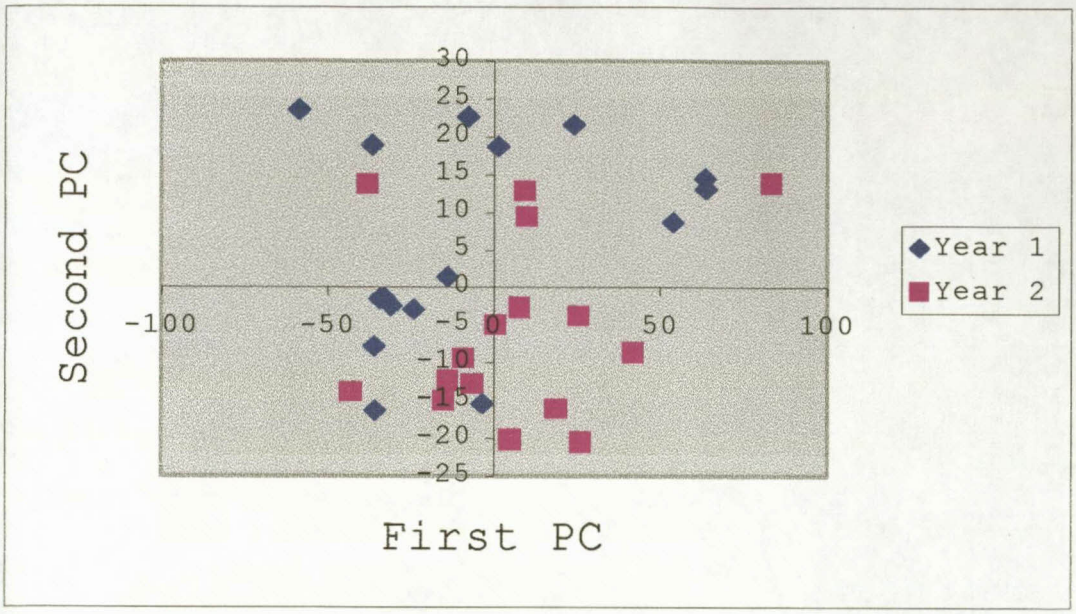


Fig 6.7. Principal component scores for 4 cultivars planted on 16 localities over two seasons.

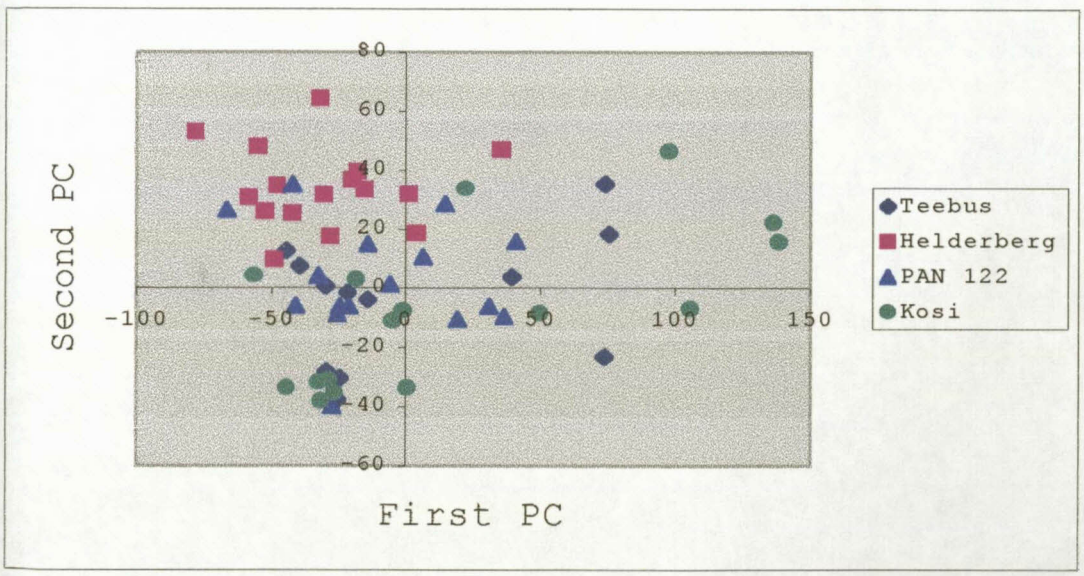


Fig 6.8. Principal component scores for 4 cultivars planted on 16 localities in the 1996 season.

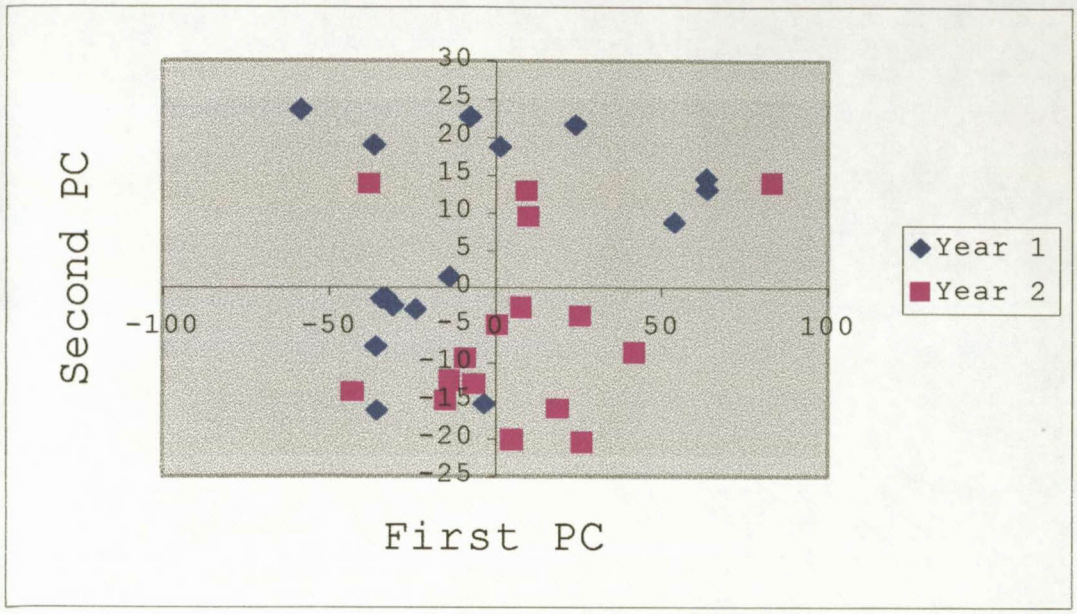


Fig 6.7. Principal component scores for 4 cultivars planted on 16 localities over two seasons.

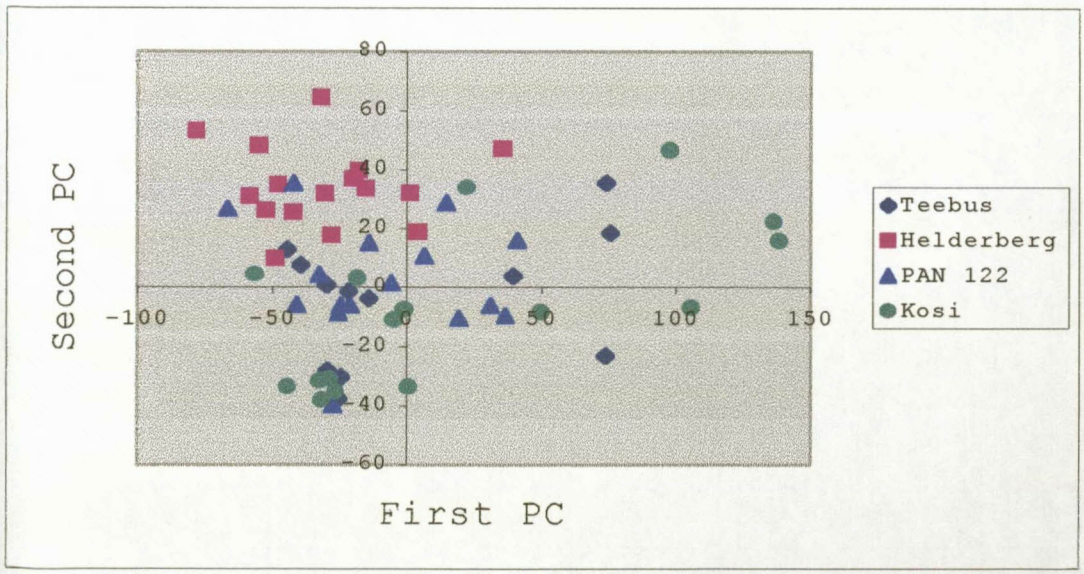


Fig 6.8. Principal component scores for 4 cultivars planted on 16 localities in the 1996 season.

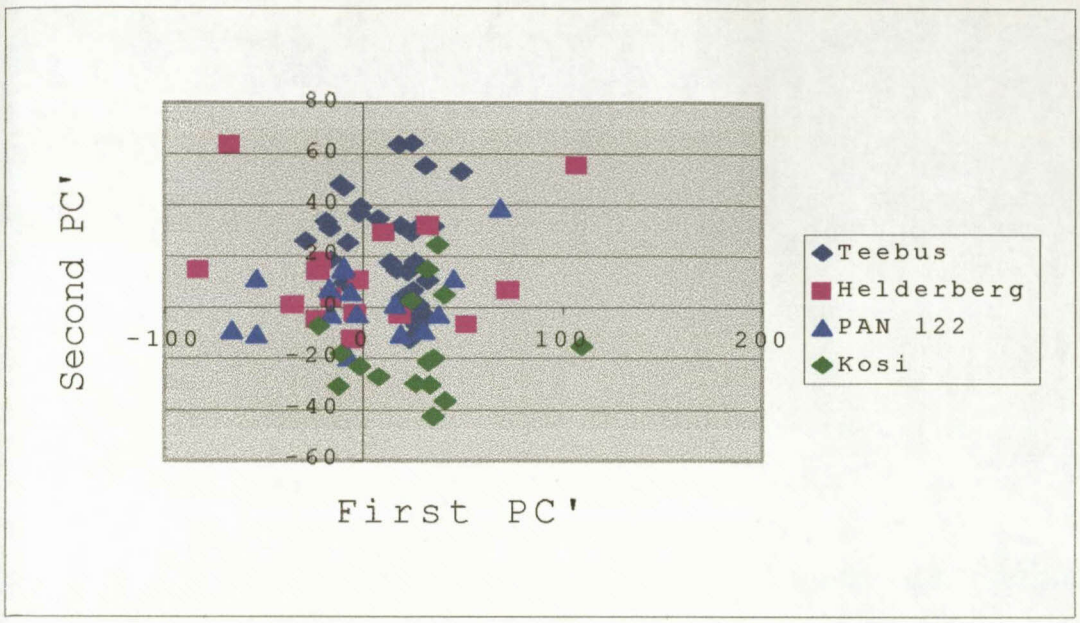


Fig 6.9 Principal component scores for 4 cultivars planted on 16 localities in the 1997 season.

The loadings on this PCs indicated that the WDM and the texture measurement of the shearing force (kg/100g) were correlated. This is possible, as Hosfield *et al.* (1983) found that texture and washed drained mass (WDM) loaded on the same factor for both navy and pinto data while these constructs changed from year to year. Beans with a higher processed bean moisture could result in softer textures.

A plot (Fig. 6.7) of the first and second PCs indicated that the scores for each locality in the different seasons grouped together with the scores for 1997 as the scores with lower seed counts and higher textures. When the four cultivars were

plotted separately (Fig 6.7b and 6.7c) for the 1996 and 1997 season it was (Fig 6.8 and 6.9, respectively) obvious that Helderberg had higher seed counts and therefore smaller seeds with a softer texture, while Teebus and Kosi had larger seeds with firmer textures on some of the localities in the first season (1995/96). The second season's PC scores indicated that Kosi had even larger seeds than Teebus for this season while the texture scores did not vary to much with the exception of Helderberg and PAN 122, which were very soft on some locations. The texture of all the cultivars on the majority of the localities were harder in the second season (1996/97) than the first season (1995/96).

6.4. Conclusion

Significant interaction between genotype, environmental and seasonal effects for canning quality traits indicated that cultivar responses to variation in localities and seasons differ. This suggests that variable seasonal effects exerted a major influence on the seed development of the different cultivars.

In South Africa the production areas differ widely in soil pH, fertility, rainfall, minimum and maximum temperatures and the GE interactions must be considered specifically within the design of strategy in dry bean breeding for canning quality,

that is in place at present.

According to Kang (1998) the GE interactions can be ignored by using genotypic means across environments even when GE interaction exists or, the GE interactions can be avoided and this involves minimising the impact of significant interactions via a cluster analysis. Environments are then more or less homogeneous and genotypes would then not be expected to show crossover interactions. The third way to handle the GE interactions in breeding is to exploit objectives like stability of performance across diverse environments or specific adaptation.

Significant GE interactions has an important influence on dry bean breeding for canning quality. It indicates that the testing of beans for canning quality for a period of years is necessary (Hosfield *et al.*, 1984). Significant GE interactions offer opportunities for breeders to plan breeding programs and allocate resources efficiently so that breeding material is tested in environments that correspond to the different production areas. The environmental limitations like soil pH, fertilizing, rainfall or temperatures that is contributing to the interactions on each specific trait, must be defined and from there the issue of genetic improvement for these specific limitations can be tackled.

According to the principal component analysis, the quality traits are not correlated to each other and this indicated that each of these measurements represent a different characteristic of the beans. Each measurement is therefore necessary to determine the overall canning quality of the different cultivars produced on different localities.

AMMI analysis can also be done in order to obtain a better clustering of genotypes and environments. The rank changes for each environment in different seasons can also be seen from this analysis.

CHAPTER 7

MULTIVARIATE ASSESSMENT OF ENVIRONMENTAL EFFECTS ON CANNING QUALITY OF SMALL WHITE BEANS (*Phaseolus vulgaris* L.) USING THE ADDITIVE MAIN EFFECTS AND MULTIPLICATIVE INTERACTION MODEL.

7.1. Introduction

The health benefit of dry beans results in higher consumption, especially canned beans, as it is a convenience food. The national production in South Africa of small white canning beans has declined from ±24 000 ton in 1990 to ±8 000 ton in 1997 (Smit, 1998). This could be due to a situation in which the canning cultivar is acceptable to the processors, but unacceptable to the producers. On the other hand, a cultivar with a high yield but an unacceptable canning quality will be unacceptable to processors.

The processors rely mainly on imports to meet their demand, while the South African producers are in a position that they cannot market their produce due to an unacceptable canning quality. Due to the R/$ exchange rate, the price of canning beans from the USA and Canada is generally unacceptably high, while S.A. produced beans

with a good quality would be accepted by the processors. This can result in an exploitable opportunity for S.A. bean producers (Smit, 1998).

The role of a crop improvement program is to develop high-yielding, profitable cultivars for sustainable production by managing variability. A successful cultivar must possess various desired traits, viz. high yield, canning quality that meets consumer and processor expectations and resistance tolerance to various environmental stresses and pests (Kang, 1998). Since genotype x environment (GE) interaction is primarily a crop breeding issue, the breeder has to determine and know to what extent selection progress achieved in one environment, can be repeated in another environment.

Environmental variation causes differential genotypic responses that often results in rank changes of genotypes. Assessing any genotype without including the interaction with the environment is incomplete. Therefore, multi location trails are planted to determine this interaction (Kang, 1998).

Variation among genotypes in sensitivity to the environment (GE interaction) presents the breeder with a

problem, as it may necessitate the development of locally adapted varieties. If there was not one cultivar superior in all situations, GE interaction indicates the potential for genetic differentiation of populations under prolonged selection in different environments (Kang, 1998).

To be able to understand GE interaction and utilise it effectively in breeding programs, as much information as possible is needed on the factors responsible for differential response of genotypes to variable environments (Kang, 1998).

Genotype x environment (GE) interactions encountered in canning quality of dry beans (*Phaseolus vulgaris* L.) are a challenge to plant breeders. GE interactions limit the effectiveness of selection when selection is based only on means of the different traits over localities (Hosfield, 1991).

The aim of this chapter was to:

1. provide patterns and relationships between the different canning cultivars as standard and choice grade cultivars,

2. determine stability of localities between seasons for the quality traits,
3. quantify and test changes in rank from one environment to another and the clustering of different environments for each quality trait.

7.2. Materials and Methods

Sixty-three trials of small white canning beans were conducted in South Africa and were established at 25 localities in the 1994/95, 1995/96 and 1996/97 growing seasons. Four different small white cultivars namely Teebus, Helderberg, PAN 122 and Kosi, were planted in blocks of three replicates. These trials were planted as described in Chapter 3. A short description of the canning quality traits and their methods of evaluation are given in Table 7.1.

7.2.1 Statistical procedures

Additive main effects and multiplicative interaction (AMMI) calculations were performed using the Genstat 5 (Genstat 5 Committee, 1997) statistical program. AMMI combines analysis of variance (ANOVA) and principal component analysis (PCA) into a single model with additive and multiplicative parameters.

AMMI analysis first fits the additive main effects of genotypes and environments by using the usual analysis of variance (ANOVA), and then describes the non-additive part, the genotype-environment interaction, by principal component analysis (PCA). Interaction PCA (IPCA) scores are then obtained for genotypes and for environments. AMMI therefore summarizes patterns and relationships of genotypes and environments (Crossa, 1990).

Biplots of these IPCA scores versus the cultivar and environment means are visual representations of the main effects, as well as interaction effects. The closer points are, the more similar they are, and further apart, they are dissimilar. A score close to zero is an indication of stability or insensitivity. After fitting the AMMI model, usually one interaction PCA (IPCA) component is retained and the rest is discarded as a residual or noise. It is this reduction of noise that makes AMMI estimates more reliable than the usual GE methods. Relative scores are also obtained for each cultivar and environment from which the interaction effect is estimated. A score close to zero is generally an indication of stability over environments sampled.

Table 7.1 Bean processing, evaluations and calculations.

Character	Description
Dry seed properties:	
Seed size	Seeds per 30g sample
Soaking:	
Soaked bean mass (g)	Weight determined after soaking of 100g dry beans for 40 min. at 88°C.
Canning objective:	
Washed drained mass (g)	Canned for 55 min at 121°C. Equilibrate for 2 weeks. Weight of rinsed beans drained for 2 min on a 250µm sieve positioned at a 15°angle.
Texture (kg force per 100 g)	Peak of the texture curve as Kg force required to shear 100 g of beans.
Texture (Total force required for 100 g)	Calculated as the surface beneath the texture curve determined over 12 seconds.
Subjective evaluation:	
Overall appearance (0-7)	Criteria included examination for : 1. loose (free) seed coats, 2. bean integrity, 3. bean colour 4. uniform bean size. (0) poor appearance; (7) excellent appearance.

7.3. Results and discussion

The main effects, interactions and IPCA scores contributed to significant variation for all the traits. The relative magnitude of the influence of the cultivar and environment, according to the sum of squares of the different effects, showed that cultivar had the greatest influence on the total variation for seed size and soaked bean mass (SBM) but the environment had the dominant influence on the washed drain mass trait (Table 7.2).

Table 7.2 AMMI analysis of dry bean canning quality: The ANOVA table for AMMI model

Seed count					
Source	**df**	**SS**	**MS**	**F**	**F_prob**
Total	755	620948	822	*	*
Block	126	30416	241	1.04	0.38 ns
Treatment	251	502869	2003	8.64	<.001
Environment	62	148451	2394	10.32	<.001
Genotype	3	207592	69197	298.38	<.001
Interaction	186	146825	789	3.4	<.001
IPCA1	64	95327	1489	6.42	<.001
Residual	122	51499	422	1.82	<.001
Error	378	87663	232	*	*
Soak bean mass(SBM)					
Source	**df**	**SS**	**MS**	**F**	**F_prob**
Total	755	25890	34.3	*	*
Block	126	2647	21	2.45	<.001
Treatment	251	20006	79.7	9.31	<.001
Environment	62	11183	180.4	21.07	<.001
Genotype	3	3542	1180.8	137.91	<.001
Interaction	186	5281	28.4	3.32	<.001
IPCA1	64	3541	55.3	6.46	<.001
Residual	122	1739	14.3	1.67	<.001
Error	378	3236	8.6	*	*
Washed drain mass (WDM)					
Source	**df**	**SS**	**MS**	**F**	**F_prob**
Total	755	109498	145	*	*
Block	126	7805	61.9	2.49	<.001
Treatment	251	92285	367.7	14.77	<.001
Environment	62	74245	1197.5	48.11	<.001
Genotype	3	2027	675.8	27.15	<.001
Interaction	186	16012	86.1	3.46	<.001
IPCA1	64	8983	140.4	5.64	<.001
Residual	122	7029	57.6	2.31	<.001
Error	378	9408	24.9	*	*
Visual Appearance					
Source	**df**	**SS**	**MS**	**F**	**F_prob**
Total	755	1094.3	1.45	*	*
Block	126	102.2	0.81	1.85	<.001
Treatment	251	825.9	3.29	7.49	<.001
Environment	62	299.7	4.83	11	<.001
Genotype	3	233.7	77.91	177.23	<.001
Interaction	186	292.5	1.57	3.58	<.001
IPCA1	64	137.1	2.14	4.87	<.001
Residual	122	155.4	1.27	2.9	<.001
Error	378	166.2	0.44	*	*

Texture (Kg)					
Source	**df**	**SS**	**MS**	**F**	**F_prob**
Total	755	193304	256	*	*
Block	126	21838	173.3	3.12	<.001
Treatment	251	150437	599.4	10.77	<.001
Environment	62	114387	1844.9	33.16	<.001
Genotype	3	11536	3845.2	69.12	<.001
Interaction	186	24515	131.8	2.37	<.001
IPCA1	64	11928	186.4	3.35	<.001
Residual	122	12587	103.2	1.85	<.001
Error	378	21029	55.6	*	*
Texture (KgS)					
Source	**df**	**SS**	**MS**	**F**	**F_prob**
Total	755	1857078	2460	*	*
Block	126	166562	1322	2.21	<.001
Treatment	251	1464085	5833	9.74	<.001
Environment	62	1050994	16952	28.3	<.001
Genotype	3	116184	38728	64.65	<.001
Interaction	186	296906	1596	2.66	<.001
IPCA1	64	161974	2531	4.22	<.001
Residual	122	134932	1106	1.85	<.001
Error	378	226432	599	*	*

This implies that seed size and SBM could be used as selection criteria while the WDM was subject to environmental effects. High genotypic mean squares to environmental mean squares implies that a trait with a high genotypic component can be tested in fewer environments than for a trait with a lower component.

The main effects, interactions and IPCA scores contributed to significant variation for visual appearance and both texture measurements. The relative magnitude of the influence of the cultivar and environment, according to the mean squares of the

different effects, showed that cultivar had the greatest influence on the differences for visual appearance as well as texture measurements (Table 7.2). This implies that visual appearance and texture could be used as selection criteria.

Table 7.3 AMMI analysis of dry bean canning quality: The genotype means and IPCA scores.

	Seed size		**Soak bean mass**		**Washed drain mass**	
Genotype	MEAN	IPCA1	MEAN	IPCA1	MEAN	IPCA1
Teebus	133.4	-2.8	188	2.9	272.9	3.2
Helderberg	173.9	4.9	190.7	-2.4	269	-3.3
PAN 122	154.9	7.4	194	-3.4	268.8	-4
Kosi	134.9	-9.6	190	2.9	270.6	4.1
	Visual Appearance		**Texture (Kg)**		**Texture (KgS)**	
Genotype	MEAN	IPCA1	MEAN	IPCA1	MEAN	IPCA1
Teebus	5.9	0.9	75.9	-3.3	242.4	-4.4
Helderberg	5.1	1.4	73.5	6.2	230.6	9.6
PAN 122	4.8	-1.9	76.2	0.7	243.6	4.7
Kosi	6.1	-0.3	83.9	-3.6	265	-9.9

Hosfield *et al.* (1984) and Hosfield and Uebersax (1980) reported significant environmental effects for canning quality of the black turtle soup and the navy bean commercial classes, respectively. Hosfield and Uebersax (1980) reported that processing quality of most navy bean cultivars is associated with various seed characteristics that appear to be highly heritable.

7.3.1. Genotype differences

7.3.1.1. Seed size and water absorption

The AMMI analysis of cultivars for seed size and water absorption separated the four cultivars into two groups that contrasted. Teebus and Kosi formed the first group while the second group consisted of Helderberg and PAN 122 (Fig.7.1).

Teebus and Kosi, the choice grade cultivars, had mean seed sizes of 133.4 and 134.9, respectively, and IPCA scores of -2.76 and -9.6, respectively (Table 7.3). On the other hand, Helderberg and PAN 122, the standard grade cultivars, had mean seed sizes of 173.9 (IPCA score = 4.93) and 154.9 (IPCA score=7.40), respectively. When both cultivars and environments have IPCA scores of the same sign, their interaction is positive; if signs are different, their interaction is negative. Helderberg was a more stable cultivar than PAN 122. Of the choice grade cultivars, Teebus was more stable (IPCA score of -2.76) than Kosi (IPCA score of -9.57) and the most stable of all the cultivars. Cultivars with a larger seed size are generally more acceptable to S.A. processors. Intriago-Ortega *et al.* (1996) reported that seed size is not influenced by rainfall.

Similar to the seed size and water absorption traits, AMMI analysis separated the four lines for water absorption during soaking (SBM) and processing (WDM) into contrasting groups (choice grade and standard grade)(Table 7.3, Fig. 7.2 and 7.3). Although Helderberg and Kosi had the same mean SBM (190.7 and 190.0), their IPCA scores were different in sign (-2.40 and 2.89) which means that they respond differently to environments.

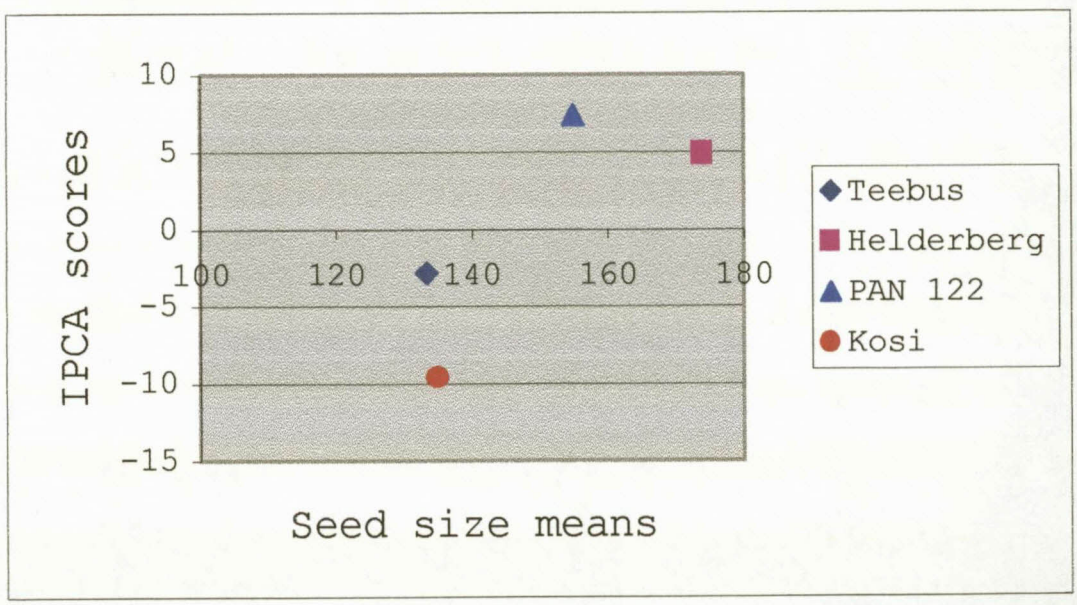


Fig 7.1. Plot of genotype IPCA1 scores vs means- Seed size.

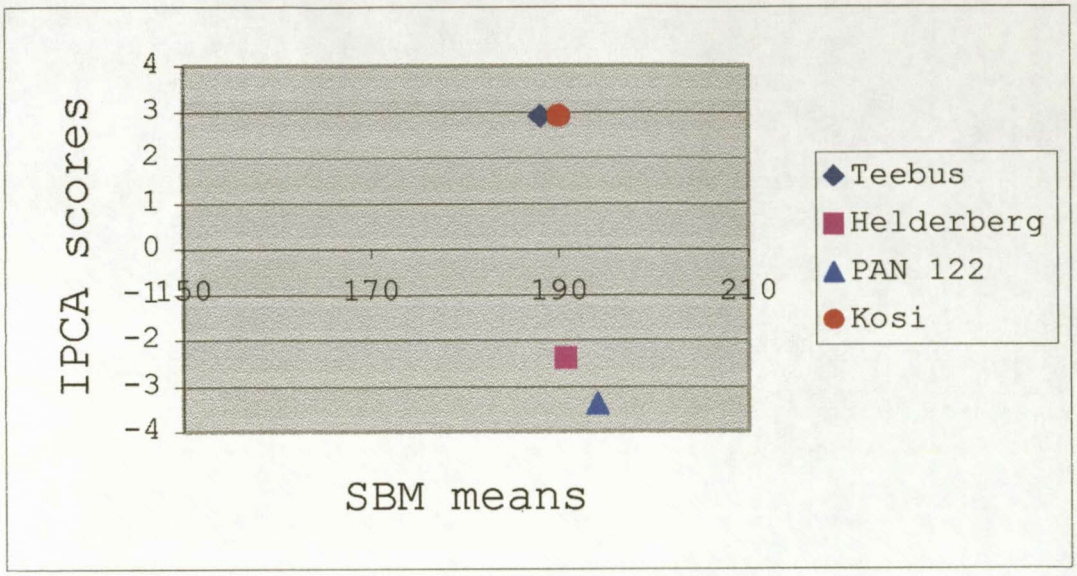


Fig 7.2. Plot of genotype IPCA1 scores vs means (SBM).

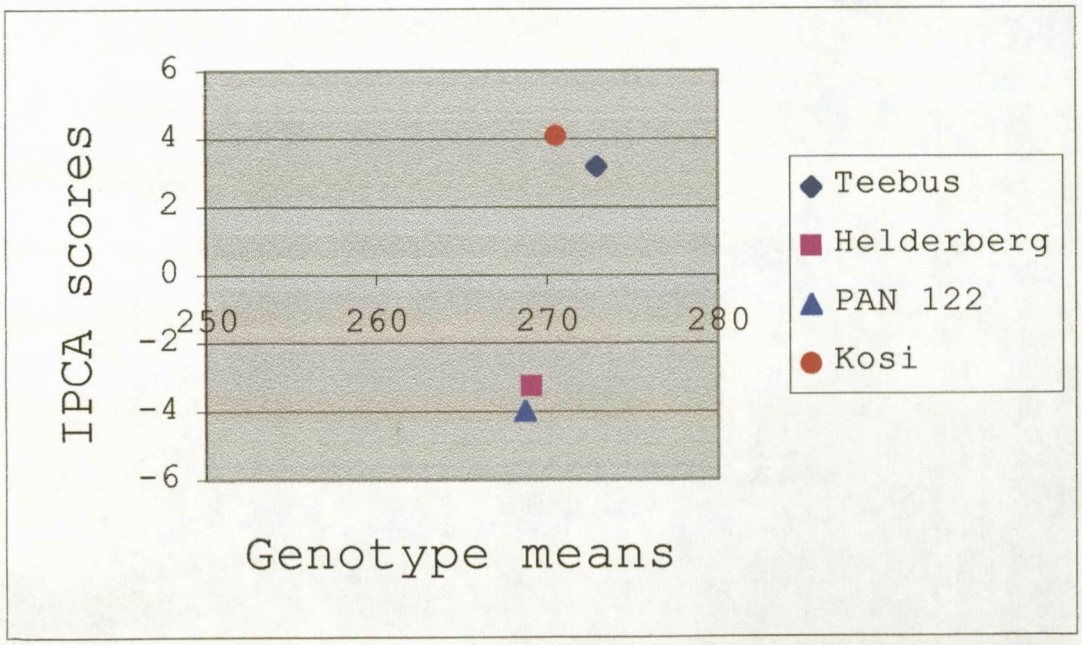


Fig 7.3. Plot of genotype IPCA1 scores vs means (WDM).

Standard cultivars (PAN 122 and Helderberg) had higher SBM than that of the choice grade cultivars (Teebus and Kosi), but the choice grade cultivars absorbed more water during processing than the standard grade cultivars. A significant correlation of -0.55 between the SBM and WDM has been reported in Chapter 4. The stability of cultivars for SBM was very similar although PAN 122 was more sensitive to environments with regards to seed size. Teebus and Kosi were very similar in mean response (SC and VA), but their scores differed, while for SBM, as well as WDM, they were very similar for means and scores (Table 7.3).

This observed difference between the standard grade and choice grade cultivars for SBM and WDM, could be the result of the rapid water absorption due to differences in permeability of the seed coat. This resulted in slower water absorption during the initial phase and as a result in lower percentage of broken seeds, higher visual appearance scores and harder textures. Brits (unpublished data) found in a study involving the anatomical and ultra structure of the seed cotyledon that the splits in the seeds are through the cell wall and not only the middle lamella. This could be a result of a more rapid rate of water absorption in the initial phase, which causes the cells to rupture. Uebersax and Ruengsakulrach (1989)

confirmed these results as they found that dry and soaked/blanced (30 minutes at 21°C + 30 minutes at 88°C) beans, fracture occurs across the cell wall.

Water diffusivity, a complex function of the microstructure, as well as chemical composition, moisture and temperature of the seed, is thought to determine the rate of water uptake during soaking. A reduced water uptake would be expected when the cell walls are strengthened and this would result in increased mechanical resistance to cellular swelling and reduced water binding capacity of dissolved solutes due to leakage into the soaking medium respectively (Del Valle *et al.*, 1992).

Reddy *et al.* (1984) mentioned that there is a wide variation in granule size and shape of starch granules that could be due to genetic control and seed maturity. They reported that the amount of amylose in the starch influences starch solubility, lipid binding and other functional properties, while the amylopectin is thought to be responsible for the solubility of starch granules and that amylose and amylopectin are responsible for the structural form of starch granules. This may be due to the maturity of the seed, cultivar differences or seed history.

Swelling of the starch granule is the first stage of hydration-related properties. The swelling may proceed in two stages in the case of navy bean starches. Water absorption of legume starches is inversely related to solubility and directly related to swelling. The starch structure-gelatinisation temperature relationship is described as follows:

1. In starches containing appreciable amounts of amylopectin, the associated amylopectin chain clusters constitute the crystalline entity that affects the gelatinisation temperature range.

2. Gelatinisation temperature is affected by degree of amylopectin branching to the extent that excessive branching diminishes rigidity of the starch granule.

3. High amylose content resists the gelatinisation process due to its insolubility in aqueous solutions (Reddy *et al.*, 1984).

The difference in water absorption of the different cultivars could therefore be a difference in seed coat, cotyledon or the percentage of amylose and amylopectin.

The absorbed water and heating initiate thermal degradation or inter/intra-cellular and cohesive materials (middle lamella) and thus allows cells to separate and soften (Uebersax and Ruengsakulrach, 1989).

7.3.1.2. Visual appearance and texture

The four cultivars were contrasted for visual appearance into two groups by AMMI analysis. Teebus and Kosi formed the first group while the second group consisted of Helderberg and PAN 122 (Fig 7.4).

The choice grade cultivars, Teebus and Kosi had mean visual appearance scores of 5.98 (IPCA1 score=0.89) and 6.1 (IPCA1 score=-0.31), respectively. Helderberg and PAN 122 had mean visual appearance scores of 5.08 (IPCA1 score=1.4) and 4.81 (IPCA1 score=-1.98), alternatively (Table 7.3). When both have IPCA scores of the same sign, their interaction effect is positive; if different, their interaction effect is negative.

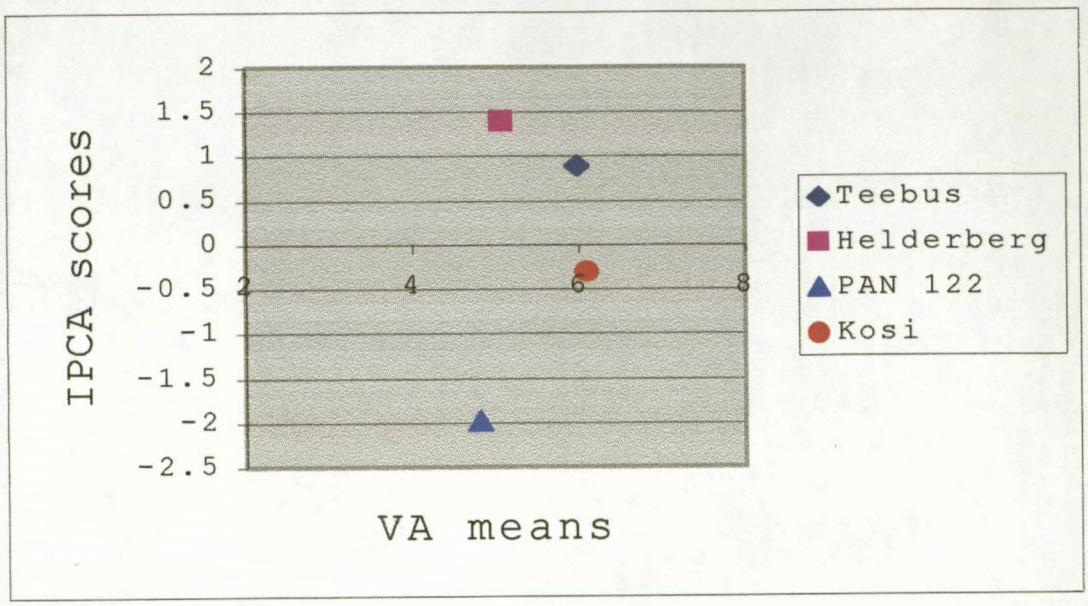


Fig 7.4. Plot of genotype IPCA1 scores vs means (VA).

Helderberg was a slightly more stable cultivar for VA than PAN 122. Between the choice grade cultivars, Kosi was more stable with an IPCA score of -0.31 than Teebus (IPCA1 score=0.89), since an interaction PCA score of nearly 0 has a small interaction (Table 7.3). Teebus and Kosi are choice grade cultivars while Helderberg and PAN 122 are standard grade cultivars. Cultivars with acceptable canning quality must exhibit only a small percentage of split beans and have a relative uniform bean size as well as an acceptable colour with shiny bean surfaces.

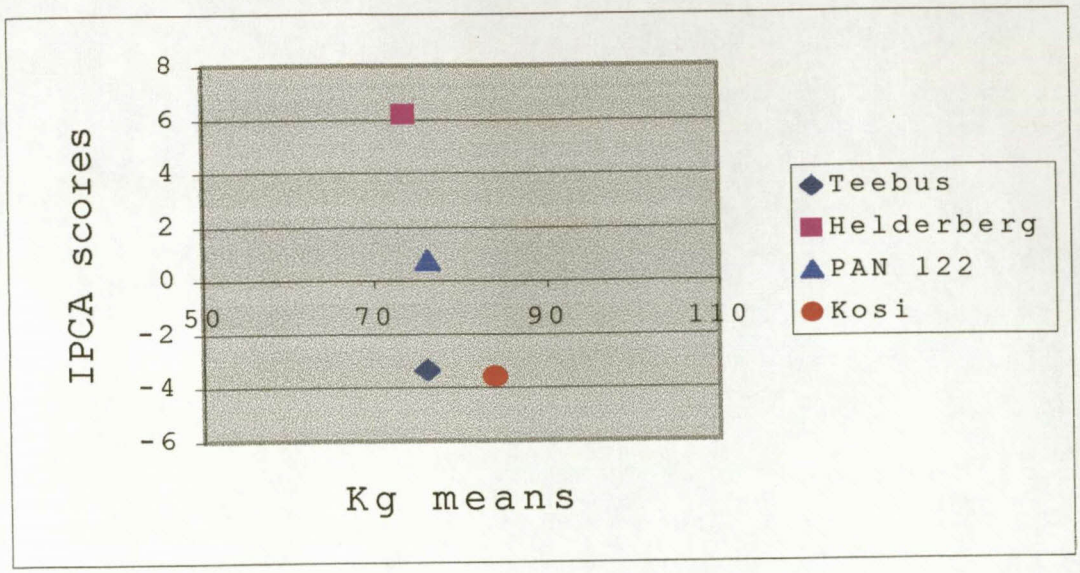


Fig 7.5. Plot of genotype IPCA1 scores vs means- Texture (Kg).

The texture (Kg and KgS) were also contrasted by texture AMMI analyses as choice grade and standard grade cultivars although the mean texture measurements were not always different. Helderberg and PAN 122 had different scores but both were positive. Helderberg (Kg IPCA1=6.2 and KgS IPCA1=9.6) was more unstable or sensitive to environment than PAN 122 (Kg IPCA1=0.7 and KgS IPCA1=4.7). Teebus and Kosi were both relatively more stable for the Kg measurement but Kosi was more unstable for the KgS measurement with an IPCA1 score of -9.9 while Teebus had an IPCA1 score=-4.4 (Table 7.3).

Helderberg had mean Kg and KgS measurements of 73.5 kg per 100g and 230.6 kg per 12 seconds, which indicated that Helderberg had the softest texture of the four cultivars (Table 7.3). PAN 122 had almost the same texture than Teebus but it reacted differently to the environmental influences since it had contrasting IPCA scores. Kosi had the firmest texture of the four cultivars. These reactions to the environmental influences are depicted on the plots of the mean values and the IPCA scores (Fig 7.5 and 7.6).

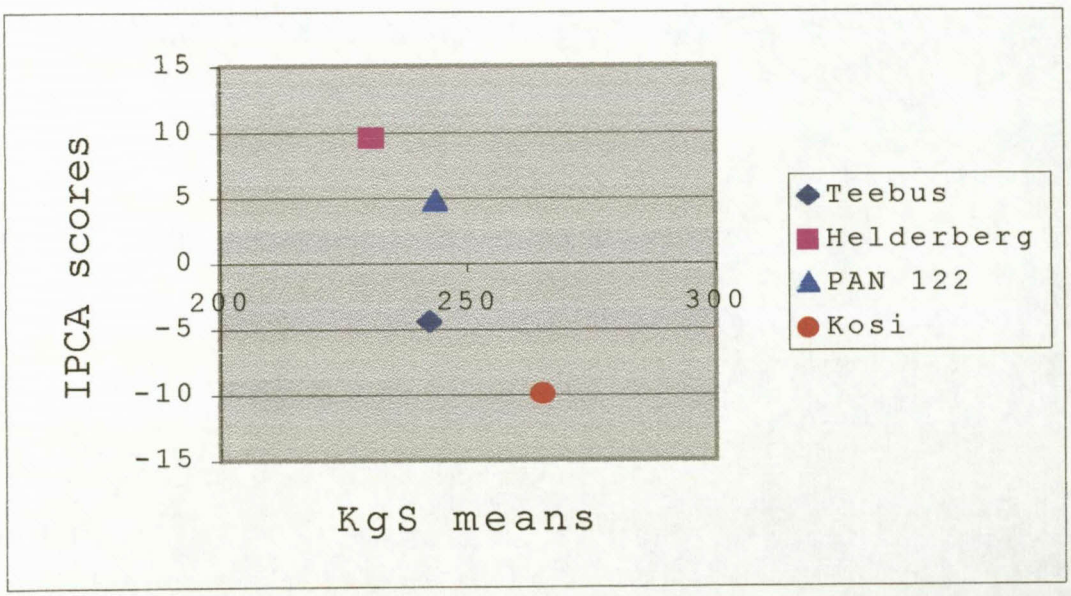


Fig. 7.6. Plot of genotype IPCA1 scores vs means-Texture (KgS).

7.3.2. Environmental differences

7.3.2.1. Seed size and water absorption

The seed sizes contrasted into two main groups (Table 7.4). The first group is the regions North West, Mpumalanga and Eastern Free state, while the second group consisted predominantly of localities in Natal. The choice grade cultivars normally have larger seed sizes than the standard grade cultivars, but in Natal the inverse was true. Since Kosi normally has a very large seed size, the smaller seed sizes in Natal are the exception. This is reflected in Table 7.4. Kosi had the largest seeds in group 1, but the smallest seeds in Natal in group 2. The clustering of the Natal localities is especially clear when this data is graphically displayed as in Fig. 7.10.

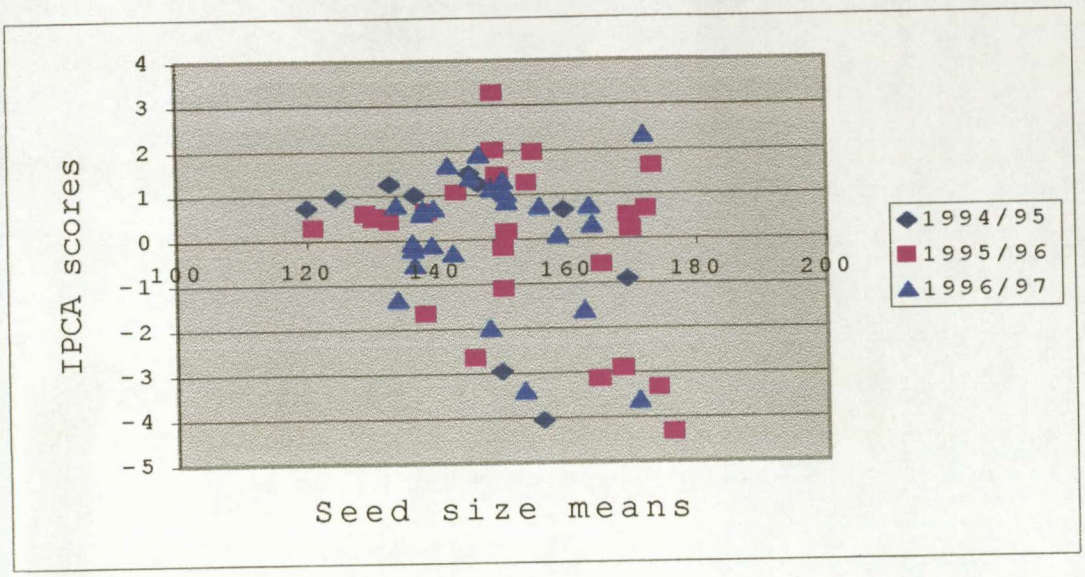


Fig 7.7. Plot of genotype IPCA1 scores vs means for years- Seed size.

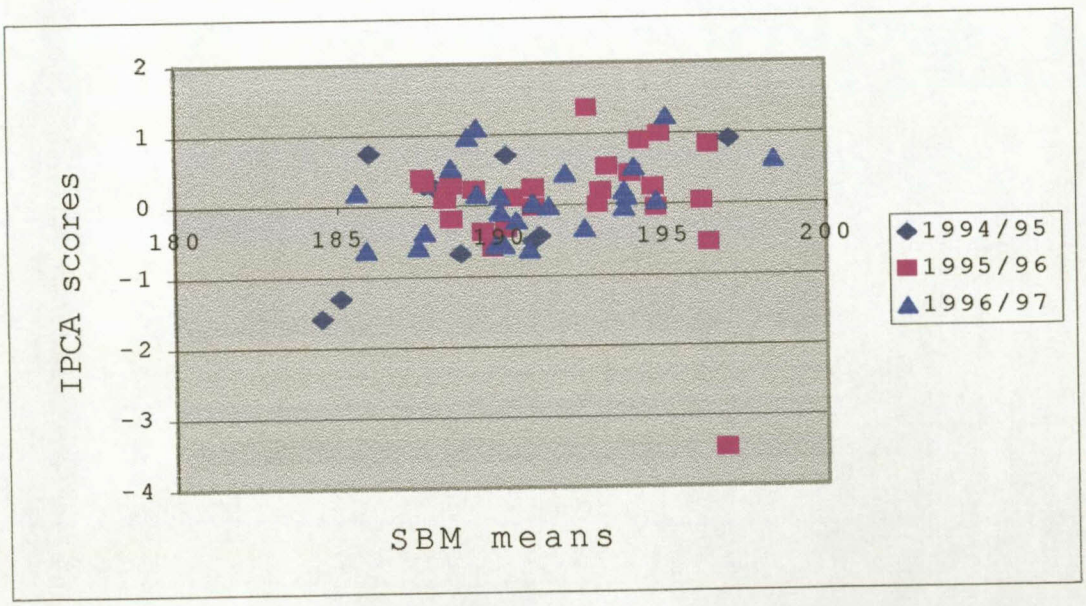


Fig 7.8. Plot of genotype IPCA1 scores vs means for years (SBM).

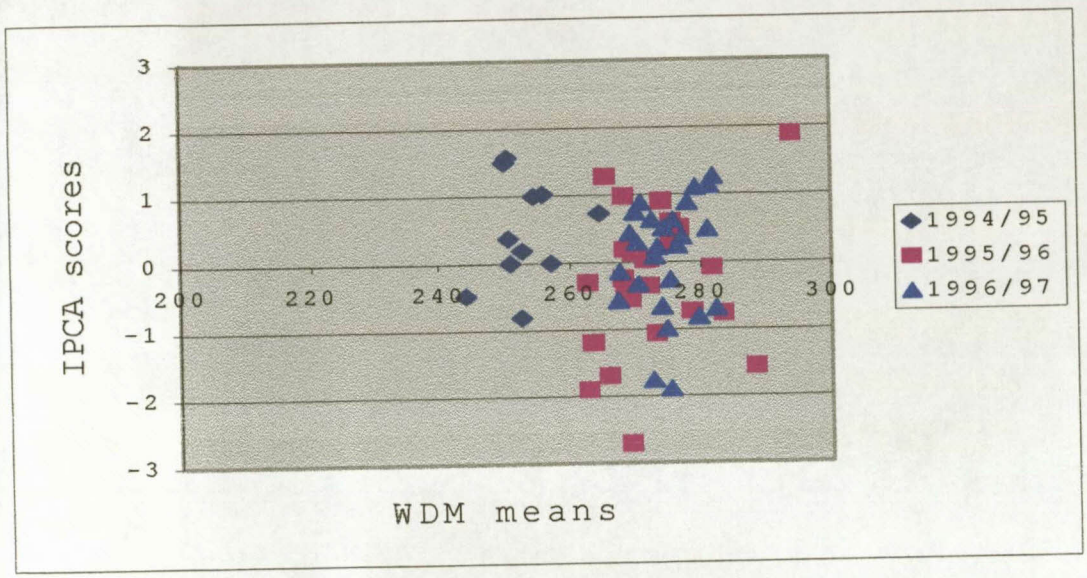


Fig 7.9. Plot of genotype IPCA1 scores vs means for years (WDM).

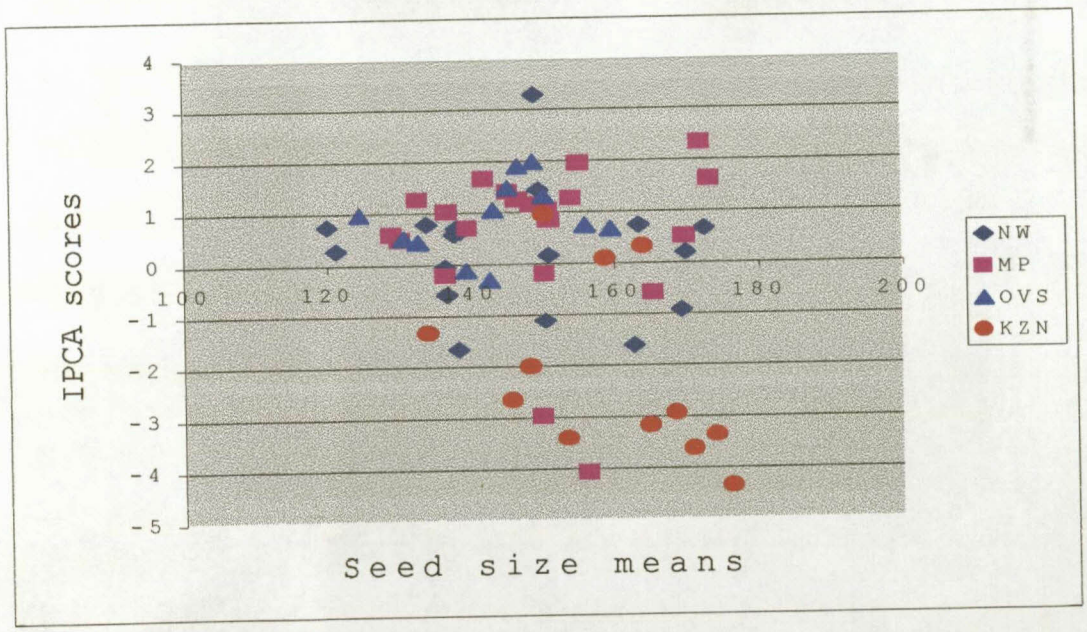


Fig 7.10. Plot of genotype IPCA1 scores vs means for regions- Seed size.

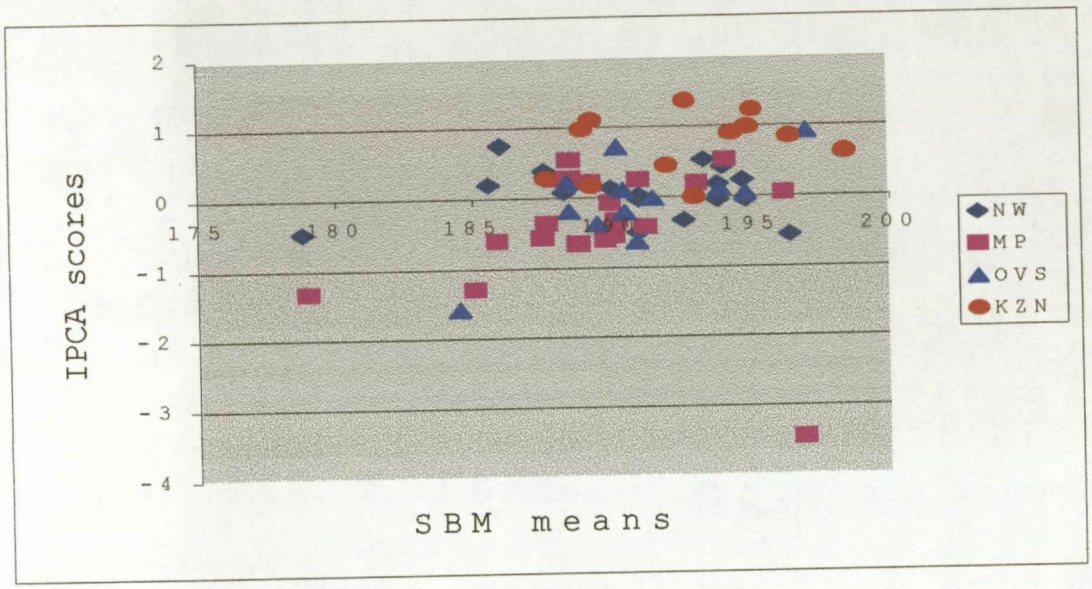


Fig. 7.11. Plot of genotype IPCA1 scores vs means for regions (SBM).

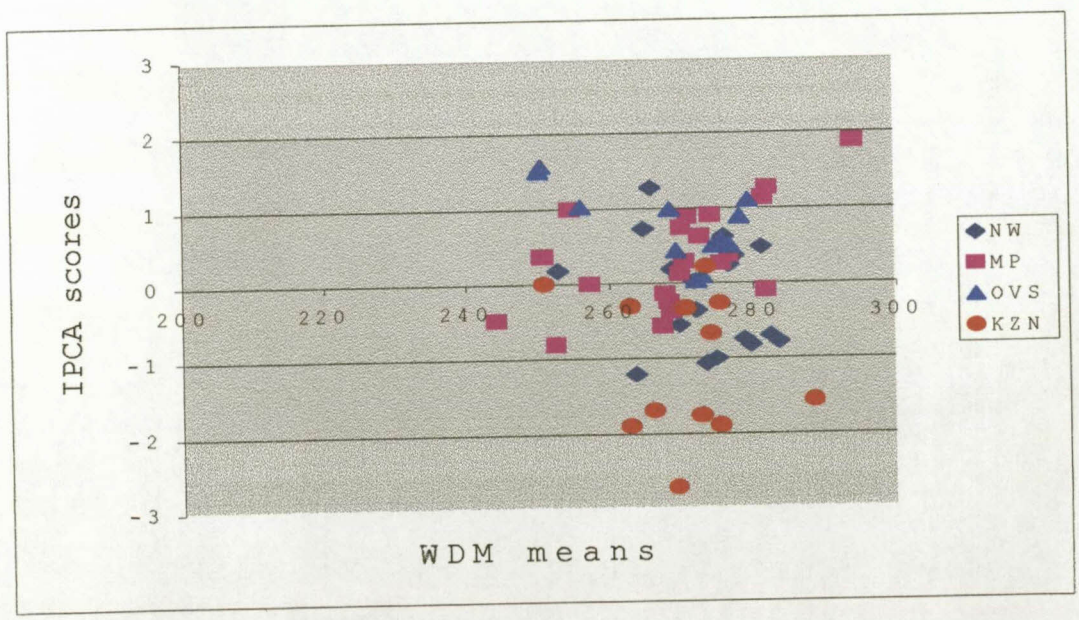


Fig. 7.12. Plot of genotype IPCA1 scores vs means for regions (WBM).

There were, however, also exceptions to the rule, as Ermelo 2 (1995), Bapsfontein (1995), Lichtenburg (1995) and Derby (1997) differentiated into group 2. Smaller seed sizes could be a result of disease infestation of the dry beans, but other environmental factors like water and temperature could have influenced seed size. Derby, for example, had an IPCA1 score of 1.43 (Mean SC=149.5) for the 1995/96 season, but a score of -1.613 (mean SC=162.7) for the 1996/97 growing season, even though disease ratings were similar for the two growing seasons (Steenekamp *et al.*, 1997; Liebenberg *et al.*, 1996).

According to Steenekamp *et al.* (1997) the rust ratings and other disease symptoms were higher for most of the Natal localities, than in the rest of the production areas in the 1996/97 growing season. Liebenberg *et al.* (1996) reported that the rust ratings and other disease ratings for the growing season 1995/96 at Greytown, Cedara and Kokstad (KwaZulu-Natal) were higher than in other production regions. The disease resistance (rust) of Teebus and Kosi is a problem.

Seven trials were planted at Potchefstroom during the three growing seasons (Table 7.4). These seven trials all had relatively low positive or low negative IPCA scores. The scores ranged from 0.723 to -1.114, although the mean

SC differed from 137.8 to 169.9 seeds per 30 g. The seed size of cultivars planted at Potchefstroom was insensitive to seasonal differences.

The mean soaked bean mass (SBM) of the different localities differentiated into three groups. The first group consisted mainly of the Natal localities and some of the 1994/95 trials. The second group was the 20 trials planted in the 1995/96 and 1996/97 seasons, except for the Kokstad trial planted in 1994/95. Eight of these trials were planted in the North West region and seven in the Mpumalanga region. The third group was the largest group and consists of 33 trials. Five 1994/95 trials in this group had the largest negative IPCA1 scores (Table 7.4). This could be due to seasonal differences.

Table 7.4 The environment means and IPCA scores ranked in descending order according to the scores, with the AMMI selection for each:- Seed size.

Nr	Environment	Year	Mean Score	IPCA scores	AMMI Selections			
	Group 1							
37	Syferbult LP	96	149	3.266	C2	C3	C1	C4
60	Bapsfontein LP	97	171.9	2.314	C2	C3	C1	C4
21	Reitz	96	148.8	1.977	C2	C3	C1	C4
22	Ermelo	96	155.1	1.938	C2	C3	C1	C4
46	Bethlehem KGS	97	146.7	1.89	C2	C3	C1	C4
48	Delmas Leeupan 2	97	142	1.656	C2	C3	C1	C4
23	Bapsfontein	96	173.2	1.611	C2	C3	C1	C4
5	Bethlehem Sensako	95	145.2	1.467	C2	C3	C1	C4
15	Derby	96	149.5	1.43	C2	C3	C1	C4
51	Chrissiesmeer	97	145.4	1.386	C2	C3	C1	C4
44	Reitz	97	150.3	1.305	C2	C3	C1	C4
9	Delmas Leeupan 2	95	132.9	1.259	C2	C3	C1	C4
26	Middelburg	96	154.1	1.252	C2	C3	C1	C4
8	Delmas Leeupan 1	95	146.5	1.235	C2	C3	C1	C4
62	Chrissiesmeer LP	97	148.5	1.133	C2	C3	C1	C4
19	Ficksburg	96	143.2	1.03	C2	C3	C1	C4
59	Delmas LP	97	150.8	1.023	C2	C3	C1	C4
10	Ermelo 1	95	136.8	1.009	C2	C3	C1	C4
3	Reitz	95	124.6	0.961	C2	C3	C1	C4
6	Kokstad	95	150.3	0.948	C2	C3	C1	C4
50	Bapsfontein	97	150.9	0.84	C2	C3	C1	C4
42	Syferbult	97	134	0.772	C2	C3	C1	C4
2	Carletonville	95	120	0.733	C2	C3	C1	C4
58	Bethlehem LP	97	156	0.724	C2	C3	C1	C4
39	Potchefstroom 2	97	163.5	0.723	C2	C3	C1	C4
47	Delmas Leeupan 1	97	139.7	0.689	C2	C3	C1	C4
61	Syferbult LP	97	138	0.684	C2	C3	C1	C4
33	Potchehefstroom LP	96	172.4	0.655	C2	C3	C1	C4
4	Bethlehem KGS	95	159.6	0.649	C2	C3	C1	C4
16	Carletonville	96	138.5	0.624	C2	C3	C1	C4
24	Wildebeestfontein	96	129.2	0.58	C2	C3	C1	C4
57	Potchefstroom LP	97	137.8	0.576	C2	C3	C1	C4
36	Bapsfontein LP	96	169.6	0.503	C2	C3	C1	C4
32	Lesotho	96	130.9	0.502	C2	C3	C1	C4
25	Wildebeestfontein	96	130.4	0.472	C2	C3	C1	C4
20	Bethlehem Sensako	96	132.9	0.423	C2	C3	C1	C4
56	Ukulinga	97	164	0.314	C2	C3	C1	C4
17	Rietrivier	96	121.2	0.273	C2	C3	C1	C4
13	Potchefstroom 1	96	169.9	0.191	C2	C3	C4	C1
18	Syferbult	96	150.9	0.159	C2	C3	C4	C1
52	Dundee	97	158.8	0.08	C2	C3	C4	C1
38	Potchefstroom 1	97	136.5	-0.059	C2	C3	C4	C1

43	Ficksburg	97	139.4	-0.127	C2	C3	C4	C1
28	PHI	96	150.4	-0.203	C2	C3	C4	C1
49	Delmas Pannar	97	136.5	-0.218	C2	C3	C4	C1
45	Bethlehem Sensako	97	142.7	-0.309	C2	C3	C4	C1
40	Carletonville	97	136.8	-0.585	C2	C3	C4	C1
34	Ermelo LP	96	165.3	-0.59	C2	C3	C4	C1
1	Potchefstroom	95	169.3	-0.92	C2	C3	C4	C1
14	Potchefstroom 2	96	150.4	-1.114	C2	C3	C4	C1
	Group 2							
63	Cedara LP	97	134.1	-1.337	C2	C4	C3	C1
41	Derby	97	162.7	-1.613	C2	C4	C3	C1
12	Lichtenburg	95	138.3	-1.66	C2	C4	C3	C1
54	Greytown 2	97	148.3	-2.004	C2	C4	C3	C1
27	Kokstad	96	145.8	-2.653	C2	C4	C1	C3
29	Greytown 1	96	168.5	-2.923	C4	C2	C1	C3
11	Ermelo 2	95	149.9	-2.968	C4	C2	C1	C3
31	Cedara	96	164.8	-3.154	C4	C2	C1	C3
35	Cedara LP	96	174	-3.36	C4	C2	C1	C3
55	Cedara	97	153.5	-3.406	C4	C2	C1	C3
53	Greytown 1	97	170.9	-3.628	C4	C2	C1	C3
7	Bapsfontein	95	156.3	-4.075	C4	C2	C1	C3
30	Greytown 2	96	176.2	-4.348	C4	C2	C1	C3

The mean soaked bean mass (SBM) of the different localities differentiated into three groups. The first consisted mainly of the Natal localities and some of the 1994/95 trials (Table 7.5). The second group was the 20 trails planted in the 1995/96 and 1996/97 seasons, except for the Kokstad trial planted in 1994/95. Eight of these trials were planted in the North West region and seven in the Mpumalanga region (Table 7.5). The third group was the largest group and consisted of 33 trials. Five 1994/95 trails in this group had the largest negative IPCA1 scores (Table 7.5). This could be due to seasonal differences.

The biplot (Fig. 7.8) of the GE IPCA1 scores versus the means indicated that the KwaZulu-Natal localities grouped together, while the Mpumalanga trials formed a group on the opposite side of the graph. Although Shellie and Hosfield (1991) worked on different bean classes, they found that the amount of water absorbed correspond with the average mean temperature and precipitation of a particular location (Table 7.5). The driest and warmest location absorbed the largest amount of water and the coolest, most humid location, absorbed the least. This corresponds with the KwaZulu-Natal localities that grouped together with the lowest water absorption during soaking. According to Redden *et al.* (1984) the difference in water absorption could be a result of the amylose and amylopectin percentage in the starch granule. Intriago-Ortega *et al.* (1996) reported that the percentage of carbohydrate could be influenced by the rainfall accumulated during the reproductive phase. This is therefore in accordance with the findings of Shellie and Hosfield, (1991).

Table 7.5 The environment means and IPCA scores ranked in descending order according to the scores, with the AMMI selection for each:-SBM.

Nr	Environment	Year	Mean score	IPCA score	AMMI selections			
	Group 1							
30	Greytown 2	96	192.7	1.3532	C4	C1	C3	C2
53	Greytown 1	97	195.1	1.217	C4	C1	C3	C2
63	Cedara LP	97	189.3	1.0886	C4	C1	C3	C2
27	Kokstad	96	194.9	0.9729	C4	C1	C3	C2
54	Greytown 2	97	189	0.9603	C4	C1	C3	C2
4	Bethlehem KGS	95	197	0.903	C4	C3	C1	C2
29	Greytown 1	96	194.3	0.8859	C4	C3	C1	C2
31	Cedara	96	196.4	0.8366	C4	C3	C1	C2
1	Potchefstroom	95	186	0.7407	C4	C3	C1	C2
5	Bethlehem Sensako	95	190.2	0.7012	C4	C3	C1	C2
	Group 2							
52	Dundee	97	198.4	0.6141	C3	C4	C1	C2
49	Delmas Pannar	97	188.5	0.5284	C3	C4	C1	C2
12	Lichtenburg	96	193.3	0.5241	C3	C4	C1	C2
62	Chrissiesmeer LP	97	194.1	0.5118	C3	C4	C1	C2
56	Ukulinga	97	192	0.4338	C3	C4	C2	C1
13	Potchefstroom 1	96	194	0.4186	C3	C4	C2	C1
14	Potchefstroom 2	96	187.6	0.3803	C3	C4	C2	C1
18	Syferbult	96	187.7	0.312	C3	C4	C2	C1
6	Kokstad	95	187.7	0.2713	C3	C4	C2	C1
24	Wildebeestfontein	96	188.5	0.2628	C3	C4	C2	C1
11	Ermelo 2	95	188	0.2513	C3	C4	C2	C1
26	Middelburg	96	191	0.2332	C3	C4	C2	C1
33	Potchehefstroom LP	96	194.7	0.2281	C3	C4	C2	C1
28	PHI	96	189.2	0.2115	C3	C4	C2	C1
19	Ficksburg	96	188.4	0.2002	C3	C4	C2	C1
38	Potchefstroom 1	97	185.6	0.1871	C3	C4	C2	C1
22	Ermelo	96	193.1	0.177	C3	C4	C2	C1
39	Potchefstroom 2	97	193.8	0.1756	C3	C4	C2	C1
55	Cedara	97	189.3	0.1492	C3	C4	C2	C1
42	Syferbult	97	190	0.1282	C3	C4	C2	C1
	Group 3							
43	Ficksburg	97	193.9	0.0962	C3	C2	C4	C1
32	Lesotho	96	190.4	0.0923	C3	C2	C4	C1
16	Carletonville	96	188.3	0.0722	C3	C2	C4	C1
58	Bethlehem LP	97	194.8	0.0332	C3	C2	C4	C1
36	Bapsfontein LP	96	196.2	0.0318	C3	C2	C4	C1
40	Carletonville	97	191	0.0149	C3	C2	C4	C1
35	Cedara LP	96	193	-0.0174	C3	C2	C4	C1
44	Reitz	97	191.5	-0.0315	C3	C2	C4	C1
15	Derby	96	191	-0.0401	C3	C2	C4	C1
37	Syferbult LP	96	194.8	-0.0549	C3	C2	C4	C1
41	Derby	97	193.8	-0.0615	C3	C2	C4	C1

50	Bapsfontein	97	190	-0.0977	C3	C2	C4	C1
20	Bethlehem Sensako	96	188.5	-0.2039	C3	C2	C4	C1
45	Bethlehem Sensako	97	190.5	-0.2292	C3	C2	C4	C1
25	Wildebeestfontein	96	190.2	-0.3444	C3	C2	C4	C1
61	Syferbult LP	97	192.6	-0.3457	C3	C2	C4	C1
51	Chrissiesmeer	97	187.7	-0.3819	C3	C2	C4	C1
21	Reitz	96	189.5	-0.386	C3	C2	C4	C1
8	Delmas Leeupan 1	95	191.2	-0.4459	C3	C2	C4	C1
57	Potchefstroom LP	97	178.8	-0.4907	C3	C2	C4	C1
2	Carletonville	95	191	-0.5154	C3	C2	C4	C1
17	Rietrivier	96	196.4	-0.5614	C3	C2	C4	C1
59	Delmas LP	97	190.1	-0.5679	C3	C2	C4	C1
60	Bapsfontein LP	97	189.9	-0.5714	C3	C2	C4	C1
48	Delmas Leeupan 2	97	187.5	-0.5901	C3	C2	C4	C1
23	Bapsfontein	96	189.8	-0.6141	C3	C2	C4	C1
47	Delmas Leeupan 1	97	185.9	-0.6292	C3	C2	C4	C1
46	Bethlehem KGS	97	190.9	-0.6432	C3	C2	C4	C1
7	Bapsfontein	95	188.8	-0.6782	C3	C2	C4	C1
9	Delmas Leeupan 2	95	185.1	-1.3097	C3	C2	C4	C1
10	Ermelo 1	95	179	-1.3407	C3	C2	C4	C1
3	Reitz	95	184.5	-1.5911	C3	C2	C4	C1
34	Ermelo LP	96	196.9	-3.4554	C3	C2	C4	C1

The environments for washed drain mass (WDM) differentiated into three groups. The first group was the largest with 39 trials (Table 7.6). The second group consisted of only nine trails, and the third group of 15 trails (Table 7.6). The third group consisted of six Potchefstroom trials, four Greytown trials, three Cedara trials and a Syferbult and Delmas Leeupan trial respectively (Table 7.6). It appears that the WDM was mainly determined by the locality, with only minor seasonal effects occuring.

Table 7.6 The environment means and IPCA scores ranked in descending order according to the scores, with the AMMI selection for each: -WDM.

Nr	Environment	Year	Mean Score	IPCA score	AMMI selections			
	Group 1							
34	Ermelo LP	96	294.1	1.8757	C1	C4	C2	C3
3	Reitz	96	250.6	1.5671	C1	C4	C2	C3
4	Bethlehem KGS	95	250.2	1.4988	C1	C4	C2	C3
17	Rietrivier	96	265.7	1.2664	C1	C4	C2	C3
48	Delmas Leeupan 2	97	282	1.2571	C1	C4	C2	C3
47	Delmas Leeupan 1	97	281.4	1.1278	C1	C4	C2	C3
58	Bethlehem LP	97	279.3	1.0946	C1	C4	C2	C3
5	Bethlehem Sensako	95	256	1.0247	C1	C4	C2	C3
7	Bapsfontein	95	254.6	0.9905	C1	C4	C2	C3
21	Reitz	96	268.4	0.9771	C1	C4	C2	C3
28	PHI	96	274.1	0.8964	C1	C4	C2	C3
46	Bethlehem KGS	97	278.1	0.8823	C1	C4	C2	C3
51	Chrissiesmeer	97	270.9	0.8791	C1	C4	C2	C3
59	Delmas LP	97	270.1	0.7327	C1	C4	C2	C3
2	Carletonville	95	264.7	0.7272	C1	C4	C2	C3
50	Bapsfontein	97	272.6	0.6175	C1	C4	C2	C3
42	Syferbult	97	275.8	0.6156	C1	C4	C2	C3
20	Bethlehem Sensako	96	275.6	0.5818	C1	C4	C2	C3
32	Lesotho	96	276.8	0.4985	C1	C4	C2	C3
43	Ficksburg	97	274.5	0.4946	C1	C4	C2	C3
61	Syferbult LP	97	281.2	0.4747	C1	C4	C2	C3
44	Reitz	97	269.3	0.4271	C1	C4	C2	C3
25	Wildebeestfontein	96	276.7	0.3738	C1	C4	C2	C3
40	Carletonville	97	277.3	0.3641	C1	C4	C2	C3
10	Ermelo 1	95	250.7	0.3622	C1	C4	C2	C3
60	Bapsfontein LP	97	270.4	0.2806	C1	C4	C2	C3
24	Wildebeestfontein	96	275.6	0.2552	C1	C4	C2	C3
41	Derby	97	276.6	0.2354	C1	C4	C2	C3
52	Dundee	97	273.5	0.2108	C1	C4	C2	C3
16	Carletonville	96	268.6	0.185	C1	C4	C2	C3
1	Potchefstroom	95	252.8	0.176	C1	C4	C2	C3
22	Ermelo	96	269.8	0.126	C1	C4	C2	C3
45	Bethlehem Sensako	97	273	0.0792	C1	C4	C2	C3
19	Ficksburg	96	272	0.023	C1	C4	C2	C3
18	Syferbult	96	271.7	0.02	C1	C4	C2	C3
6	Kokstad	95	251	-0.0005	C1	C4	C2	C3
11	Ermelo 2	95	257.3	-0.0078	C1	C4	C2	C3
36	Bapsfontein LP	96	281.8	-0.1006	C1	C4	C2	C3
62	Chrissiesmeer LP	97	267.8	-0.1519	C1	C4	C2	C3
	Group 2							
23	Bapsfontein	96	268.3	-0.2528	C1	C2	C3	C4
55	Cedara	97	275.4	-0.2717	C1	C2	C3	C4
27	Kokstad	96	262.9	-0.3167	C1	C2	C3	C4

56	Ukulinga	97	270.5	-0.3382	C1	C3	C2	C4
15	Derby	96	272	-0.3619	C1	C3	C2	C4
26	Middelburg	96	268.7	-0.3818	C1	C3	C2	C4
9	Delmas Leeupan 2	95	244.2	-0.4864	C1	C3	C2	C4
12	Lichtenburg	96	269.6	-0.5585	C1	C3	C2	C4
49	Delmas Pannar	97	267.4	-0.5781	C3	C1	C2	C4
	Group 3							
54	Greytown 2	97	274.1	-0.6783	C3	C2	C1	C4
38	Potchefstroom 1	97	282.4	-0.703	C3	C2	C1	C4
37	Syferbult LP	96	278.8	-0.7505	C3	C2	C1	C4
33	Potchehefstroom LP	96	283.6	-0.7819	C3	C2	C1	C4
8	Delmas Leeupan 1	95	252.6	-0.8154	C3	C2	C1	C4
57	Potchefstroom LP	97	279.7	-0.8245	C3	C2	C1	C4
39	Potchefstroom 2	97	274.9	-1.0038	C3	C2	C1	C4
14	Potchefstroom 2	96	273.4	-1.0747	C3	C2	C1	C4
13	Potchefstroom 1	96	263.6	-1.2095	C3	C2	C1	C4
35	Cedara LP	96	288.6	-1.5687	C3	C2	C1	C4
31	Cedara	96	266.1	-1.7018	C3	C2	C1	C4
53	Greytown 1	97	272.7	-1.7601	C3	C2	C1	C4
63	Cedara LP	97	275.4	-1.8992	C3	C2	C1	C4
29	Greytown 1	96	263	-1.9069	C3	C2	C1	C4
30	Greytown 2	96	269.4	-2.7135	C3	C2	C1	C4

7.3.2.2. Visual appearance and texture

The ranking of the different cultivars; according to the visual appearance IPCA1 scores, the localities can be divided into two groups (Table 7.7). The first group consisted of the localities with high positive and high negative scores and therefore the localities that were unstable for the visual appearance. The group of localities with high positive scores was mainly localities planted in the 1994/95 season.

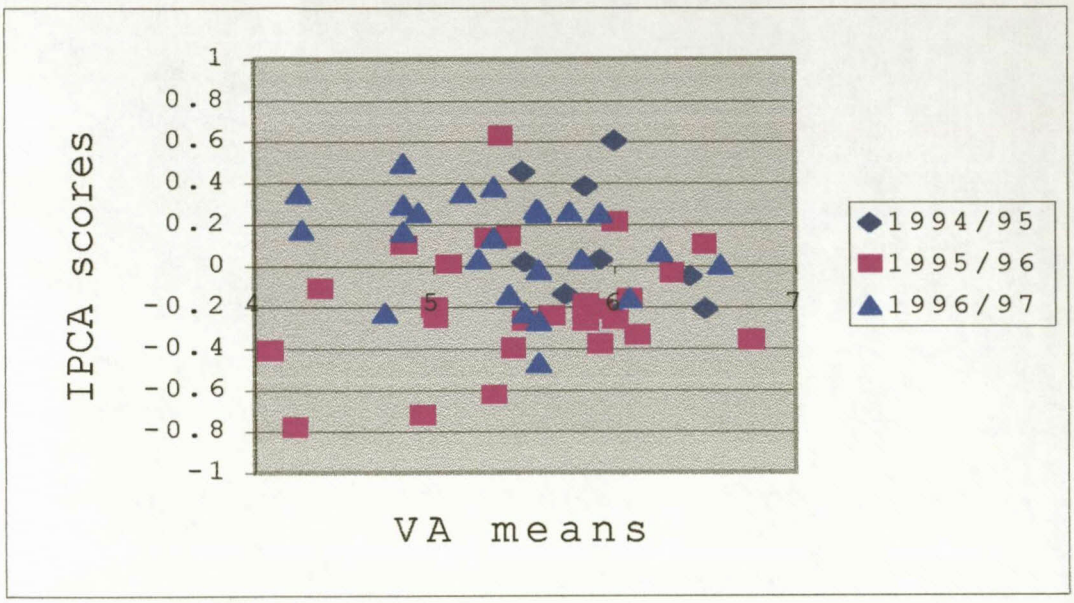


Fig 7.13. Plot of genotype IPCA1 scores vs means for years- (VA).

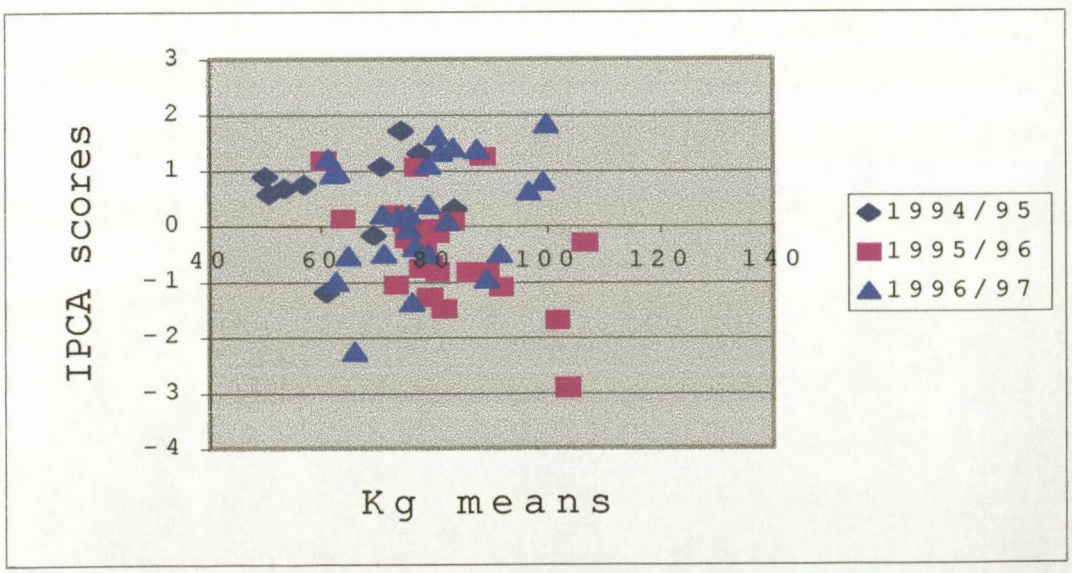


Fig. 7.14. Plot of genotype IPCA1 scores vs means for years (kg).

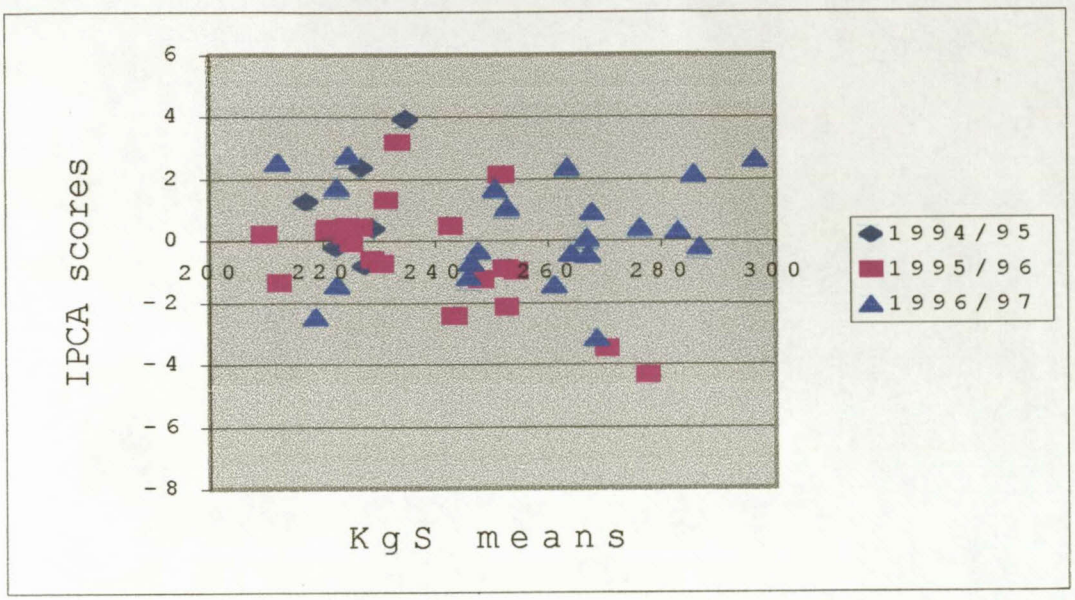


Fig. 7.15. Plot of genotype IPCA1 scores vs means for years- (kgS).

The ranking of the cultivars as choice grade and standard grade cultivars, within these two groups was mainly the same. The localities with high negative scores were mainly localities in KwaZulu-Natal.

The plot of mean visual appearance and the IPCA1 scores (Fig. 7.13) showed that the 1994/95 season localities clustered together but the regions did not show any visible clustering (Fig. 7.16). This could be a result of the lower mean rainfall during the reproductive phase in the 1994/95 season than the other two seasons (Liebenberg *et al.*, 1995; Liebenberg *et al.*, 1996; Steenekamp *et al.*, 1997). It is therefore possible that water stress during

the reproductive phase could influence the visual appearance.

The environments differentiated for texture (Kg per 100g) into two main groups namely localities with positive and localities with negative scores (Table 7.8). The first group consisted of 32 trials and the second group of 31 trials. The plot of the mean scores versus the IPCA1 of the texture measurement (kg per 100g) (Fig. 7.14) scores showed that the 1994/95 season always grouped together. This could therefore be due to seasonal differences. The plot of the mean scores versus the IPCA1 of the texture measurement (kg per 100g) with the regions grouped together did not showed any specific groupings of regions (Fig 7.17).

Table 7.7 The environment means and IPCA1 scores ranked in descending order according to the scores, with the AMMI selection for each:- Visual appearance.

Nr	Environment	Year	Mean Score	IPCA1 score	AMMI selections			
	Group 1							
3	Reitz	95	3.917	0.8101	C1	C2	C4	C3
18	Syferbult	96	5.375	0.6302	C1	C2	C4	C3
10	Ermelo 1	95	6	0.6049	C1	C2	C4	C3
6	Kokstad	95	6	0.6049	C1	C2	C4	C3
	Group 2							
54	Greytown 2	97	4.833	0.4948	C1	C4	C2	C3
2	Carletonville	95	5.492	0.4521	C1	C4	C2	C3
7	Bapsfontein	95	5.833	0.3833	C1	C4	C2	C3
57	Potchefstroom LP	97	5.333	0.382	C1	C4	C2	C3
61	Syferbult LP	97	5.167	0.3505	C1	C4	C2	C3
62	Chrissiesmeer LP	97	4.25	0.3487	C1	C4	C2	C3
52	Dundee	97	4.833	0.2915	C1	C4	C2	C3
51	Chrissiesmeer	97	5.567	0.271	C1	C4	C2	C3
46	Bethlehem KGS	97	5.583	0.2621	C1	C4	C2	C3
41	Derby	97	5.75	0.2581	C1	C4	C2	C3
63	Cedara LP	97	4.917	0.2542	C1	C4	C2	C3
44	Reitz	97	5.583	0.2528	C1	C4	C2	C3
42	Syferbult	97	5.917	0.2528	C1	C4	C2	C3
24	Wildebeestfontein 1	96	6	0.2128	C1	C4	C2	C3
58	Bethlehem LP	97	4.267	0.1699	C1	C4	C2	C3
53	Greytown 1	97	4.833	0.1618	C1	C4	C2	C3
36	Bapsfontein LP	96	5.417	0.1414	C1	C4	C2	C3
14	Potchefstroom 2	96	5.3	0.135	C1	C4	C2	C3
60	Bapsfontein LP	97	5.333	0.1316	C1	C4	C2	C3
40	Carletonville	97	5.333	0.1289	C1	C4	C2	C3
37	Syferbult LP	96	6.5	0.1014	C1	C4	C2	C3
30	Greytown 2	96	4.833	0.1001	C1	C4	C2	C3
45	Bethlehem Sensako	97	6.25	0.0614	C4	C1	C2	C3
55	Cedara	97	5.25	0.03	C4	C1	C2	C3
59	Delmas LP	97	5.817	0.03	C4	C1	C2	C3
5	Bethlehem Sensako	95	5.917	0.0286	C4	C1	C2	C3
4	Bethlehem KGS	95	5.5	0.0161	C4	C1	C2	C3
32	Lesotho	96	5.083	0.0077	C4	C1	C2	C3
43	Ficksburg	97	6.583	0.0037	C4	C1	C2	C3
49	Delmas Pannar	97	5.583	-0.0212	C4	C1	C2	C3
34	Ermelo LP	96	6.317	-0.0336	C4	C1	C2	C3
8	Delmas Leeupan 1	95	6.417	-0.05	C4	C1	C2	C3
23	Bapsfontein	96	4.367	-0.1103	C4	C1	C3	C2
9	Delmas Leeupan 2	95	5.725	-0.1392	C4	C1	C3	C2
47	Delmas Leeupan 1	97	5.417	-0.1418	C4	C1	C3	C2
56	Ukulinga	97	6.083	-0.1575	C4	C1	C3	C2

21	Reitz	96	6.083	-0.1588	C4	C1	C3	C2
13	Potchefstroom 1	96	5.833	-0.1818	C4	C1	C3	C2
19	Ficksburg	96	5	-0.2041	C4	C1	C3	C2
11	Ermelo 2	95	6.5	-0.2067	C4	C1	C3	C2
27	Kokstad	96	5.917	-0.2112	C4	C1	C3	C2
39	Potchefstroom 2	97	5.5	-0.2316	C4	C1	C3	C2
50	Bapsfontein	97	4.733	-0.2316	C4	C1	C3	C2
1	Potchefstroom	95	6	-0.2356	C4	C1	C3	C2
16	Carletonville	96	5.65	-0.2423	C4	C1	C3	C2
20	Bethlehem Sensako	96	5.017	-0.253	C4	C1	C3	C2
28	PHI	96	6	-0.2618	C4	C1	C3	C2
12	Lichtenburg	96	5.833	-0.2658	C4	C1	C3	C2
26	Middelburg	96	5.5	-0.2671	C4	C1	C3	C2
38	Potchefstroom 1	97	5.583	-0.2716	C4	C1	C3	C2
15	Derby	96	6.125	-0.3375	C4	C1	C3	C2
25	Wildebeestfontein 2	96	6.75	-0.3581	C4	C1	C3	C2
22	Ermelo	96	5.917	-0.3804	C4	C1	C3	C2
33	Potchehefstroom LP	96	5.442	-0.3979	C4	C1	C3	C2
	Group 3							
17	Rietrivier	96	4.083	-0.4099	C4	C3	C1	C2
48	Delmas Leeupan 2	97	5.583	-0.4709	C4	C3	C1	C2
31	Cedara	96	5.333	-0.6276	C4	C3	C1	C2
29	Greytown 1	96	4.933	-0.7218	C4	C3	C1	C2
35	Cedara LP	96	4.225	-0.7839	C3	C4	C1	C2

Cultivar rankings for texture (Kg per 100g over 12 seconds) for the IPCA1 scores for localities grouped the localities into three groups (Table 7.9). The first group consisted of ten localities (seven localities planted in the 1996/97 season), while the second group consisted of 26 localities and the third group of 27 localities. The second group consisted of localities planted in the North West, Mpumalanga and Free state localities, while group three consisted of 11 localities planted in Natal. It appears that texture was mainly determined by the locality, with only minor seasonal effects occuring. This was however not evident from the plot of the texture (KgS) IPCA scores vs the means (Fig 7.18).

Table 7.8 The environment means and IPCA1 scores ranked in descending order according to the scores, with the AMMI selection for each:-Texture (Kg).

Nr	Environment	Year	Mean Score	IPCA1 score	AMMI selections			
	Group 1							
60	Bapsfontein LP	97	99.94	1.8332	C2	C3	C4	C1
9	Delmas Leeupan 2	95	74.24	1.7151	C2	C4	C3	C1
58	Bethlehem LP	97	80.42	1.6304	C2	C4	C3	C1
50	Bapsfontein	97	83.33	1.4092	C2	C4	C3	C1
51	Chrissiesmeer	97	87.64	1.3791	C2	C4	C3	C1
54	Greytown 2	97	81.11	1.3167	C2	C4	C3	C1
10	Ermelo 1	95	77.36	1.3093	C2	C4	C3	C1
16	Carletonville	96	88.54	1.2381	C2	C4	C3	C1
47	Delmas Leeupan 1	97	61.39	1.2033	C2	C4	C3	C1
32	Lesotho	96	60.4	1.1693	C2	C4	C3	C1
41	Derby	97	78.9	1.096	C2	C4	C3	C1
7	Bapsfontein	95	70.8	1.0643	C2	C4	C3	C1
21	Reitz	96	77.12	1.0539	C4	C2	C3	C1
48	Delmas Leeupan 2	97	62.89	0.9495	C4	C2	C3	C1
46	Bethlehem KGS	97	62.04	0.9264	C4	C2	C3	C1
3	Reitz	95	49.85	0.8913	C4	C2	C3	C1
62	Chrissiesmeer LP	97	99.3	0.7925	C4	C2	C3	C1
5	Bethlehem Sensako	95	56.84	0.7451	C4	C2	C3	C1
2	Carletonville	95	53.17	0.6771	C4	C2	C3	C1
59	Delmas LP	97	96.8	0.6235	C4	C2	C3	C1
8	Delmas Leeupan 1	95	50.55	0.5734	C4	C2	C3	C1
63	Cedara LP	97	78.88	0.3837	C4	C3	C2	C1
4	Bethlehem KGS	95	83.53	0.3085	C4	C3	C2	C1
44	Reitz	97	75.45	0.2042	C4	C3	C1	C2
17	Rietrivier	96	72.68	0.2002	C4	C3	C1	C2
40	Carletonville	97	70.99	0.1988	C4	C3	C1	C2
28	PHI	96	74.6	0.1654	C4	C3	C1	C2
45	Bethlehem Sensako	97	73.54	0.1532	C4	C3	C1	C2
36	Bapsfontein LP	96	64.05	0.1162	C4	C3	C1	C2
35	Cedara LP	96	83.14	0.0944	C4	C3	C1	C2
49	Delmas Pannar	97	82.37	0.0715	C4	C3	C1	C2
34	Ermelo LP	96	74.88	0.0569	C4	C3	C1	C2
	Group 2							
15	Derby	96	78.84	-0.0539	C4	C1	C3	C2
52	Dundee	97	75.58	-0.0632	C4	C1	C3	C2
18	Syferbult	96	80.53	-0.1529	C4	C1	C3	C2
6	Kokstad	95	69.38	-0.1666	C4	C1	C3	C2
37	Syferbult LP	96	75.37	-0.2229	C4	C1	C3	C2
20	Bethlehem Sensako	96	76.67	-0.2813	C4	C1	C3	C2
13	Potchefstroom 1	96	106.62	-0.3001	C4	C1	C3	C2
19	Ficksburg	96	78.43	-0.3212	C4	C1	C3	C2
1	Potchefstroom	95	77.12	-0.3568	C4	C1	C3	C2

43	Ficksburg	97	76.57	-0.383	C4	C1	C3	C2
55	Cedara	97	71.17	-0.5007	C4	C1	C3	C2
42	Syferbult	97	91.66	-0.5012	C4	C1	C3	C2
57	Potchefstroom LP	97	78.88	-0.5071	C4	C1	C3	C2
56	Ukulinga	97	64.82	-0.5446	C4	C1	C3	C2
14	Potchefstroom 2	96	79.31	-0.7004	C4	C1	C3	C2
25	Wildebeestfontein 2	96	77.89	-0.7691	C4	C1	C3	C2
24	Wildebeestfontein 1	96	80.62	-0.8186	C4	C1	C3	C2
26	Middelburg	96	86.23	-0.8239	C4	C1	C3	C2
22	Ermelo	96	89.22	-0.8323	C4	C1	C3	C2
12	Lichtenburg	96	86.37	-0.8547	C4	C1	C3	C2
61	Syferbult LP	97	89.37	-0.9646	C4	C1	C3	C2
39	Potchefstroom 2	97	62.62	-1.0045	C4	C1	C3	C2
33	Potchehefstroom LP	96	73.37	-1.0771	C4	C1	C3	C2
30	Greytown 2	96	92.11	-1.1085	C4	C1	C3	C2
11	Ermelo 2	95	60.91	-1.2047	C4	C1	C3	C2
23	Bapsfontein	96	79.11	-1.286	C4	C1	C3	C2
53	Greytown 1	96	76.16	-1.3802	C4	C1	C3	C2
27	Kokstad	96	81.79	-1.4969	C4	C1	C3	C2
29	Greytown 1	96	101.97	-1.7058	C4	C1	C3	C2
38	Potchefstroom 1	97	65.87	-2.2626	C4	C1	C3	C2
31	Cedara	96	103.68	-2.9044	C4	C1	C3	C2

Table 7.9 The environment means and IPCA1 scores ranked in descending order according to the scores, with the AMMI selection for each:- Texture (KgS).

Nr	Environment	Year	Mean Score	IPCA1 score	AMMI selections			
	Group 1							
10	Ermelo 1	95	234.9	3.925	C2	C3	C4	C1
21	Reitz	96	233.3	3.164	C2	C3	C4	C1
48	Delmas Leeupan 2	97	224.5	2.737	C2	C3	C4	C1
50	Bapsfontein	97	296.6	2.627	C3	C2	C4	C1
47	Delmas Leeupan 1	97	212	2.521	C3	C2	C4	C1
58	Bethlehem LP	97	263.5	2.37	C3	C2	C4	C1
9	Delmas Leeupan 2	95	226.9	2.366	C3	C2	C4	C1
16	Carletonville	96	251.6	2.141	C3	C2	C4	C1
54	Greytown 2	97	285.8	2.133	C3	C2	C4	C1
51	Chrissiesmeer	97	300.2	1.77	C3	C2	C4	C1
	Group 2							
46	Bethlehem KGS	97	222.4	1.734	C3	C4	C2	C1
45	Bethlehem Sensako	97	250.7	1.68	C3	C4	C2	C1
32	Lesotho	96	193.2	1.601	C3	C4	C2	C1
2	Carletonville	95	173.1	1.526	C3	C4	C2	C1
28	PHI	96	231.5	1.325	C4	C3	C2	C1
60	Bapsfontein LP	97	337.9	1.28	C4	C3	C2	C1
7	Bapsfontein	95	217	1.267	C4	C3	C2	C1
62	Chrissiesmeer LP	97	330	1.197	C4	C3	C2	C1
43	Ficksburg	97	252.7	1.063	C4	C3	C2	C1
3	Reitz	95	174.9	1.062	C4	C3	C2	C1
5	Bethlehem Sensako	95	186.8	0.975	C4	C3	C2	C1
41	Derby	97	267.9	0.922	C4	C3	C2	C1
8	Delmas Leeupan 1	95	166.7	0.721	C4	C3	C1	C2
59	Delmas LP	97	309.2	0.687	C4	C3	C1	C2
18	Syferbult	96	242.8	0.49	C4	C3	C1	C2
15	Derby	96	224.4	0.455	C4	C3	C1	C2
20	Bethlehem Sensako	96	226.6	0.431	C4	C3	C1	C2
61	Syferbult LP	97	276.1	0.4	C4	C3	C1	C2
17	Rietrivier	96	221.2	0.382	C4	C3	C1	C2
4	Bethlehem KGS	95	228.9	0.382	C4	C3	C1	C2
42	Syferbult	97	282.9	0.304	C4	C3	C1	C2
19	Ficksburg	96	221	0.297	C4	C3	C1	C2
25	Wildebeestfontein	96	209.6	0.2	C4	C3	C1	C2
37	Syferbult LP	96	223.8	0.198	C4	C3	C1	C2
44	Reitz	97	266.8	0.07	C4	C3	C1	C2
34	Ermelo LP	96	225.1	-0.087	C4	C3	C1	C2
	Group 3							
6	Kokstad	95	222.3	-0.226	C4	C1	C3	C2
49	Delmas Pannar	97	286.7	-0.226	C4	C1	C3	C2
57	Potchefstroom LP	97	247.6	-0.336	C4	C1	C3	C2

52	Dundee	97	264.2	-0.428	C4	C1	C3	C2
63	Cedara LP	97	267	-0.466	C4	C1	C3	C2
36	Bapsfontein LP	96	199.6	-0.535	C4	C1	C3	C2
24	Wildebeestfontein	96	229	-0.595	C4	C1	C3	C2
56	Ukulinga	97	246.3	-0.719	C4	C1	C3	C2
14	Potchefstroom 2	96	230.5	-0.747	C4	C1	C3	C2
1	Potchefstroom	95	227.5	-0.797	C4	C1	C3	C2
22	Ermelo	96	252.4	-0.908	C4	C1	C3	C2
23	Bapsfontein	96	254.2	-0.999	C4	C1	C3	C2
40	Carletonville	97	245.9	-1.195	C4	C1	C3	C2
26	Middelburg	96	248	-1.263	C4	C1	C3	C2
33	Potchehefstroom LP	96	212.3	-1.355	C4	C1	C3	C2
11	Ermelo 2	95	191.8	-1.382	C4	C1	C3	C2
39	Potchefstroom 2	97	222.4	-1.447	C4	C1	C3	C2
55	Cedara	97	261.2	-1.45	C4	C1	C3	C2
12	Lichtenburg	96	252.8	-2.132	C4	C1	C3	C2
13	Potchefstroom 1	96	314.7	-2.277	C4	C1	C3	C2
35	Cedara LP	96	243.2	-2.444	C4	C1	C3	C2
38	Potchefstroom 1	97	218.6	-2.467	C4	C1	C3	C2
53	Greytown 1	97	268.6	-3.157	C4	C1	C3	C2
27	Kokstad	96	270.4	-3.481	C4	C1	C3	C2
30	Greytown 2	96	277.7	-4.329	C4	C1	C3	C2
29	Greytown 1	96	307.6	-4.847	C4	C1	C3	C2
31	Cedara	96	305.7	-6.108	C4	C1	C3	C2

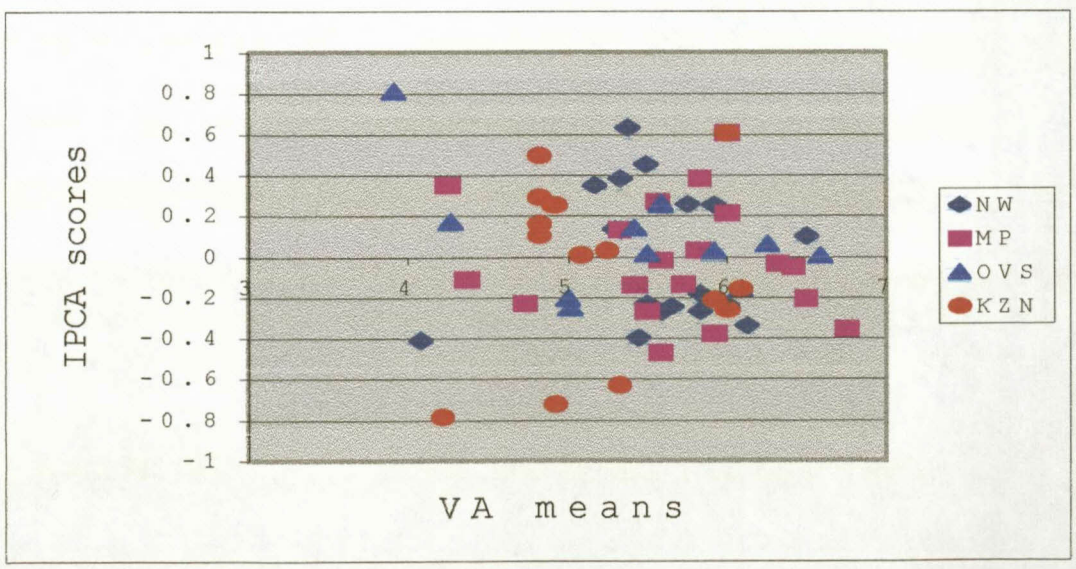


Fig. 7.16. Plot of genotype IPCA1 scores vs means for regions (VA).

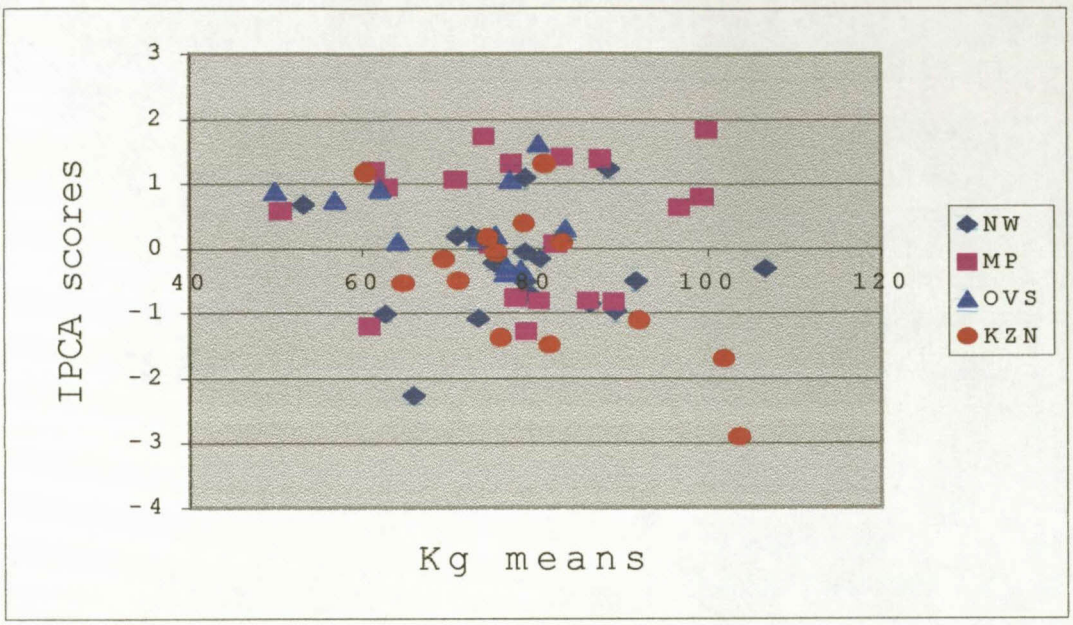


Fig. 7.17. Plot of genotype IPCA1 scores vs means for regions (kg).

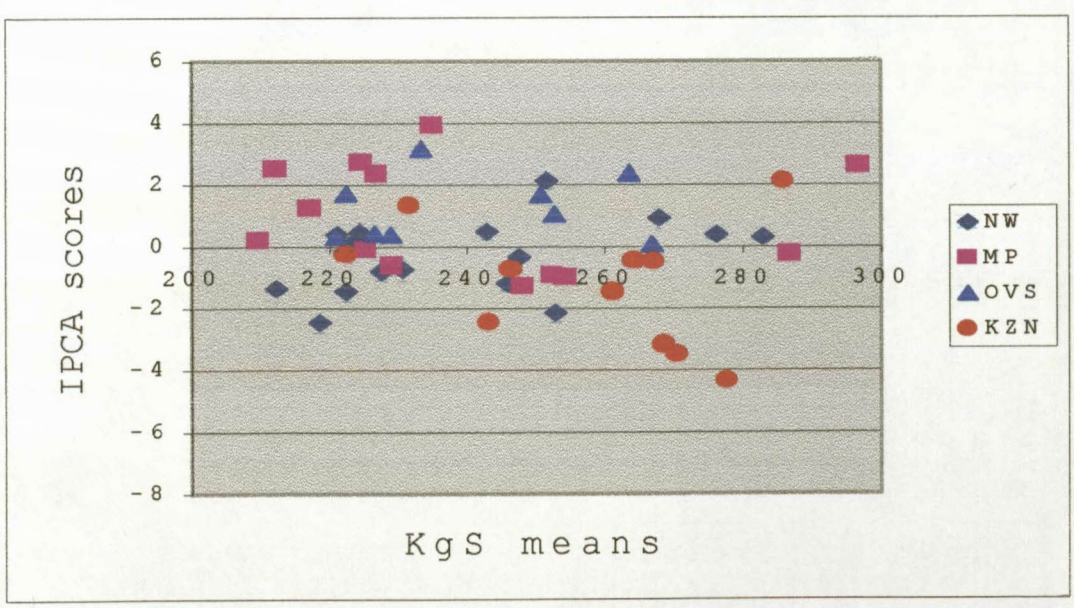


Fig. 7.18. Plot of genotype IPCA1 scores vs means for regions(KgS).

7.4. Discussion

Significant chemical and structural changes occur within the cell during processing. In the canned bean, fracture occurs in the middle lamella, leaving the cell intact and account for the texture differences (Sgarbieri and Withaker, 1982). The protein bodies lose their normal spherical structure due to swelling and denaturation while starch granules demonstrate the deformation, expansion and loss of birefringence associated with gelatinization (Sgarbieri and Withaker, 1982), although the presence of intact cell walls impede conformational changes. A cooked bean flavour develops through the degradation or interaction of native tissue constituents mediated by the Maillard reaction (Uebersax and Ruengsakulrach, 1989).

Uebersax and Ruengsakulrach (1989) stated that exposure to high temperature and humidity storage may potentiate phytase which hydrolyses phytate, thus reducing chelation of the Ca^{++} and Mg^{++} ions within the middle lamella. Pectic substances allow divalent cation cross-linking and thus, forming intercellular polyelectrolyte gels that significantly contribute to the textural quality (Uebersax and Ruengsakulrach, 1989). The separation of

bean cells during cooking can be related to transposition or removal of divalent cations, particularly calcium and magnesium from bridge positions within the pectinaceous matrix of the middle lamella (Sgarbieri, 1989). Therefore, the higher the percentage Ca in the beans, the more the cation cross-linking and the firmer the texture. Since a previous publication described the canonical correlation between the Ca content and the texture, it is possible that more Ca in the beans resulted in higher texture measurements.

The percentage of carbohydrate, and more specifically the amylose and amylopectin ratio could be influenced by the environment (Reddy *et al.*, 1984; Intriago-ortega *et al.*, 1996). Reddy *et al.* (1984) reported that the gelatinisation temperature is affected by degree of amylopectin branching to the extent that excessive branching diminishes rigidity of the starch granule. High amylose content resists the gelatinization process due to its insolubility in aqueous solutions (Reddy *et al.*, 1984). Environmental influences on the different cultivars could be the influence on the carbohydrate content and the formation of different amylose/amylopectin ratios intercellular.

Hosfield and Uebersax (1980) reported that different

curve shapes were observed with a shear force component, which is involved in the extrusion of beans, and a predominant component due to compression. They reported that the curve types appear to be a characteristic of the genotype and that a curve with a large shear force component result when a component within a product causes an excessive pressure requirement in order to bring the product to a yield point prior to extrusion.

Binder and Rockland (1964) reported a compression-type curve for cooked lima beans when seed coats are removed and a curve with a large shear component when bean coats were intact. This indicated that the texture measured by the peak of the texture curve (Kg) could be an indication of the texture of the seed coat. The total force needed for extrusion as measured by the area underneath the texture curve (KgS) could be an indication of the texture of the cotyledons of the beans.

A reduced water uptake would be expected when the cell walls are strengthened, due to cation cross-linking, and this would result in increased mechanical resistance to cellular swelling and reduced water binding capacity of dissolved solutes due to leakage into the soaking medium respectively (Del Valle *et al.*, 1992). Increased

mechanical resistance to cellular swelling and reduced water binding capacity could also indicate a significant influence on the texture of the processed beans.

Phenolic acids have been recognised to influence quality of dry bean during storage and subsequent thermal processing due particularly to reaction and cross-linking with proteins. Storage of dry beans at high temperature and humidity conditions will result in "hard-to-cook" (HTC) phenomenon. This defect, characterised by extended cooking time required for adequate cotyledon softening, is distinguished from a defect termed "Hard shell". Although the beans harvested for this study were not exposed to high temperatures or high humidity conditions in order to eliminate the hard-to-cook phenomenon, this is an indication that phenolic acids could also be responsible or partly responsible for the environmental influence.

7.5. Conclusions

Seed size and water absorption during soaking of the various cultivars was predominantly genetically determined. It does, however, appear that disease infestations can influence the seed size significantly.

The differences in water absorption between cultivars could be ascribed to different factors. The first factor was the influence of the seed coat on water absorption. Seed coat thickness can be genetically determined, or by the environment. The second factor was the size and the shape of the starch granule, which is determined mainly genetically. The third factor was the amylose/amylopectin ratio in the seeds. This ratio was also determined genetically. Since the literature indicates that the accumulated rainfall influences the carbohydrate content during the reproductive phase, the environment could thus influence the water absorption.

These environmental influences are evident in the graphical displays (biplots) of the different localities since KwaZulu-Natal locations always grouped together with smaller seed size and higher SBM and lower WDM.

The smaller seed sizes of KZN localities could be due to the high incidence of various diseases in the KZN region during all three seasons. The grouping of localities of the 1994/95 season for the WDM, could be due to drought conditions that prevailed during the reproductive phase, since the mean WDM was lower in this season.

The visual appearance as well as the two texture measurements was predominantly genetically determined although there were significant environmental influences that differed between localities and between seasons. There were definite cultivar differences and this implied that these quality traits could be used for selection criteria.

The difference between the choice grade and standard grade cultivars could be the difference in the chemical composition of the middle lamella, seed coat thickness, starch contents, or pectic substances with different reactions to environmental influences. This will result in a thicker seed coat or the insoluble metal-pectin complex formed in the middle lamella, which may result in a harder texture.

The starch content and the amylose/amylopectin ratio could also influence the texture since a high amylose content resists the gelatinization process while high amylopectin results in excessive branching and diminishing rigidity of the starch granule.

The difference between cultivars could therefore be a complex effect of the chemical and structural

composition, which is genetically determined, and the changes that occur during processing within the seed coat as well as the cotyledons. The environmental influences could be any factor such as the rainfall, minimum temperatures, soil pH and fertilising of the trials on the different localities that influenced the chemical composition.

CHAPTER 8

CONCLUDING DISCUSSION

The canning quality of dry bean cultivars in South Africa is important because the processors need cultivars with acceptable canning quality in order to provide an acceptable product to the consumers. If the producers do not have at their disposal cultivars with an acceptable canning quality, the processors have to import beans. The producers then have no choice but to produce non-canning types, i.e. sugar beans, haricot and cariocas.

Dry bean breeders need suitable screening methods to provide information on the canning quality of small white bean breeding populations and enable them to make effective selection decisions in strategy. A micro-canning method, assessing water absorption, visual appearance and texture as quality traits was developed and compared to the commercial processing procedures used in South Africa.

It was necessary to determine all parameters that influence the canning quality of the small white beans in tomato sauce, as well as the component interrelationships between the different traits. In order to achieve this, 22 sensory and

physico-chemical traits were evaluated to identify the most important traits. Correlations, principal factor and principal component analyses showed that the most important factors are seed size, water absorption, visual appearance and texture. The colour of the beans is not important in South Africa since the colour of the tomato sauce masks the natural colour of the beans.

The canning quality attributes are related to each other but low correlation coefficients indicated that selection for the measured traits should be carried out independently. However, no single parameter could explain variation in seed yield and canning quality attributes.

The chemical composition of the dry seeds may influence the canning quality of the genotypes under selection. For example the percentage potassium (K^{2+}) in the dry seeds influenced the water absorption. Lower levels of percentage potassium available in the seed will enhance the water absorption, and to a lesser degree a firmer texture and a better visual appearance. On the other hand, higher percentage calcium (Ca^{2+}) in the seed enhances greater cation cross-linking. Pectic substances allow divalent cation cross-linking and thus, forming intercellular polyelectrolyte gels that significantly contribute to the textural quality.

In this study canonical variate analysis (CVA) was used when it was more important to show differences between groups, than between individuals. Through the use of CVA, the cultivars Teebus and Kosi (choice grade cultivars) were most similar, and cultivars Kamberg (unacceptable cultivar) and Kosi (choice grade cultivar) most dissimilar, and the variation between groups accounted for 87.0% of the total variation.

The canonical variate analysis provided a method to distinguish between choice grade, standard grade and unacceptable cultivars. Applying the model described to independent data sets resulted in co-ordinates that differentiated the cultivars as choice grade, standard grade or unacceptable cultivars.

The extent of genetic variation is important for the breeder since it will help him to select breeding parents. Significant differences between the small white canning bean and coloured bean classes for most of the quality traits were found. When coloured bean genotypes were used to incorporate certain agronomically important characteristics, the canning quality of the offspring must be determined.

Significant interactions between genotypes, environments and seasonal effects for canning quality traits, indicated those cultivar responses to variation in localities and seasons

differed. Seasonal effects exerted a major influence on the seed development of the different cultivars. In South Africa the production areas differed widely in soil pH, fertility, rainfall, minimum and maximum temperatures and GE interactions were found. GE must be considered when formulating a strategy for breeding dry beans for canning quality. Environmental effects resulted in inconsistent quality measurements since the trait expression is strongly influenced by the GE interactions.

All traits were shown to have a large genetic component except the WDM, which had a larger environmental component in the GE interaction. Differences in water absorption between cultivars could be a result of seed coat thickness, the size and shape of the starch granule or the amylose/amylopectin ratio in the seeds. Since these all are quantitative traits, the environmental effect largely masks the inherent genetic component.

The differences between the choice grade and standard grade cultivars could be related to the differences in the chemical composition of the seed. The calcium content of the middle lamella, seed coat thickness, starch contents and pectic substances could be influenced by different environmental conditions. This could result in a thicker seed coat, or an insoluble cation-pectin complex formation in the middle

lamella, which can result in a firm texture. The starch content and the amylose:amylopectin ratio could also influence the texture, since a high amylose content resists the gelatinization process, while high amylopectin results in excessive branching and diminishing rigidity of the starch granule.

From the results in this study the difference between cultivars could therefore be due to a complex interaction of the chemical and structural composition, which is genetically determined, and the changes that occur during processing within the seed coat as well as in the cotyledons. The environmental influences could relate to any factor, such as the rainfall, minimum temperatures, soil pH and fertility of the soil that influenced the chemical composition.

By the use of AMMI analyses, KwaZulu-Natal was grouped separately as a region for all measured traits, while the rest of the localities in SA were grouped together. This could be caused by the effect of a higher disease incidence in the KwaZulu-Natal localities. However, the higher minimum temperatures and lower soil pH might have also influenced the canning quality. As a result of this, it is recommended that no quality evaluations be done in this region in future on beans for use in breeding programs.

Due to external factors, quality traits showed large variation from year to year, thus breeding material should be tested for more than one year in order to select the superior and more stable lines.

Emanating from this, the GE interactions can not be ignored, and the utilisation of mean values over different localities will result in slower genetic progress. The elimination of the canning quality evaluations of KwaZulu-Natal could improve the genetic progress made in finding a cultivar with overall adaptability.

Considering all the information generated in this study, the following overall recommendations can be made:

- Due to the interactions found between KwaZulu-Natal on the one hand and the other regions on the other, consideration have to be given to demarcating one or two particular areas in South Africa, for the exclusive production of small white canning beans. The production areas, Eastern Free State and Mphumalanga, can be used, where the beans are also agronomically adapted.
- Regarding the breeding programme, quality tests on the breeding material should be limited to areas supplying useful information from year to year, e.g. Free State and Mphumalanga. Yield testing and disease evaluation should, however, be continued in the other areas in order to

evaluate adaptation.

- ❖ The third option is to exploit the interactions by breeding for specific adaptation in a region or homogeneous area. For example, if a low soil pH influence the texture of the processed beans selection for low pH tolerance can be done on a locality with low pH soils.

Another option is to use the best homogeneous area for the production of small white beans for canning. On the other hand, the crossover interactions could be eliminated and the breeding program could be simplified with such a decision.

SUMMARY

It is important to the producers, processors and consumers in South Africa to have dry bean cultivars with acceptable canning quality. Therefore, dry bean breeders needs suitable screening methods to evaluate the various lines at an early stage (F4) when only small amounts of seed are available.

A micro-canning method to evaluate canning beans in tomato sauce has been developed and compared to the commercial processing procedures with comparable results. External factors that influenced the canning quality like the water quality were investigated. This micro-canning method could therefore be used to investigate the effect of genotype and environment interactions that significantly influenced the canning quality.

The objectives of this study were to:

- Evaluate different genetic material for use as parents in the breeding program.
- To obtain a better understanding of canning quality characteristics of beans and to ensure that the most important characteristics are evaluated and the component interrelationships.

- Determine the genotypic, environmental and genotype x environment interactions that influenced the canning quality.
- To ascertain the patterns of interrelationships of the canning quality parameters and chemical analysis.
- To investigate the patterns and relationships between standard and choice grade cultivars.
- To investigate stability of localities between seasons as well as the clustering of different environments and seasons.

Small seeded white beans, carioca and yellow haricot beans were used to determine variability in canning quality but as a result of a lower canning quality of coloured beans, only small seeded white beans were used for further investigations.

As a result of the investigations of different characteristics, only the seed size, water absorption during soaking and canning, the texture and subjective visual appearance evaluations were used to determine canning quality. These characteristics were interrelated but no single parameter could explain variation in canning quality. Canonical correlation analysis was used to determine to what extent variation of chemical components was responsible for differences in canning quality and these results indicated

that mainly potassium and calcium would influence the water absorption and texture, respectively.

Canonical variate analysis was used to determine the difference between unacceptable, standard and choice grade cultivars. A model was described from these analysis that could be applied to independent data sets that results in coordinates that differentiates the lines or cultivars as unacceptable, standard and choice grade.

Significant interactions between genotype, environmental and seasonal effects for canning quality traits indicated that cultivar responses to variation in localities and seasons differ. Environmental effects resulted in inconsistent quality measurements since trait expression is strongly influenced by genotype x environment interactions.

Results from this study suggested that the difference between cultivars could therefore be due to a complex interaction of the chemical and structural composition, which is genetically determined and influenced by the environment, as well as the changes that occur during processing.

The Additive Main Effects and Multiplicative Interaction (AMMI) model mainly grouped KwaZulu-Natal separately as a

region with poor canning quality. The rest of South Africa's localities grouped different for each season.

Resulting from this investigation, several recommendations can be made:

- Breeding material should be tested for more than one season in order to select superior and more stable lines.
- Elimination of canning quality evaluations of KwaZulu-Natal could improve the genetic progress.
- Exploitation of the interactions by breeding for specific adaptation in a region of homogeneous area.

Demarcating one or two areas in South Africa for the exclusive production of small white canning beans could improve the overall canning quality of the small white bean production in South Africa.

OPSOMMING

Dit is belangrik vir die produsente, prosesseerders en verbruikers in Suid-Afrika om droëboon kultivars met 'n aanvaarbare inmaakkwaliteit tot hulle beskiking te hê. Die droëboonteler moet dus verskillende lyne in die teelprogram reeds in 'n vroeë staduim toets wanneer slegs klein hoeveelhede saad beskikbaar is.

'n Mikro-inmaakmetode om kleinsadige wit bone in tamatiesous te toets is ontwikkel en vergelyk met die kommersiële prosesserings metodes met aanvaarbare resultate. Eksterne faktore wat die inmaakkwaliteit beïnvloed soos die water kwaliteit is ook ondersoek. Die mikro-inmaakmetode is dus gebruik om die effek van die genotipe en omgewings interaksies wat die inmaak kwaliteit betekenisvol beïnvloed te ondersoek.

Die doel van hierdie studie was om:

- Genetiese materiaal te evalueer vir die gebruik in die teelprogram as ouers.
- Inmaakkwaliteits eienskappe van die bone te ondersoek om sodoende te verseker dat net die belangrikste eienskappe geëvalueer word en om vas te stel wat is die interverwantskappe.

- Genetiese, omgewings en die genetiese en omgewings interaksies wat die inmaakkwaliteit beïnvloed te bepaal.
- Om te bepaal wat is die interverwantskappe tussen die inmaakkwaliteit en die chemiese komponente.
- Om die tendense en verwantskappe tussen standaard- en keurgraad cultivars sowel as die onaanvaarbare cultivars te bepaal.
- 'n Ondersoek na die stabiliteit van lokaliteite van siesoen tot seisoen asook die groeperinge van verskillende omgewings en seisoene te bepaal.

Klein wit inmaakbone, carioca en geel haricot bone is gebruik om variëteit se inmaakkwaliteit te bepaal maar as gevolg van 'n swak inmaakkwaliteit van die gekleurde bone is besluit dat verdere ondersoeke slegs op die wit bone gedoen sal word.

As 'n resultaat van die navorsing van verskillende eienskappe is slegs die saadgrootte, waterabsorpsie gedurende week en inmaak, die tekstuur en 'n subjektiewe visuele voorkoms evaluering gebruik vir die bepaling van inmaakkwaliteit. Hierdie eienskappe is verwant aan mekaar maar daar is nie een parameter wat die variasie in inmaakkwlaiteit kan definieer nie. Kanoniese korrelasie analise is gebruik om vas te stel tot watter mate die chemiese komponente verantwoordelik was vir die verskille inmaakkwaliteit en hierdie resultate het

aangedui dat kaluim en kalsuim die water absorpsie en tekstuur, repektiewelik, beïnvloed.

Kanoniese veranderlike analise is gebruik om die verskille tussen onaanvaarbare, standaard en keurgraad cultivars te ondersoek. 'n Model is bereken sodat onafhanklike koördinate bereken kan word om sodoende die cultivar as keurgraad, standaardgraad of onaanvaarbaar te klassifiseer.

Betekenisvolle interaksies tussen genotipe, omgewings en jaar effekte vir inmaakkwaliteits eieskappe het getoon dat cultivar reaksies op veranderinge in die omgewings en seisoene verskil. Omgewingseffekte veroorsaak onstabiliteit in die inmaakkwalitet aangesien uitdrukking van sekere genetiese eienskappe baie beïnvloed word deur die genetiese en omgewings interaksies.

Resultate van hierdie studie dui dus daarop dat die verskille tussen die inmaakkwaliteit van die cultivars 'n komplekse interaksie is van die chemiese en strukturele samestelling wat genetiese bepaal word, maar deur die omgewing beïnvloed word, sowel as veranderinge wat gedurende prosessering voorkom. Die AMMI model ("Additive Main Effects and Multiplicative Interaction") het hoofsaaklik getoon dat KwaZulu-Natal apart groepeer met 'n deurgaans swak kwaliteit. Die res van Suid-Afrika se lokaliteite groepeer saam. Lokaliteite vir 'n

spesifieke seisoen kan ook saam groepeer vir sekere eienskappe.

Vanuit hierdie studie kan dus aanbeveel word dat:

- Die teelprogram se materiaal vir meer as een seisoen getoets moet word om die goeie en stabiele cultivars te verkry.
- Die inmaakkwaliteit evaluerings vir die KwaZulu-Natal gebied uitgelaat moet word om sodoende genetiese vordering te versnel.
- Die interaksies wat die inmaakkwaliteit beïnvloed moet tot voordeel van die teelprogram gebruik word deur cultivars te kry wat vir spesifieke homogene areas aangepas is.
- Ten einde die omgewingsinteraksies uit te skakel kan sekere homogene areas in Suid-Afrika gekies word vir die produksie van kleinsadige wit cultivar spesifiek vir die gebruik as inmaak bone om sodoende te verseker dat die prosesserders altyd goeie kwaliteit inmaakbone tot hulle beskikking het en die produsente goeie pryse ontvang vir hulle produkte.

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