DEVELOPMENT AND APPLICATION OF A SMALL-SCALE CANNING PROCEDURE FOR THE EVALUATION OF SMALL WHITE BEANS *(PHASEOLUS VULGARIS)*

BY

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SLEUTELWOOORDE

Industriële inmaak, inmaakkwaliteit, inmaakparameters, inmaaktegnieke, inmaakvoorspellingsmodel, kanoniese variansieanalise kleinwit droëbone, kultivarevaluasie, laboratorium inmaak, , *Phaseolus vulgaris,* teelmonsters

LIST OF ABBREVIATIONS

ANOVA	-	Analysis of variance
B/T	-	Broad/thickness ratio
Ch UI	-	Chymotrypsin inhibitor unit
CTIA	-	Chymotrypsin Inhibiting Activity
CV	-	Coefficient of variance
CVA	-	Canonical variate analysis
CV 1	-	Canonical variate 1
CV 2	-	Canonical variate 2
FS	-	Free State
GP / MP	-	Gauteng / Mpumalanga
HTC	-	Hard-to-cook
HC	-	Hydration coefficient
H^2	-	Heritability
ICT	-	Industrial canning technique
KZN	-	KwaZulu Natal
L/B	-	Length/breadth ratio
LCEP	-	Laboratory canning evaluation procedure
LCT	-	Laboratory canning technique
MC	-	Moisture content
MCEP	-	Modified canning evaluation procedure
MCT	-	Modified canning technique
NW / NC	-	North West / Northern Cape
PWDWT	-	Percentage washed drained weight
PWDWT1	-	Percentage washed drained weight 24 h after canning
PWDWT2	-	Percentage washed drained weight 7 days after canning
RMSE	-	Root mean square error
100SM	-	Hundred seed mass
SPLT1	-	Splits (kg 100 g^{-1} 12 s^{-1})
SPLT2	-	Splits (kg s^{-1})
TIA	-	Trypsin Inhibiting Activity
TUI	-	Trypsin inhibitor unit
TXT1	-	Texture (kg 100 g^{-1} 12 s^{-1})

TXT2	-	Texture (kg s^{-1})
VA	-	Visual appearance
WDWT	-	Washed drained weight
WU	-	Water uptake

CONTENTS

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CHAPTER 1
LITERATURE REVIEW

1.1 INTRODUCTION

Dry beans serve as an important source of protein throughout the world (Barampana & Simard, 1993). *Phaseolus vulgaris* (common bean) is the most-consumed dry bean species (Sgarbieri, 1989). In less developed countries, such as Central and South America, beans are consumed as a staple food for their protein value (Bolles *et al*., 1990). Poor and middle-income families (Bolles *et al*., 1990) in countries with a shortage of animal protein (Koehler *et al*., 1987), often consume dry beans for this reason, since legume proteins are much cheaper than protein from animal sources (Iyer *et al*., 1980). Dry beans are also a valuable source of dietary fibre (Wang & Chang, 1988), carbohydrates (Mbofung *et al*., 1999), certain vitamins (Hosfield, 1991; Mbofung *et al*., 1999), minerals (Hosfield, 1991) and energy (Antunes & Sgarbieri, 1980; Hosfield, 1991). Dry beans are at the same time low in fat (especially saturated types) and Na and contain no cholesterol (Morrow, 1989). Despite often being referred to as the "poor people's" diet, the health benefits beans are recognized in the USA by the American Heart Association, American Cancer Society and the American Diabetes Association (Morrow, 1989). Cooking of dry beans is necessary to tenderise the seed coat and cotyledons, to develop acceptable flavour and texture and to make bean protein nutritionally available (Rockland & Jones, 1974; Rodríguez-Sosa *et al*., 1984).

Dry beans are generally subjected to various treatments, such as storage under different environmental conditions, soaking in water or salt solutions, cooking at normal or elevated pressure, frying after cooking prior to consumption (Sgarbieri & Whitaker, 1982) or germinated and cooked beans (Reddy *et al*., 1984). In South Africa small white beans are canned in tomato sauce and sold as "baked beans" (De Lange & Labuschagne, 2000). About 20 % of the total South African dry bean harvest is annually used for canning. This indicates that that about 14 000 ton of dry beans with an approximate rand-value of 59 million are expected to be used by the canning industry during the 2003/04 crop season. In the UK canned navy beans are called "baked beans" (Malcolm McIntyre Consultancy, 1988). The latter are mainly eaten on toast, as a snack or as a side dish with grilled or fried food (Malcolm McIntyre Consultancy, 1988). Canned beans are also used in soups and cold salads (Machiorlatti *et al*., 1987).

Consumers of dry beans have certain sensory and palatability requirements that must be met in order to be acceptable (Hosfield *et al*., 1984a). Consumers are especially aware of the texture, intactness, colour (Faris & Smith, 1964; Hosfield *et al*., 1984b), appearance and digestibility (Hosfield *et al*., 1984b) of beans. Ease of preparation (Hosfield *et al*., 1984b; Giami & Okwechime, 1993) and the saving of cooking fuel are also important. Bean cultivars that take a longer time to soak and cook will therefore be rejected (Giami & Okwechime, 1993). Processors of beans are constrained by consumer preferences, but they also require beans to be easy to cook, to be processed efficiently (Hosfield *et al*., 1984b; Walters *et al*., 1997) and deliver high processor yields (Walters *et al*., 1997).

While many positive aspects of dry beans contribute to their successful marketing, some dry bean properties limit its popularity. The long cooking time and consequent high-energy requirements for dry bean preparation present one such a property (Stanley & Aguilera, 1985). Aspects that should receive attention in order to market dry beans successfully were identified by Uebersax *et al*., (1991) as the following:

1. Improvement of nutrient content (e.g. sulphur containing amino acids)
2. Improvement of digestibility.
3. Reduction of antinutritional factors (e.g. enzyme inhibitors). These factors could be reduced, inactivated or eliminated by soaking (discussed in 1.6.2.1), blanching (discussed in 1.6.3.1) and / or cooking (discussed in 1.6.2.3).
4. Reduction of flatus production factors (e.g. oligosaccharides). Compounds causing flatulence are decreased during the soaking and autoclaving steps of the canning process as discussed in 1.6.5.3 and 1.6.2.3 respectively.
5. Control over quality problems induced by storage (e.g. hard-to-cook beans). Hard-to-cook beans could affect the canning quality of beans

directly, but are eliminated by the soaking and cooking process, as well as other processing procedures.

6. Canned bean products could offer some solutions for the problem of long preparation times, as it offers the consumer an already prepared product.

All these factors could have an impact on the canned bean industry and resistance towards bean products. The latter four could possibly be of greater importance in the canned bean industry. The canner of dry beans have to consider these problems, as they are continually striving towards improved consumer support (Dajani, 1977).

1.2 CHEMICAL COMPOSITION OF DRY BEANS

As mentioned in 1.1, dry beans are a valuable source of nutrients, such as proteins, carbohydrates, dietary fibre, minerals, vitamins and energy.

1.2.1 Protein and amino acids

The protein content of legumes is provided in Table 1.1. Hosfield & Uebersax (1980) classified dry bean protein contents of 22 % as acceptable and 31 % as superior.

Table 1.1 Ranges in protein content of legumes and dry beans

Observation	Percentage protein	
	Minimum	Maximum
Legumes (Iyer *et al*., 1980)	20.0	30.0
Legumes (Stanley & Aguilera, 1985)	20.0	40.0
Phaseolus vulgaris (Hsieh *et al*., 1992)	22.9	28.7
Ten types of dry bean (Deshpande *et al*., 1984)	18.1	24.4
Thirty six dry bean cultivars (Koehler *et al*., 1987)	19.6	32.2
Eighteen samples of small white beans (Heinen & Van Twisk (1976)	20.0	21.0
Four small white bean cultivars (Koehler *et al*., 1987)	21.1	23.1

The proteins mainly found in common beans, are albumins (soluble in deionised water) and globulins (soluble in diluted salt solutions). More than 80 % of total nitrogen in beans is extractable in a 0.25 to 0.50 *N* NaCl solution. The remaining proteins, which are mostly glutelins and structural proteins bound to cell membranes and organelles, are extractable using strong acids or bases (Sgarbieri, 1989).

About 80 % of the total proteins found in legumes are storage proteins. These proteins serve to supply the young seedling with nitrogenous compounds and amino acids (Stanley & Aguilera, 1985). Another function of legume proteins is the important role they play in water uptake in the later stages of soaking (Sefa-Dedeh & Stanley, 1979). The ranges in amino acid content of dry beans are provided in Tables 1.2. Dry bean cultivars are deficient in sulphur-containing amino acids (Gupta, 1982), such as methionine and cystine and have small deficiencies in valine, leucine, isoleucine and threonine (Koehler *et al.*, 1987). The cysteine deficiency is of special significance, since methionine is synthesised via cysteine, when levels of the first are deficient (Koehler *et al.*, 1987), and cystine and cysteine therefore have a sparing effect on methionine utilisation by animals (Sgarbieri & Whitaker, 1982). All dry bean cultivars are good lysine sources, indicating that dry beans could be added to lysine-deficient cereal products (Sgarbieri & Whitaker, 1982; Koehler *et al.*, 1987), while cereal products in turn provide higher proportions of sulphur-containing amino acids (Sgarbieri & Whitaker, 1982).

Table 1.2 Ranges in amino acid content of four varieties of dry bean (Barampana & Simard, 1993)

Amino Acid	**Amino acid content (mg.g^{-1} dry bean powder)**	
	Minimum	**Maximum**
Isoleucine	5.95	9.01
Leucine	10.98	17.57
Lysine	10.47	15.83
Methionine	0.64	2.31
Phenylalanine	6.90	11.98
Threonine	7.38	10.95
Valine	8.08	10.02

Proteins in dry beans are of great nutritional value, but biological utilisation is limited due to:

1. Deficiency of sulphur-containing amino acids (Antunes and Sgarbieri, 1980).
2. Presence of several antinutritional and toxic components (Antunes & Sgarbieri, 1980), which will be discussed in 1.2.6.
3. Low digestibility of bean proteins (Antunes & Sgarbieri, 1980).
4. The different degrees of heating required by different preparation techniques of beans affect the protein quality and digestibility (Reddy *et al*., 1984). Crude protein leaching into the canning medium also results in starchiness of the medium, thereby decreasing the quality of the product (Lu & Chang, 1996). The objective of breeding should therefore be to obtain high protein retention and not merely high protein contents (Wassimi *et al*., 1988).

1.2.2 Carbohydrates

Legume seeds are good sources of carbohydrates (Stanley & Aguilera, 1985; Koehler *et al*., 1987) (Table 1.3). These carbohydrates are classified as water-soluble (e.g. sugars and certain pectins) or insoluble (e.g. starch and cellulose). From both groups some carbohydrates can be utilised as human energy sources, while others cannot be utilised, due to their resistance to human digestive enzymes (Kadam *et al*., 1989).

Table 1.3 Carbohydrate content and composition of legumes and dry beans

Observation	Percentage	
	Minimum	Maximum
Carbohydrates		
Legumes (Kadam *et al*., 198)	24.0	68.0
Legumes(Stanley & Aguilera, 1985)	60.0	70.0
Ten dry bean cultivars (Deshpande *et al*., 1984)	70.8	76.2
Phaseolus vulgaris (Hsieh *et al*., 1992)	65.9	71.6
Starch		
Legumes (Stanley & Aguilera, 1985)	30.0	40.0
Legume flour (Naivikul & D'Applonia, 1979)	33.8	41.9
Six types of dry bean (Su & Chang, 1995)	34.0	45.0
Sugars (five types of raw legume) (Jood *et al*., 1985)		
Sucrose	1.2	1.6
Raffinose	0.8	1.1
Stachyose	0.8	2.5
Verbascose	2.6	3.4
Unavailable polysaccharides		
Four legumes (Kamath & Belavady, 1980):		
Unavailable carbohydrates	15.2	25.6
Non-cellulose polysaccharides water-soluble	0.9	2.4
Non-cellulose polysaccharides insoluble	5.6	8.7
Cellulose	4.6	13.7
Legumes crude fibre (Flemming, 1981)	3.0	4.5
Four types of dry bean crude fibre (Meiners *et al*., 1976)	6.3	7.0

1.2.2.1 Starch

Starch is the major carbohydrate fraction in dry beans (Reddy *et al*., 1984). Table 1.3 provides the starch content of dry bean and legumes. Starch is mainly found in the bean cotyledon as granules embedded in a proteinaceous matrix (Aguilera & Steinsapir, 1985; Kadam *et al*., 1989), with 39.3 % of the cotyledon composed of starch on a dry basis (Powrie *et al*., 1960).

Starch granules are composed of a mixture of amylose and amylopectin (Kadam *et al*., 1989), with a range of 19.5 to 25.8 % amylose (Naivikul & D’Applonia, 1979). Initial pasting temperatures of 77 °C for navy and pinto bean starches are found, but no pasting viscosity peaks as in the case of wheat flour (Naivikul & D’Applonia, 1979). Legume starch contains 0.06 to 0.07 % nitrogen, 0.22 to 0.52 % fat, 0.05 to

0.26 % acid-detergent fibre and 78.2 to 92.4 % water binding capacity (Naivikul & D'Applonia, 1979).

1.2.2.2 Sugars

Legumes contain higher sugar levels than the 1 to 5 % found in cereals (Kadam *et al*., 1989). Mono- and polysaccharides, including oligosaccharides, are distributed throughout the seed (Stanley & Aguilera, 1985). Some monsosaccharides present in legume seeds are glucose, fructose, galactose, xylose, rhamnose and arabinose (Flemming, 1981). Stachyose is the major oligosaccharide in dry beans, while raffinose occurs in moderate to low levels (Reddy *et al*., 1984).

Flatulence, caused by dry bean ingestion, is primarily due to the raffinose family of the oligosaccharides, including stachyose and verbascose (Iyer *et al*., 1980), while sucrose is also associated with gas-producing factors (Gupta, 1982). Raffinose, verbascose and stachyose induce flatus in mammals, due to the absence of enzymes to hydrolyse these sugars (Flemming, 1981) in the upper human digestive tract. These sugars are fermented in the large intestine by microflora, which produce hydrogen, carbon dioxide and methane that result in flatulence (Olson *et al*., 1982).

1.2.2.3 Unavailable polysaccharides

Polysaccharides of plant cell walls, composed of dietary fibre, are also known as 'unavailable' polysaccharides (Table 1.3). Available carbohydrates (mono- and oligosaccharides, dextrins and starches) are digested by enzymes from the endogenous secretions of the gastro-intestinal tract and absorbed. Contrasting to these, unavailable carbohydrates are resistant to enzymatic digestion and are degraded by colonic microflora to mainly free fatty acids (Kamath & Belavady, 1980).

Unavailable carbohydrates are composed of non-cellulose polysaccharides, cellulose, lignin (Kamath & Belavady, 1980) and hemicelluloses (Kadam *et al*., 1989) and many of these are composed of D-mannose and D-galactose, found only in legume seeds (Kadam *et al*., 1989). Alpha-cellulose and lignin, together with pentosan are the major components of the seed coat of dry beans (Muller, 1967). The seed coat contributes about 7.7 % to the dry matter of mature beans (Powrie *et al*., 1960) and forms the outermost layer of the seed (Kadam *et al*., 1989). The crystalline nature of cellulose provides the seed coat with rigidity (Srisuma *et al*., 1991), while the cellulose and lignin compounds are the source of the strong physical properties of the seed coat and its protective function (Srisuma *et al*., 1991).

Non-cellulose polysaccharides (mainly constituted from hexoses in legumes) are classified as water-soluble and insoluble (Kamath & Belavady, 1980). Common beans have insoluble and soluble dietary fibre contents of 20.3 % and 3.7 % respectively (Hsieh *et al*., 1992). Many of the water-soluble polysaccharides have swelling and gelling abilities in water (e.g. guar gum from cluster beans) (Kadam *et al*., 1989). Hexoses, pentoses and uronic acids are formed via hydrolysis from both water-soluble and insoluble non-cellulose polysaccharides (Kamath & Belavady, 1980). The soluble pectin content in both canned and raw beans correlates significantly (r = –0.97), with the firmness of canned navy beans (Wang *et al*., 1988). Beans with high soluble contents would therefore produce less firm beans, when canned in the absence of $CaCl_2$ (Chang, 1988).

1.2.3 Lipids

The total lipid content of legumes is mostly lower than 2 % (Table 1.4). Lipids in dry beans are mainly found in the embryo axis, with lipid content 3.11 %, while the cotyledons and seed coat contain 1.65 and 0.48 % respectively (Powrie *et al*., 1960). Muller (1967) also found lipids to be a minor component in the seed coat. Lipids in the seed coat are likely to be present in the form of a wax-like material (Powrie *et al*., 1960).

Table 1.4 Ranges in total lipid content of dry beans

Observation	Percentage total lipids	
	Minimum	Maximum
Four dry bean varieties (Barampana & Simard, 1993)	0.7	1.3
Four dry bean types (Meiners *et al*., 1976)	1.0	1.5
Ten dry bean types (Deshpande *et al*., 1984)	1.1	2.0

Table 1.5 Total lipid, fatty acid and sterol composition of dry beans (Drumm *et al*. 1990)

Component	Percentage
Lipid fractions	
Neutral lipids	1.39
Glyco lipids	0.20
Phospholipids	1.01
Fatty acids (as % of total lipid)	
Linolenic	35.00
Linoleic	33.23
Oleic	11.88
Palmitic	15.39
Stearic	2.03
Sterols (as % of total sterols)	33.00
B-sitosterol	17.66
Stigmasterol	11.00
Campesterol	4.32

The lipid fractions and fatty acid composition of dry beans are provided in Table 1.5. Due to the unsaturated lipids of legumes with a high oxidation potential, off-flavours and odours could develop during storage (Stanley & Aguilera, 1985). The role of dry bean lipids in flavour development during processing are assumed little, due to the low levels found (Drumm *et al*., 1990).

1.2.4 Minerals

Legumes are an important source of minerals, such as Ca, Mg, Fe, Zn and K (Iyer *et al*., 1980). More specifically, dry beans are an excellent source of K and good source of Fe, Cu, Zn, P and Mg (Sgarbieri, 1989). The ash and mineral content of dry beans is given in Table 1.6. The seed coat tissue of dry beans displays the highest ash content (8.44 %), followed by the embryo axis (3.58 %) and cotyledon (3.50 %) (Powrie *et al*., 1960).

Table 1.6 Ranges in the ash content and mineral composition of dry beans

Observation	Content	
	Minimum	**Maximum**
Percentage ash		
Four types of dry bean (Meiners *et al*., 1976)	2.9	3.5
White beans (Hosfield & Uebersax, 1980)	3.4	4.2
Mineral composition (mg.100 g^{-1})		
Four dry bean varieties (Barampana & Simard, 1993)		
K	442.0	631.0
Ca	24.8	72.6
Mg	28.1	43.8
Fe	6.0	9.5
Cu	0.7	1.3
Zn	6.4	8.8
P	360.0	665.0
Small white beans (Koehler *et al*., 1987)		
K	1118.0	1617.0
Ca	175.0	233.0
Mg	146.0	180.0
Fe	6.5	8.8
Zn	3.0	3.4
P	396.0	502.0

The Ca and Mg content were identified to be related to the firmness of cooked pinto bean (Quenzer *et al*., 1978). Wang *et al*. (1988) however found the Ca content not to correlate well with the firmness of navy and pinto beans, unless $CaCl_2$ were added. Moscoso *et al*. (1984) identified the Ca content of the seed coat to be associated with bean firmness.

1.2.5 Vitamins

Legume seeds are an important source of vitamins, especially B-vitamins, in the human diet (Barampana & Simard, 1993). Dry beans were identified as a good source of vitamins B1, B2, B6, folacin and niacin (Sgarbieri, 1989). Nordstrom & Sistrunk, (1979) also identified dry beans as a significant source of thiamine, but not riboflavin.

Thiamine and riboflavin levels in small white beans vary between 0.727 to 1.010 mg.100 g^{-1} and 0.175 to 0.218 mg.100 g^{-1} respectively. The variability in 36 dry bean cultivars for thiamine and riboflavin was very low (means = 0.748 mg ± 0.15 and 0.189 mg ± 0.03 respectively), but both the vitamin E and riboflavin content were found to be affected by bean type (Nordstrom & Sistrunk, 1979).

1.2.6 Antinutritional factors

Legumes contain toxic substances, such as trypsin inhibitors, phytohaemagglutinins (substances agglutinating and destroying red cells), factors causing lathyrism and favism, cyanogenic factors, goitrogenic factors, saponins and alkaloids (Gupta, 1982). These compounds adversely affect enzyme activity, digestibility, nutrition and health, but many of them could be inactivated or eliminated by processing procedures, such as dehulling, pre-soaking and diffusion, sterilization, steaming and cooking (Elkowicz & Sosulski, 1982). Some important antinutritional factors are discussed in 1.2.6.1 to 1.2.6.4.

Table 1.7 Ranges in levels of antinutritional factors in dry beans

Observation	Content	
	Minimum	Maximum
Tannins		
Cowpea varieties (mg.g^{-1}) (Giami & Okwechime, 1993)	1.03	1.96
Four *Phaseolus vulgaris* varieties (mg catechin equivalent.g^{-1})	0.11	28.78
Trypsin-inhibiting activity		
Four dry bean varieties (TUI x 10^{-3}.g^{-1} protein) (Barampana & Simard, 1993)	4.77	27.98
Phytic acid		
Four dry bean varieties (mg.g^{-1}) (Barampana & Simard, 1993)	12.37	23.60
Soybean, navy and northern beans (mg.g^{-1}) (Elkowicz & Sosulski, 1982)	10.00	12.00
Hemagglutinin		
Four dry bean varieties (HU x 10^{-3}.mg^{-1}) (Barampana & Simard, 1993)	0.40	6.98

TUI = trypsin inhibitor unit

HU = Hemagglutinin unit

1.2.6.1 Tannins

Tannins (Table 1.7) in dry beans describe any naturally occurring phenolic compound with molecular mass of 500 to 3 000, that contains 1 or 2 phenolic hydroxyl or other suitable groups per 100 MW, that enables it to form cross-linkages to proteins and other macromolecules (Ma & Bliss, 1978). These heat resistant substances, which are not destroyed by cooking, interfere with the physiology and utilisation of nutrients by the animal (Sgarbieri, 1989). This is caused by the cross-linkages of tannins to protein, which leads to low protein digestibility and availability in dry beans (Wassimi *et al*., 1988). Tannins could possibly interfere with the biological utilisation of minerals and certain vitamins, but the importance of these reactions has not yet been identified (Sgarbieri, 1989).

Tannins are mainly found in tissues other than cotyledons (e.g. testa) and dark-coloured dry beans generally contain higher tannin levels. White, buff and ivory-white coloured testa beans contain no or very small levels of tannin (Ma & Bliss, 1978). Barampana & Simard (1993) also found higher tannin levels in coloured beans than white beans.

1.2.6.2 Trypsin- and chymotrypsin inhibiting activity (TIA and CTIA)

Trypsin- and chymotrypsin inhibiting activity are measured in trypsin inhibitor units (TUI) and chymotrypsin inhibitor units (Ch UI) respectively (Antunes & Sgarbieri, 1980). Trypsin inhibiting activity is concentrated in the protein fractions of legumes (Elkowicz & Sosulski, 1982). Levels of TIA (Table 1.7) are significantly influenced by variety, locality and variety x locality interaction (Barampana & Simard, 1993).

1.2.6.3 Phytate and phytic acid

The phytic acid content of dry beans is provided in Table 1.7. As in the case of TIA, the phytate content of beans is present in the protein fractions (Elkowicz & Sosulski, 1982). Phytic acid is a chelating agent, which might lower the bioavailability of minerals, such as Zn, Mn, Cu and Fe (Sgarbieri, 1989).

Although phytic acid is regarded as an antinutritional factor in beans, the phytic acid phosphorous content of red kidney beans is an indicator of cookability. This is because phytic acid favours a more rapid rate of dissolution of pectic substances in beans during cooking (Moscoso *et al.*, 1984). Red kidney beans with a phytic acid content of less than 400 mg.100 g^{-1} were experienced as less cookable (Moscoso *et al.*, 1984). Wang *et al.* (1988) found similar results on navy beans and a strong negative correlation (r = -0.89) between firmness and phytic acid phosphorous were observed.

1.2.6.4 Hemagglutinin

Hemagglutinins (Table 1.7) are glucoproteins with the ability to bind saccharides and proteins containing saccharides in a very specific fashion (Sgarbieri & Whitaker, 1982). Phytohemagglutinin activity is a potent biological activity due to its ability to bind complex carbohydrates and other glycoproteins (Coffey *et al.* 1985). The hemagglutinin activity in dry beans is also mainly found in the protein fractions (Elkowicz & Sosulski, 1982).

1.2.7 Other components

A number of volatile components in raw and cooked beans are possible flavour precursors. Two components identified with a possible influence on uncooked bean flavour are oct-1-en-3-ol and hex-*cis*-3-en-ol, while thialdine, *p*-vinylguaiacol, 2,4-dimethyl-5-ethylthiazol and 2-acetylthiazole are important components in cooked bean flavour (Buttery *et al*, 1975).

1.3 PHYSICAL PROPERTIES OF DRY BEANS

1.3.1 Bean defects

Visible defects to beans could affect the physical condition and acceptability of beans to the canner. These include the following: Presence of foreign material, damage due to insects, damage caused by disease, mechanical damage, mould development and bin-burned beans. The producer has to produce clean, wholesome and sound beans, in order to prevent the processor of following highly discriminating policies against poor quality beans during normal crop years (Dajani, 1977).

1.3.2 Moisture content (MC)

Hsieh *et al*. (1992) found the MC of two types of beans to be 13.1 to 15.3 %, 9.7 to 10.8 % and 7.4 to 8.7 % for immature, mature and overmature seeds respectively. Some legumes are consumed in the fresh or immature stage, but most are harvested at a moisture content of 20 % and left to field dry to about 10 % moisture (Stanley & Aguilera, 1985). Moisture content at time of harvest is extremely important, as 12.3 % moisture or less lead to visible damage of navy beans during mechanical harvesting (Barriga, 1961). Moisture content at harvesting is less important in the prevention of split beans in the case of harvesting by hand, than with mechanical harvesting (Forney *et al*., 1990). Harvest moisture is influenced by rainfall conditions and sporadic rainfall caused 'Ruddy' kidney beans to have harvest MC of 18 to 30 % (Forney *et al*., 1990). Too high moisture levels in beans on storage at high temperature cause brown discoloration or off-flavoured beans (Uebersax *et al*., 1991). Storage of high MC beans at high temperature over long periods would lead to poor cookability (Burr *et al*., 1968).

Care should be taken to standardise the initial MC of dry beans with different moisture levels or from different storage conditions before soaking and processing. This is necessary to ensure good, stable canning quality within the same variety and to eliminate the effect of different initial MC values on cotyledon tenderisation during soaking and cooking (Hosfield & Uebersax, 1980). A too low MC at time of processing could lead to water imbibition problems during processing (Nordstrom & Sistrunk, 1979) and affect the rate of water uptake (Hosfield & Uebersax, 1979). Beans that become too dry before soaking become water-impermeable, resulting in poor water uptake. The problem could be overcome by a short blanching period of 1 to 2 min in boiling water before soaking (Priestly, 1978). Too low initial MC of beans lead to brittle seed coats with consequential cracking, thereby delivering a poor quality canned product (Nordstrom & Sistrunk, 1979). Dry beans (11 – 14 % moisture) therefore split more during canning than semi-dry beans (50 – 60 % moisture) (Gonzalez *et al*., 1982). A dry bean MC of 12 to 16 % is suitable for canning purposes (Uebersax *et al*., 1991).

1.3.3 Seed size and dimensions

The hundred seed mass (100SM) of dry beans is the mass of 100 randomly selected seeds (Balasubramanian *et al.*, 1999) and is a function of the seed size (Deshpande *et al*., 1984). Small types of beans (e.g. small white) have low 100SM with mean values of 15.03 g.100^{-1} beans, while larger beans (e.g. dark red kidney beans) have larger mean values of 48.77 g.100^{-1} beans (Deshpande *et al*., 1984). Six small white bean cultivars had mean seed count values per 30 g of 147.7 and ranged from 98 to 227 seeds per 30 g. Cultivar, environment and the cultivar x environment interaction affected these seed count values significantly (De Lange & Labuschagne, 2000). The 100SM is highly correlated with MC of dry beans (Faris & Smith, 1964).

Small seeded dry bean cultivars have lengths of less than 10 mm, while those of large beans are over 15 mm. Breadths vary between 5.41 and 8.71 mm and thickness between 4.60 to 7.47 mm. The length / breadth (L/B) ratio of beans indicate the shape of beans and the long and slender kidney bean have an L/B value of 2.0. The broad thickness (B/T) ratios of dry beans vary between 1.17 to 1.65, with small white beans at the lower and pinto beans at the higher end of the scale (Deshpande *et al.*, 1984). Seed thickness correlate with optimal cooking times of beans, although the correlation coefficient ($r = 0.41$) is not significant (Deshpande & Cheryan, 1986). The rate of water uptake of beans is also related to bean size, as small (white) beans take up water more rapidly than medium- sized beans (black). Large beans (red) display the slowest water uptake rate (Del Valle *et al*., 1992). These results are in contrast with those of Heinen & Van Twisk (1976) who did not find a relationship between seed size and water uptake rate. Deshpande & Cheryan (1986) identified surface area, which is a function of the size and shape of beans, to play a role in the rate of water uptake. These beans did not include different bean types, but only small white beans. Hardshell beans (1.3.8) occur more often among smaller size beans and the incidence of hardshell decreases sharply as seed size increases (Bourne, 1967). It is therefore clear that the size of beans selected for canning purposes, is an important consideration in terms of quality. Beans used for canning purposes should be fully mature and uniform in size (Uebersax *et al*., 1991).

1.3.4 Density and bulk density

Density of dry beans is measured by the displacement of xylene (Deshpande *et al*., 1984) or distilled water (Heil *et al*., 1992) by a given mass of beans. Bulk density is an indication of the volume of a known mass of dry beans in a measuring cylinder (Deshpande *et al*., 1984). The density of 10 types of dry beans were found to vary between 1.21 and 1.36 $g.cm^{-3}$, while bulk density varied from 0.68 to 0.73 $g.cm^{-3}$, with smaller bean types having higher density and bulk density values (Deshpande *et al*., 1984). Red kidney beans contain a large cavity between the two cotyledons, causing a reduction in the density of the beans. The reduction in density would depend on the size of the cavity (Bourne, 1967).

Bulk density of dry bean cultivars correlates positively with fat content (r = 0.76) and negatively with 100SM (r = -0.57). The latter correlation indicates that larger bean types (e.g. kidney beans) would require larger storage space, due to their high mass and low bulk density (Deshpande *et al*., 1984). The higher the density of dry beans, the greater is the damage caused during canning. This indicates that bean density might be an useful indication of damage that can be expected during the canning process (Heil *et al*., 1992).

1.3.5 Hardness

The hardness of dry beans is expressed as the force (in pounds) required to shear each bean in a shear press (Deshpande *et al*., 1984). Hardness values were found to vary from 20.16 to 41.85 lb force.bean^{-1}, with small seeded cultivars (with lengths less than 10 mm), having lower values. The remaining cultivars did not indicate a relationship between seed size and hardness. Fat content correlates negatively with hardness (r = -0.61) for all bean cultivars, indicating that fat might act as a plasticizer that lower the force required to shear beans (Deshpande *et al*., 1984).

1.3.6 Water Uptake (WU)

The purpose of soaking and blanching prior to autoclaving is to ensure uniform and complete WU in order to prevent further expansion of beans in the can. Secondly, soaking prevents the presence of hard seeds in the canned product (Priestly, 1978). The WU rates of dry beans and soybeans are mostly calculated by determining the mass increase of beans with a certain mass after a specific period of soaking (Sefa-Dedeh & Stanley, 1979; Hsu *et al*., 1983; Deshpande *et al*., 1984). The WU process of dry legumes is a complex process of diffusion, accompanied by swelling, while the seed coat and cotyledons display resistance against swelling (Quast & Da Silva, 1977). Swelling of cotyledons during soaking is more than could be attributed to WU alone, which indicates that other factors also play a role in expansion (Uebersax & Bedford, 1980). As mentioned in 1.2.1, legume proteins play an important role in WU in the later stages of soaking (Sefa-Dedeh & Stanley, 1979). Beans that are unable to take up water during soaking are known as ‘non-soakers’ (Edwards, 1995).

Water uptake is an important parameter for the canning industry. After receiving dry beans, a sample of 500 g is often soaked in water at room temperature for about 20 hours to determine WU. Those beans that are unable to take up at least 90 % water are rejected for canning purposes. Only seven samples from 18 small white bean samples from breeding trials were able to pick up more than 90 % water (Heinen & Van Twisk, 1976). Ten bean types were found to have different rates of water imbibition, with the smaller beans, such as small white having the fastest rate (imbibed after 6 h), while other cultivars only finished water uptake after 12 to 18 h (Deshpande *et al*., 1984). Rodríguez-Sosa *et al*. (1984) also found the WU rates of different bean types to vary between 7 and 18 h to double their mass. Wang *et al*. (1988) noticed that most beans were saturated after 10 h of soaking and water absorption reached a plateau after 14 h. Red kidney bean samples were observed to imbibe water faster during the first 6 h of soaking, after which the rate slowed down until saturation (Moscoso *et al*., 1994). During the first stage of soaking, water is mainly taken up by proteins, while starch gelatinisation plays a more important role in water uptake during the second phase of cooking (Deshpande & Cheryan, 1986).

Temperature was found to influence the rate of WU of soybeans, with higher temperatures increasing the rate (Hsu *et al*., 1983), but Thanos (1998) found only temperatures above 40 °C efficient in decreasing the time necessary for maximum WU. Water uptake rate and kernel size for soybeans correlate negatively ($r = -0.53$), as smaller kernels have an increased surface area exposed for water transfer. Density and WU rate correlate positively ($r = 0.59$), as higher densities are usually associated with smaller kernel sizes, with better WU rates (Hsu *et al*., 1983). Deshpande *et al*. (1984) also found correlations between WU rates and density ($r = 0.71$) and bulk density ($r = 0.60$) in dry beans, but only for the initial stages of WU (first 6 h). Final WU rates (after 24 h) correlated with L/B ratio ($r = 0.88$) and 100 SM ($r = 0.83$), which eliminates the influence of volume on final WU rates (Deshpande *et al*., 1984). Differences in climatic conditions in growing areas also influence the WU of dry beans (Morris *et al*., 1950).

Seed coat thickness plays an important role in WU during the first 3 h of soaking, whereafter its contribution decreases and the importance of hilum size increases. During the later stages of soaking, the protein concentration becomes increasingly important in WU (Sefa-Dedeh & Stanley, 1979). The seed coat’s high moisture content (76.6 %) after soaking illustrates the influence of the dry bean seed coat on WU, indicating a high capacity for water migration through the seed coat. White bean seed coats are preferentially permeable to water when compared to those of black and red beans (Del Valle *et al*., 1992). After WU the cotyledons display moisture contents of 53.8 %, with both bound and free water mostly present in the proteinaceous and cellulosic parts of the cells (Powrie *et al*., 1960).

1.3.7 Leaching losses

Leaching losses of dry beans are determined by drying and weighing the aliquots of the soaking water of the beans. Beans, such as small white beans, that imbibe water at a faster rate, also lose more solids during soaking (2.5 g.100 g^{-1} beans). The concentration gradient and the rate of diffusion and the physical barrier present (i.e. cotyledon cell wall and seed coat) might influence leaching losses. Small white beans are quickly hydrated (after 6 h) and the seed coat loosened, which leads to greater solid losses by the end of soaking (24 h) (Deshpande *et al*., 1984).

1.3.8 Hardshell and hard-to-cook (HTC) defects

Hardshell describes the condition in dry mature seeds in which the seeds fail to imbibe water within a reasonable time when it is moistened. This condition is a problem to plant breeders and food processors, as these beans fail to sprout and do not soften on cooking (Bourne, 1967). The palisade layer within the seed coat, hilum and various waterproofing substances mostly cause hardshell. These substances might play a role in lignification, through their production of pigmented polyphenol complexes that might interact with proteins, but the mechanism is not completely known (Stanley & Aguilera, 1985). Hardshell is absent in dehulled stored bean samples, indicating that it is a seed coat associated defect. Hardshell is storage related, as fresh beans do not contain this defect (Del Valle *et al*., 1992).

The hydration capacity of beans is inversely proportional to the formation of hardshell defect (Antunes & Sgarbieri, 1979). The presence of salt in the soaking solution has no significant effect on WU by hardshell beans (De Valle *et al*., 1992). Separation of hardshell beans by means of differences in relative densities is unsuccessful even after cooking, as the densities of hardshell beans are close to that of normal beans (Bourne, 1967).

Great Northern beans contain more hardshell than other beans after 24 h of soaking, while some Great Northern strains contain less hardshell than others, indicating that variety and strain influence the hardshell defect in beans (Morris *et al*. 1950). Soft black also have a higher incidence of hardshell (Del Valle *et al*., 1992). The diameter of beans influences the occurrence of hardshell (Del Valle *et al*., 1992), while testa colour also relates to the incidence of hardshell. Red and brown seeded beans are more susceptible to hardshell (Wassimi *et al*., 1981). Storage of beans at temperatures and relative humidities of 25 °C and 65-70 % and higher increase the occurrence of hardshell in beans during storage. These beans become harder and requires longer cooking times, while the protein efficiency ratio (PER), biological availability of methionine and protein digestibility decreases. Addition of methionine to these beans raises the PER significantly, but without affecting digestibility significantly (Antunes & Sgarbieri, 1979).

As the processing of dry beans with hardshell defect will result in poor textural quality, these beans should be treated beforehand to allow them to imbibe water. This is done effectively by steaming the beans or treating them with hot water before soaking (Morris *et al*., 1950).

Hard-to-cook (HTC) beans are improperly stored beans that do not soften sufficiently to be eaten, after having been cooked for a reasonable time (Aguilera & Rivera, 1992). Hard-to-cook and soft beans imbibe the same volume of water, but water of HTC beans is mainly found in the intercellular spaces, while that of soft beans is inside the cells (Aguilera & Rivera, 1992). The three main problems experienced due to HTC beans are: a) nutritional problems to people in humid tropical and subtropical areas who are dependent on beans for their main source of protein, b) economic problems due to the loss of the important functional property of beans and c) energy problems due to the long cooking time necessary to achieve softness of these beans (Dos Santos Garruti & Bourne, 1985).

The HTC defects in beans are not related to hardshell beans, as factors unrelated to WU cause HTC (Jackson & Varriano-Marston, 1981). The HTC defect is of special importance in countries where high temperatures and humidities are experienced. The mechanism is chemical in nature and not physical as in the case of hardshell beans, with agronomic factors the major cause. Four theories for the cause of HTC beans are mentioned. Hard-to-cook beans were firstly identified to be related to losses in Na during storage of beans under inadequate conditions (De Léon *et al.*, 1992). A second theory for the hardening process is due to retrogradation during storage. The retrograded starch would require more heat energy to break the hydrogen bonds in the starch and therefore has longer cooking times (Deshpande & Cheryan, 1986). Thirdly, Jones & Boulter (1983) proposed that HTC beans could be the consequence of the failure of cotyledon cells to separate during cooking. Fourthly, it was stated that HTC beans are caused by the restricted metabolism allowed when beans are stored at high temperature and relative humidity, causing membrane breakdown. These membranes would in turn reduce imbibition during osmosis, and would allow bivalent cations from hydrolysed phytin to reach and bind with pectin (Jones & Boulter, 1983).

The hardening process initiates with a lag period, followed by a period of rapid hardening, and ends in a period of hardening at a slower rate to reach plateau values (Del Valle *et al.*, 1993). Aguilera & Rivera (1992) also found a slower rate of hardening during the first two months of storage at high temperature and relative humidity, after which the hardening rate accelerated. Lower moisture content of beans stored for long periods delays the initiation of the faster rate hardening process (Aguilera & Rivera, 1992).

Impermeable or semi-permeable packaging material modifies the atmosphere in bags by increasing water vapour and therefore the humidity in the bags, which could promote hardening. The production of water vapour is minimised when beans are stored at low initial MC of 10 %. After one year of storage at 35 °C beans are hard, but those stored at 12 % MC are harder than the ones stored at 10 % (Aguilera & Rivera, 1992).

The addition of Na and K to soaking and cooking solutions decrease the cooking time of hardened beans (De Léon *et al.*, 1992). Similarly, the addition of NaCl and $NaHCO_3$ or just $NaHCO_3$ reduces the effect of hardness remarkably (Parades-López *et al*., 1991). Hard beans also soften better in the presence of salts or Na / EDTA (Aguilera & Rivera, 1992). The reason for this is the disruption of the cell surfaces by the salts, allowing increased penetration of water into the cells. This allows the gelatinisation of the starch during cooking, causing softening of beans (Aguilera & Rivera, 1992). Calcium or other divalent ions on the other hand has the ability to form salt bridges between adjacent polymer chains in the middle lamella in beans, leading to lower WU and harder beans (Nelson & Hsu, 1985). The EDTA binds the Ca in the beans, since the latter has a firming effect on beans (Aguilera & Rivera, 1992). The effects of other mono- and divalent ions on the canning quality of beans are discussed in 1.5.3.6.2 and 1.5.3.6.4.

1.4 CANNING OF DRY BEANS

1.4.1 Definition of canning

Canning is the heat sterilization process during which all living organisms in food are killed, to assure that no residual organisms could grow in the can. Properly sealed and heated canned foods should remain stable and indefinitely unspoiled in the absence of refrigeration. The sealing step is critical and heat is applied under pressure for a specific temperature-time combination. The latter is determined by the type of food, pH, container size and consistency or bulkiness of the food, but heating of food for longer than necessary is undesirable, as the nutritional and eating quality of food are affected negatively by prolonged heating (Brock *et al*., 1994).

1.4.2 The canning process

Canning of beans is mainly composed of two processes, namely the soaking / blanching process and thermal processing / heat sterilization.

The purpose of soaking before canning is to remove foreign material, facilitate cleaning, aid in can filling through uniform expansion, ensure product tenderness and to improve colour (Uebersax *et al.*, 1987). During soaking, dry beans should increase 80 % in mass and reach a 53 – 57 % MC. Soaking beans before cooking would also accelerate the cooking rate (Wassimi *et al*., 1981). Blanching is the immersion of foods into hot water (80 to 100 °C) or steam for several minutes (Jay, 1986). The main purpose of blanching is the inactivation of enzymes, which might produce off-flavours, but also to soften the product and remove gasses to reduce strain on can seams during retorting (Jones & Beckett, 1995). The blanching process is also responsible for the increase of bean MC to the final 50 – 55 % and the removal of dry bean flavour and odour (Priestly, 1978).

Conditions for heat sterilization of low acid foods are defined to ensure that all spores of *Clostridium botulinum* are destroyed and to prevent the spoilage of the product by heat-resistant, non-pathogenic organisms. Sterilization should normally be performed at 121 °C for at least three minutes (Jones & Beckett, 1995). The F-value is defined as the time in minutes to destroy a defined population of spores and vegetative cells of an organism for specified log reductions at a defined temperature (Jay, 1986). The sterilization value (F_0-value) for *Clostridium botulinum* is 2.45 min, but commercial heat sterilization is usually designed to deliver higher F_0-values than 3.0 min to provide additional safety (Wang & Chang, 1988). In the case of beans additional sterilization would also provide adequate softening of the texture. When dry beans were sterilized at 115.6 and 121.1 °C, the targeted F_0-value for *Clostridium botulinum* was obtained after 35 and 15 min respectively (Wang & Chang, 1988). Contrasting these results, Bolles *et al*. (1990) found higher lethality levels for beans canned at both the above temperatures. Beans processed at 121 °C (30 min) had an F_{0}-value of 28.2, while those processed at 115.6 °C (45 min) had an F_0-value of 11.4 min.

1.4.2.1 Industrial canning

1.4.2.1.1 Soaking and / or blanching

The industrial canner makes use of either a long / cold or short / hot soaking process. With the first, soaking takes place for 6 to 18 h, changing water every 4 to 6 h to prevent bacterial activity. Cold soaking is followed by blanching in continuous rotary water blanchers at 90 – 95 °C for 5 min (Priestly, 1978). Alternatively blanching could be done at 85 °C for 4 to 6 min, 90 °C for 7 min (Priestly, 1978) or 85 – 90 °C for 5 min (Heinen & Van Twisk, 1976). The overnight soaking process has the following disadvantages: It is a lengthy process, difficult to control swelling and microbiological stability and germination could take place, resulting in worm-like material in the beans if broken off during further processing (Priestly, 1978).

Hot soaking takes place in slowly running continuous blanchers or pipe blanchers, where product heating takes place at 85 – 90 °C for 30 min. The main disadvantage of this process is that the product does not become as tender as in the case of slowly hydrated beans (Priestly, 1978).

1.4.2.1.2 Heat sterilization

Soaked blanched beans are filled into the can, hot sauce added (95 °C), and the can seamed and heat sterilized immediately. Sterilization is done in static retorts, agitating retorts or hydrostatic sterilizers. Rotation increases the rate of heat transfer, thereby reducing processing time and the gelation tendency of the sauce (Priestly, 1978). Sterilization is done for 60 min at 115 °C (Heinen & Van Twisk, 1976).

1.4.2.2 Laboratory canning

1.4.2.2.1 Soaking and / or blanching

The soaking and / or blanching process for laboratory canned beans could also consist of a long or shorter soaking period. Soaking beans for 10 h leads to saturation of most beans, while WU reaches a plateau after 14 h (Wang *et al.*, 1988). With laboratory canning, De Lange & Labuschagne (2000) omitted the soaking process and replaced it with a blanching period of 40 min at 88 °C. Balasubramanian *et al*. (1999) used a soaking step of 30 min at room temperature, followed by blanching for 30 min at 88 °C.

Soaking beans overnight, improves hydration and swelling with consequential larger bean sizes. Higher Ca levels in soaking / blanching water increase the firmness of beans (Occeña *et al*., 1992), which will be discussed in 1.5.2.6.3.

1.4.2.2.2 Heat sterilization

De Lange (1999) heat sterilized canned beans in a vertical autoclave at 121.1 °C for 50 min. Bolles *et al*. (1990) sterilized at 121.1 °C for 30 min, also using a vertical autoclave. Sterilizing beans at 115.6 °C for 35 min or 121 °C for 15 min in the presence of $CaCl_2$ and EDTA containing brine, resulted in optimal sterilization values, reduction of trypsin inhibiting activity and bean firmness values (Wang & Chang, 1988).

1.4.2.2.3 Storage

Canning beans for quality evaluation are usually followed by a two-week storage period at ambient conditions prior to evaluation, to allow proper bean-brine equilibration (Machiorlatti *et al*., 1987; Bolles *et al*., 1990). During the first seven days of equilibration water migration activity increases within the can, indicating that beans in a can is a dynamic system during the first week after processing (Bolles *et al*., 1982).

1.5 CANNING QUALITY OF DRY BEANS

1.5.1 Canning quality parameters

1.5.1.1 Hydration coefficient (HC)

The mechanisms of WU during the soaking of dry beans were discussed in 1.3.6. Beans imbibe more water during a 2 h soaking period at ambient temperature, than a 30 min soak at 25 °C followed by 30 min soaking at 87.8 °C (Bolles *et al*., 1990). The HC indicates the increase in dry bean mass due to water uptake during soaking, relative to the dry state (Hosfield *et al*., 1984b). The HC of dry beans could be calculated with the following formula (Hosfield & Uebersax, 1980):

$$HC = ((\text{Mass of soaked beans (g)} / \text{Mass of dry beans (g)}) \times 100$$

Uncooked beans generally undergo a mass increase of 80 % during soaking (Hosfield *et al*., 1984a; Hosfield, 1991), thereby obtaining a MC of 53 to 57 % (Hosfield, 1991). A HC value of 1.80 is therefore usually considered optimal for dry beans (Hosfield *et al*., 1984a; Hosfield, 1991). Hosfield & Uebersax (1980) found the HC of seven types of white dry beans to range from 1.82 to 1.94 and significant differences ($P < 0.01$) between bean types were found for HC. Balasubramanian *et al*. (1999) found the same order of HC ranges (1.84 to 1.96) and significant differences ($P < 0.05$) in HC values for three navy bean cultivars

The HC is important in bean canning, as a larger quantity of beans is necessary to fill a certain can volume, when the HC ratio is low. A higher HC would therefore improve canning yield (Ghaderi *et al*., 1984). Soaking prior to canning also decreases the firmness of cooked cowpeas (Giami *et al*., 1993). However HC correlated poorly with the firmness of canned beans, but the number of non-hydrated seeds correlated negatively with HC (r = -0.95) (Lu *et al*., 1996).

1.5.1.2 Washed drained weight (WDWT) and percentage washed drained weight (PWDWT)

The WDWT refers to the mass of rinsed beans drained for 2 min on a number 8 mesh (0.239 cm) screen positioned at a 15 ° angle (Hosfield & Uebersax, 1980; Hosfield *et al*., 1984b). Percentage washed drained weight is calculated as follows (Balasubramanian *et al*., 1999):

PWDWT = (WDWT (g) x 100 / Mass of can contents (g)) x 100

As WDWT is a function of the equilibrium of beans and brine in the can, it is highly dependent on the MC of beans after soaking, the fill weight and the brine fill (Uebersax & Bedford, 1980). Drained weight of dry beans relates to “processors yield” (Varner & Uebersax, 1995), as it would require fewer beans with a high WDWT to fill a can than in the case of beans with low WDWT (Hosfield, 1991). According to Canadian government regulations the PWDWT of dry beans should be at least 60 % (Balasubramanian *et al*., 1999). According to 1976 South African regulations of the Inspection Services Division of the Department of Agricultural Economics, the drained weight of canned beans should be at least 271 g (Heinen & Van Twisk, 1976), but the size of the can for which these regulations were determined were not mentioned. A low WDWT is a possible indication of excessive solid loss during processing, while a high WDWT indicates large swelling capacities (Hosfield, 1991).

The WDWT of dry beans is moderately to highly heritable and is more influenced by genetic than environmental factors (Walters *et al*., 1995). Balasubramanian *et al*. (1999) also found cultivar effects to significantly influence ($P < 0.05$) WDWT and PWDWT, while the cultivar x locality x season interaction was also found to affect these factors significantly ($P < 0.05$). The WDWT and PWDWT of five commercial types of navy beans ranged between 59.5 and 60.9 (Balasubramanian *et al*., 2000). Blanching conditions affect WDWT and the addition of Ca to any blanching method decreases WDWT (Larsen *et al*., 1988). It was seen in 1.4.2.3 that the can is considered as a dynamic system during the first seven days after canning, which explains why Bolles *et al*. (1982) found variability in WDWT during the first seven days, but gradual increases in WDWT up to day 35 after canning. As discussed in 1.5.3.6.4, PWDWT of beans is also influenced by the canning medium. Beans canned in tomato sauce have significantly lower PWDWT than those canned in water (Nordstrom & Sistrunk, 1977; Priestly, 1978). Percentage washed drained weight correlates negatively with the HC for navy (r = -0.83) and pinto (r = -0.90) bean cultivars (Wang *et al*., 1988).

1.5.1.3 Sensory quality of canned beans

Figure 1.1 indicates the elements contributing to the sensory quality of canned beans. Each element will be discussed individually in 1.5.1.3.1 to 1.5.1.3.4.

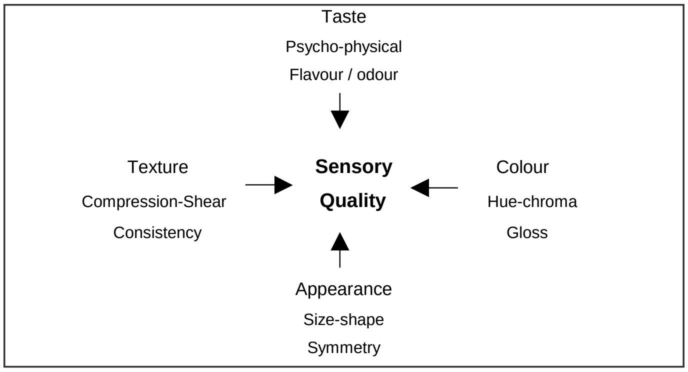


Fig 1.1 Elements contributing to the sensory quality of canned beans (After Machiorlatti *et al*., 1987).

1.5.1.3.1 Texture

Texture is used as an indication of the degree of consumer acceptance of canned beans (Ghaderi *et al*., 1984; Hosfield, 1991) as it affects the perceived stimulus of chewing (Ghaderi *et al*., 1984). Texture, which is measured by a shear press, is an indication of the firmness of beans (Ghaderi *et al*., 1984) and is measured as kg force required to shear 100 g of beans (Hosfield & Uebersax, 1980). The shear press ignores other kinaesthetic perceptions, such as viscosity, gumminess and adhesion

(Ghaderi *et al*., 1984; Hosfield, 1991). The shear press curve is used to indicate maximum shear force by means of maximum peak height. A higher maximum peak height indicates firmer beans (Bolles *et al*., 1990). Consumers usually rate texture of beans from "too soft" or "mushy" to "too firm / tough" or "hard" (Machiorlatti *et al*., 1987; Hosfield, 1991). Acceptability of canned beans correlates with texture (r = 0.92) (Rodríguez-Sosa *et al*., 1984), while members of a sensory panel of navy beans also preferred softer beans (Uebersax & Bedford, 1980).

In the USA the cultivar Sanilac, with a texture value of 72 kg.100 g^{-1}, is considered the industrial standard for canning quality (Hosfield & Uebersax, 1980). Beans should soften during processing, but not to such a degree that individual integrities are lost (Hosfield & Uebersax, 1980). Texture values of four types of small white beans ranged between 59.1 and 89.9 kg 100 g^{-1} (Hosfield & Uebersax, 1980), while those of navy bean cultivars were softer and ranged between 38.5 and 48.7 kg.100g^{-1} (Balasubramanian *et al*., 1999).

The HC and soaking properties influence textural differences in white beans, but not in the case of tropical black and non-black dry beans (Hosfield & Uebersax, 1980). Walters *et al*. (1995) also identified significant correlations between the HC and texture, but He *et al*. (1989) found no correlation between WU during soaking and texture of beans. Bolles *et al*. (1990) indicated that no soaking prior to cooking results in significantly firmer beans than those that underwent soaking. Their studies also indicated that thermal processing time / temperature combinations affected bean softness, which was confirmed by Wang & Chang (1988) who noticed firmness of beans to decrease, with an increase in processing time. Beans heat sterilized at 120 °C for 14 or 16 min was significantly harder than those canned at 115.6 °C for 45 min (Wang *et al*., 1988). Soluble pectins in raw and canned navy beans correlate negatively and with equal correlation coefficients (r = -0.97) with the hardness of beans (Wang *et al*., 1988). The phytic acid phosphorous content of navy beans also correlates significantly with the hardness of beans (r = -0.89) (Wang *et al*., 1988). Other canning quality parameters that correlate with texture are WDWT (Ghaderi *et al*., 1984; Occeña *et al*., 1992; Walters *et al*., 1997; Balasubramanian *et al*., 1999) and PWDWT which both correlate negatively to texture (Balasubramanian *et al*., 1999).

Positive correlations are also found between the cooking time necessary to soften dry beans and the seed mass (Giami & Okwechime, 1993).

A relationship between texture of beans and bean solids was observed. The more bean solids, the higher the bean to brine ratio, with consequential firmer beans (Bolles *et al*., 1982). Texture is influenced by bean temperature, since shear values decrease as the temperature of canned beans on evaluation increases (Machiorlatti *et al*., 1987). These firmer textures at lower evaluation temperatures could probably be the consequence of gelatinisation or retrogradation of bean starch. Bean firmness after cooking relates to the phytin, Ca, Mg and free pectin levels, while the thickness of the palisade layer of the seed coat, as well as the lignin and alpha-cellulose in the seed coat also play a role in firmness (Muller, 1967).

1.5.1.3.2 Colour

The colour of food is caused by the absorption of more light at some wavelengths by pigments. Colour is one of the properties of beans that consumers have specific preferences about (Hosfield, 1991). The colour of dry and cooked beans is usually measured with a HunterLab colour meter (Hunter Associates Laboratory Inc., Reston, VA). The L-value indicates white to black, a_L-value indicates red to green and b_L-value indicates yellow to blue (Hosfield *et al*., 1984b; Chung *et al*., 1995).

Lightness (L-values) and yellowness (b_L-values) of white beans are higher, but redness is lower (a_L-values) (Rodríguez-Sosa *et al*., 1984). Eighteen different types of dry small white bean samples indicated that the colour of some were greyish. After canning in tomato sauce, no differences in colour were observed (Heinen & Van Twisk, 1976). Bolles *et al*., (1990) noticed amongst five types of beans that navy beans were the lightest in colour (L-value = 60.8), while black turtle soup was the darkest in colour (L-value = 16.8).

All bean types were found darker after processing (Paredes-López *et al*., 1986; Bolles *et al*., 1990), although processing beans at 115.6 ° for 45 min and 121.1 °C for 30 min had no significant influence on the colour of processed beans (Bolles *et al.*, 1990). Soaking or cooking times affects the redness (b_L-values) (Paredes-López *et al.*, 1986), while storage under unfavourable conditions that would cause hard-to-cook beans reduces the lightness character of beans (Paredes-López *et al.*, 1991).

Beans canned without soaking pre-treatment are significantly darker in colour than those that received a soaking treatment (Bolles *et al.*, 1990; Occeña *et al.*, 1992), illustrated by the significant correlation ($r = -0.89$, $P < 0.01$) between L-values and bean hydration (Lu *et al.*, 1996). An increase in the Ca content of dry beans significantly ($P < 0.05$) increases the lightness (L-value) of the canned beans ($r = 0.60$) (Lu & Chang, 1996). This effect may be a result of the measurement of retained solids and decreased seed breakdown. Generally, the more intact the seed the greater the surface reflection would be, resulting in brighter appearing beans. The same was found by Wang *et al.* (1988) when EDTA and $CaCl_2$ were added to the brine. The EDTA chelates free metal ions that would cause the formation of colour complexes. The tannin content is one very important factor, which affects the darkness in colour of uncooked dry beans. With some exceptions, the higher the tannin content, the darker the beans (Ma & Bliss, 1978).

1.5.1.3.3 Visual appearance (VA)

Visual appearance is one of the preferences of consumers of beans, which is determined subjectively (Hosfield, 1991). Visual appearance of canned beans is an evaluation of the general suitability of beans for commercial processing (Hosfield & Uebersax, 1980). Beans are evaluated for intactness (Balasubramanian *et al.*, 1999), splits, free seed coats (Hosfield & Uebersax, 1980; Balasubramanian *et al.*, 1999) and brine consistency (Hosfield & Uebersax, 1980).

The VA of six small white bean cultivars ranged between 4.5 to 8.0 on a scale from 1 to 10, where 1 represented poor and 10 excellent VA values. Significant differences ($P < 0.05$) in VA were found for cultivars, environments, as well as the cultivar x environment interaction (De Lange & Labuschagne, 2000). In another study white beans displayed VA values of 3.0 to 4.0 on a scale from 1 to 5, but differences between cultivars were not significant (Hosfield & Uebersax, 1980).

Washed drained weight correlates significantly and negatively with VA, with correlation coefficients ranging from –0.26 to –0.58. Although high WDWT values are desirable for dry bean processors, its negative correlation with VA warns that selection for WDWT would jeopardise the VA of the beans (Walters *et al*., 1995). Visual appearance also correlates positively with texture (r = 0.22 to 0.49), suggesting that selection of lines based on VA, should improve acceptability of texture values (Walters *et al*., 1995).

1.5.1.3.4 Splits

Splitting of cooked beans is one of the factors that determine the intactness of cooked beans, and is determined subjectively (Hosfield, 1991). Beans that appear intact before canning, might also develop large percentages of splits during retort processing, causing the product to be unappealing and may lead to price reductions (Sastry *et al*., 1985). Not only would splitting of canned beans result in the exudation of starch into the canning medium, causing graininess of the sauce, but could also lead to clumping of individual beans (Lu & Chang, 1996), which is discussed in 1.5.1.3.5 . Starch material might also be deposited on the bottom of the can and thereby reduce the quality of the canned product (Forney *et al*., 1990). Splitting might even lead to complete breakdown of beans (Faris & Smith, 1964). In small white beans a larger percentage of split beans would be more tolerable than in beans, such as kidney and pinto beans, which appear better in the absence of bean splits (Gonzalez *et al*., 1982), but this would have to be determined by the specific consumer market.

The blanching method applied before canning influences splitting of canned beans significantly ($P < 0.05$). Blanching for 60 min at 77 °C results in the lowest split values (Larsen *et al*., 1988). Splitting is also reduced in canned beans by the addition of Ca to the canning medium (Wang & Chang, 1988). Beans that weigh more, due to greater WU levels, have a higher tendency to split (Forney *et al*., 1990). Sastry *et al*.

(1985) also found lower moisture absorption during hydration to reduce splitting. Van Buren *et al*. (1986) found that firmer beans and beans with lower PWDWT would have fewer splits. The reason for this is that swelling of the beans put the skin under pressure, causing it to rupture. Larger sized beans would take up less water during canning, due to a larger volume-to-surface ratio, with consequential lower split values (Faris & Smith, 1964). This explains the correlation between splitting with canning and 100SM (Faris & Smith, 1964). The addition of $CaCl_2$ to the brine reduces splitting and clumping of canned navy and pinto beans (Wang *et al*., 1988).

De Lange & Labuschagne (2000) found split values of canned small white bean cultivars to range from 4 to 8 on a 10-point scale (10 indicates high split values) and splits were indicated to be significantly influenced ($P < 0.05$) by environment, cultivar and the cultivar x environment interaction. Yield was also found to correlate significantly with splits (r = -0.19, $P < 0.05$) (De Lange & Labuschagne, 2000). Seed damage while handling beans correlates positively with split values of canned beans (Faris & Smith, 1964), but no correlation between seed coat damage and splits were found in canned navy beans (Lu *et al*., 1996).

1.5.1.3.5 Degree of clumping

One of the factors determining the intactness of cooked beans is the clumping of beans in the can, which is determined subjectively (Hosfield, 1991). The degree of packing indicates the degree of clumping that would occur after processing, which might lead to cultivar rejection by the processor (Hosfield & Uebersax, 1980). Intact beans will undergo little bean breakdown during canning, while excessive bean breakage during cooking would result in starch exudation into the canning medium, with consequential clumping of individual beans. Softening of beans while processing is thus important, but beans must still maintain their individual integrity (Hosfield & Uebersax, 1980).

Beans canned without the addition of Ca tend to have high degrees of clumping (Wang & Chang, 1988). Beans with low HC values will undergo more swelling and hydration during thermal processing, than those with high HC values. This may cause the formation of a compact mass at the can bottom, with consequential clumping (Balasubramanian *et al*., 1999). Beans that display severe clumping would also have lower PWDWT, as starch from the clumped portion of the canned beans would leach through the screen during washing (Wang *et al*., 1988).

The degree of clumping of white beans was shown to vary between 1.0 and 2.0 on a 3-point scale, where 1 = no clumping and 3 = solid clumping at the bottom of can (Hosfield & Uebersax, 1980). Turbidity of the liquid of micro-cooked beans correlates with the clumping of the canned beans ($r = 0.53$, $P=0.05$) (Lu *et al*., 1996).

1.5.1.3.6 Flavour and taste

The reducing sugars present in beans (1.2.2.2) participate in Maillard reactions, which contribute to the flavour of beans (Drumm *et al*., 1990). Volatile components formed during processing are also expected to contribute to the unique flavour characteristics of different bean classes (Drumm *et al*., 1990). The role of lipids in flavour development of beans during processing is assumed small (1.2.3), although a rancid off-flavour might develop in beans after prolonged storage. Unsaturated fatty acids in beans might develop flavour changes, due to the action of lipoxidase present in beans during processing, following prolonged storage (Muneta, 1964).

1.5.1.4 Viscosity

Brine viscosity is a function of soluble solids leaching into the canning medium during thermal processing, which is influenced by polymers and macromolecules (starch, proteins and non-starch polysaccharides). Other factors besides leached solids might also be involved in the viscosity of the brine (Chung *et al*., 1995).

Rapid Visco Analyser pasting viscosity of bean flour correlates significantly with WDWT ($r = 0.80$, $P < 0.01$) of beans. Pasting viscosity also correlates with firmness (r –0.77, $P < 0.05$) of canned navy beans. Navy beans with high pasting viscosities therefore display high WDWT and low firmness values (Lu *et al*., 1996).

1.5.2 Factors affecting canning quality

The major characteristics responsible for canning quality of beans are the physical characteristics of the seed, processing and cooking characteristics and chemical composition of beans (Hosfield & Uebersax, 1979). Other factors affecting the canning quality would be discussed in 1.5.2.1 to 1.5.2.6.5.

1.5.2.1 Cultivar and genotype

Genotype differences of dry beans affect the cooked bean quality (Bolles *et al*., 1982). Cultivar differences also affect culinary quality (Hosfield & Uebersax, 1980). Genotype differences affect the texture of processed beans, as it could have a profound effect on the biological behaviour of the beans during processing (Bolles *et al*., 1982). Hosfield *et al*. (1984a) also identified the genotype component to play an important role in texture, and in WDWT.

Different cultivars of navy and pinto beans were observed to have either significant or highly significant differences in 100SM, a_L and b_L colour values, mass of soaked beans, texture and MC of processed beans. Cultivar differences for clumping and splits were not significant, however (Ghaderi *et al*., 1984). Differences in the drained weight of navy and pinto bean cultivars were also observed (Wang *et al*., 1988). Significant differences ($P < 0.05$) were found for all canning quality properties (seed size, soaked bean mass, WDWT, VA, splits, texture ((kg 100 g^{-1}.12 s^{-1}) and texture (kg.s^{-1})), as well as for biochemical analysis values (% N, % Ca and % K) of small white beans (De Lange & Labuschagne, 2000). Both the cooking time of beans (Proctor & Watts, 1987) and the final hardness of beans after prolonged storage (Michaels & Stanley, 1991) were significantly affected by cultivar. Kamberg was identified as an unacceptable cultivar in terms of canning quality, due to more splits and smaller seed sizes than Teebus and Arctic (De Lange & Labuschagne, 2000). The negative correlation between seed mass and percentage acceptable beans was found to be only applicable within a cultivar, as some cultivars have much larger than average sized seeds (Forney *et al*., 1990).

The canning quality properties of different types of beans also differ significantly. Canning quality of light and dark red kidney beans are significantly different (Chung *et al*., 1995). All black bean cultivars have high clumping values, compared to navy and pinto bean cultivars (Balasubramanian *et al*., 1999).

1.5.2.2 Locality and season

Genetic improvement of dry bean traits is complicated by the unpredictable consequences that environment might have on traits (Hosfield, 1991). It is therefore necessary to evaluate canning quality traits over a number of localities and seasons, to identify cultivars with stability in canning traits (Walters *et al*., 1995).

Differences in canning quality traits of navy beans from different localities are not only attributed to genotype differences, but also environmental effects (i.e. soil, temperature and moisture levels) (Varner & Uebersax, 1995). Significant differences in correlation coefficients between starchiness of the bean medium and clumping at two different localities, Arthur ($r = 0.89$, $P < 0.01$) and Hatton ($r = 0.19$) were observed. These differences were caused by the influence of locality on these canning properties (Lu & Chang, 1996). The cooking time of beans is also significantly influenced by locality (Proctor & Watts, 1987). De Lange & Labuschagne (2000) found biochemical analysis traits (N, Ca and K) and all canning quality traits, excluding WDWT, to be significantly influenced ($P < 0.05$) by environment. The final hardness values of beans after prolonged storage were also significantly influenced by environment (Michaels & Stanley, 1991). Contrary to these results, canning quality traits of navy beans grown at irrigated sites were not significantly different from those of dryland sites (Balasubramanian *et al*., 1999).

Seasonal effects were displayed by the lightness colour values of red kidney beans, as these values decreased over a three year period (Chung *et al*., 1995). Texture values were also significantly affected by season (Uebersax & Bedford, 1980). Canning heritability is an indication of the effect of environment on certain canning quality traits. Contrary to what is expected from the above discussion, all canning quality traits were indicated to display moderate to high heritability values, suggesting limited environmental effects (Walters *et al*., 1995).

1.5.2.3 Cultivar, locality and season interactions

Significant cultivars x locality interactions are an indication that cultivars do not perform consistently over different localities (Ghaderi *et al*., 1984). Large environmental influences often cause genotype x environment interactions, which make the improvement of a genetic trait difficult (Hosfield, 1991). This necessitates the testing of cultivars over time and over localities (Ghaderi *et al*., 1984).

Pinto bean cultivars grown at three localities displayed significant cultivar x locality interactions for most canning quality parameters, except for HC, mass of soaked beans, texture, L-value and MC of processed beans (Ghaderi *et al*., 1984). De Lange & Labuschagne (2000) found the cultivar x locality interaction to be significant for all canning parameters of small white beans, except for WDWT. Cultivar x environment interactions were found highly significant for initial and final hardness values and hardening ratio of prolonged stored beans (Michaels & Stanley, 1991). The cultivar x locality interaction was not significant in the case of the cooking time of beans (Proctor & Watts, 1987).

The cultivar x season interaction of the HC of navy and pinto beans was found to be significant, due to a lower HC of one cultivar during one season than during the other. Several canning quality traits of these beans were identified to display significant year x locality interactions, caused by an early fall frost in one locality during 1996. The cultivar x season x locality interaction was also found to be significant for most canning quality traits, except for clumping, VA and cooked liquid traits (Balasubramanian *et al*., 1999).

1.5.2.4 Seed damage

Seed damage during threshing, cleaning and handling reduces the quality of canned beans, as damaged seed coats are displayed as splits during canning (Faris & Smith, 1964). The lower the moisture levels (less than 12.3 %) in navy beans, the more visible the damage (Barriga, 1961) resulting form brittle seed coats that crack under mechanised handling.

1.5.2.5 Seed storage and seed maturity

The deterioration that beans undergo during storage includes lower WU, increase in cooking time, as well as changes in texture, colour and flavour. This leads to a loss of the commercial value of beans (Sgarbieri, 1989). The time of storage, as well as the storage conditions, affects the textural properties of canned bean (Bolles *et al*., 1982). Care should therefore be taken to ensure that the initial MC of dry beans, as well as storage conditions, are standardised before soaking and processing (Hosfield & Uebersax, 1980).

The hard-to-cook defect in dry beans (1.3.8) is the consequence of storing beans under tropical conditions of high temperature and humidity (Stanley and Aguilera, 1985). Mould growth also increases with storage at increased relative humidity, temperature and time (Uebersax & Bedford, 1980). Beans stored at 30 and 40 °C for 6 months were 1.8 and 2.1 times harder respectively than control beans that were stored at 2 ° C for the same period. The fracturability of these beans was also 2.7 and 3.3 times higher for beans stored at 30 and 40 °C respectively for six months as compared to the control. Chewiness and gumminess of these beans also showed the largest increase for those stored at 40 °C. Storage at elevated temperatures changes the normal soft, moist, pasty, starchy texture of cooked beans into a hard, fracturable, lumpy, non-pasty, dry texture (Dos Santos Garruti & Bourne, 1985). Hunter L-values decrease, while a_L- and b_L-values of dry and canned beans increase with prolonged storage under these conditions. These colour changes are mostly caused by non-enzymatic browning, but also by mould growth (Uebersax & Bedford, 1980). Water uptake values of beans stored under these conditions are also lower (Uebersax & Bedford, 1980).

1.5.2.6 Canning process

1.5.2.6.1 Soaking and blanching process

Canning beans without a soaking or blanching step prior to thermal processing causes beans to clump solidly at the bottom of the can and these beans do not absorb enough water from the canning medium (Wiese & Jackson, 1993). Unblanched beans have acceptable drained weight and fewer splits, but are firmer (Davis, 1976). Soaking, followed by blanching, increases WU in beans, compared to only a soaking step (Thanos, 1998). Beans that are soaked without blanching also need longer processing times for the gelatinisation of starch, compared to those that are blanched (Wiese & Jackson, 1993). The necessity of blanching in canning depends on the type of beans, e.g. elimination of blanching with light red kidney beans is feasible, but not for navy beans, which display excessive splitting and matting (Davis, 1976).

Blanching of beans was found to decrease the WDWT (Wiese & Jackson, 1993), but applying a steam-blanching process instead of water blanching, led to increased WDWT of up to 16 % for white beans (Drake & Kinman, 1984). Davis (1976) also found steam blanching of beans to increase drained weight. The texture of water-blanched beans was found softer than those of steam-blanched beans (Davis, 1976; Drake & Kinman, 1984) while the colour was also lighter (Drake & Kinman, 1984). Steam blanching was also found to reduce turbidity of the canning medium, compared to water-blanching treatments and subjective scores of steam-blanched beans were higher. Contrary to these results, Davis *et al.* (1980) observed steam-blanched products to be equivalent to water-blanched products.

1.5.2.6.2 Water hardness

An increase in Ca level in soak water increases the firmness of beans linearly, while decreasing HC, WDWT, PWDWT (Balasubramanian *et al.*, 2000) and splitting (Larsen *et al.*, 1988). The higher the Ca concentration in the soak solution the less the decrease in the texture values and swelling of the beans during soaking (Uebersax & Bedford, 1980). A direct relationship between Ca level and texture of canned beans was also observed by Occeña *et al*. (1992). Priestly (1978) also found too high Ca levels in the soaking water to have a negative effect on the cooking time and product consistency. The addition of Ca to distilled water also significantly increased the hardness of canned beans, compared to those canned in distilled water (He *et al.*, 1989).

A sensory panel found the texture of beans canned in distilled water to be too soft, while the addition of Ca improved firmness and quality (He *et al.*, 1989). Beans were only evaluated as too firm when water reached 1 036 ppm Ca acetate. Normal hardness of water would therefore not cause problems with the texture of good quality beans (He *et al.*, 1989), but Ca could be added to increase bean firmness (Larsen *et al.*, 1988).

Increasing the ratio of monovalent to divalent ions in the soaking water of beans reduces the cooking time of beans (De León *et al.*, 1992). Beans soaked in Na / EDTA solutions, which extracts Ca from the beans, are similar to fresh beans, but the surface cells are more disrupted and more gelatinised starch is visible (Aguilera & Rivera, 1992). The sensory quality of beans soaked in salt solutions and cooked in water is better than those that are soaked and cooked in the same salt solutions (De León *et al.*, 1992).

1.5.2.6.3 Soaking and blanching time and temperature

Increasing the temperature of blanching from 50 to 70 °C, was noticed to increase the PWDWT of navy beans (Balasubramanian *et al.*, 2000), but Van Buren *et al*. (1986)

found increased soaking temperatures to lower PWDWT and splitting and increase firmness. Wiese & Jackson (1993) also found increased soaking temperatures to decrease PWDWT. Thanos (1998) only noticed the increasing effect of blanching temperatures above 60 °C on PWDWT when soft water was used. The combined effect of higher temperatures and water hardness was also noticed, as well as the suppressing effect that Ca has on WU (1.5.3.6.2). The firming effect of Ca on beans, as well as the delaying effect of Ca on WU rate, is greater when soaking is done at high temperatures. Brown coloration is also more frequent in the presence of severe heat treatment during soaking (Uebersax & Bedford, 1980). This effect is accelerated at higher soaking temperatures (Larsen *et al*., 1988).

Increased soaking time lowers texture shear values, while increasing WU and the volume of beans. Higher soaking temperatures accelerate this effect of soaking time on WU and volume (Uebersax & Bedford, 1980).

Blanching at 77 °C was found to significantly decrease splitting of beans, compared to no blanching or blanching at 88 °C (Van Buren *et al*., 1986). Blanching dry beans above 40 °C was noticed to decrease the time necessary for sufficient WU (Thanos, 1998). A combination of higher blanching temperatures for a shorter time (e.g. blanching at 99 °C for 30 min vs. 77 °C for 60 min) were noticed to decrease WU (Larsen *et al*., 1988). Severe heat treatment (e.g. 99 °C for 30 min), however, increased the yellow-brown discoloration of the beans, compared to the firm beans with a glossy shine observed at lower temperatures (e.g. 70 °C for 60 min). Soaking of beans at 25 °C was noticed to improve canned bean quality, compared to soaking at 15 or 35 °C (Junek *et al*., 1980).

The soaking and blanching treatment of beans affect the processing time to attain commercial sterility (Wiese & Jackson, 1993). Elevating soaking temperatures during canning could therefore be beneficial in the canning industry, but the cost aspects of heat should be taken into consideration (Thanos, 1998).

1.5.2.6.4 Canning medium

Beans are intended to absorb enough water from the canning medium to thicken the sauce. Insufficient water absorption might therefore lead to the sauce not being viscous enough (He *et al*., 1989). Increased Ca ion concentrations in the canning medium decrease drained weights and splitting and increase bean solids and texture (Van Buren *et al*., 1986; Larsen *et al*., 1988). These effects of Ca are more pronounced when Ca is added to the soaking water, than to the canning medium (Uebersax & Bedford, 1980; Larsen *et al*., 1988) due to the significantly greater increase in beans water content and total Ca during soaking compared to can equilibration. Chang (1988) noticed that Ca in the canning medium would lower drained weight when concentrations between 1 and 10 mM were used. Bolles *et al*. (1982) and Van Buren *et al*. (1986) also found increased Ca levels in the canning brine to affect PWDWT and texture.

Navy beans canned in brine containing Ca / EDTA displayed decreased redness and increased yellowness (Chang, 1988). These results were confirmed by Wang *et al*. (1988), but L-values were also found to increase.

NaCl in the canning medium does not significantly affect splitting of beans (Van Buren *et al*., 1986). Beans canned in tomato sauce were noticed to have significantly lower PWDWT and higher texture values than those canned in water (Nordstrom & Sistrunk, 1977). Tomato sauce had lower pH values, that could have caused the inhibition of swelling, due to insoluble complexes formed by organic acids and amylose in the beans or reduced the swelling of protein and starch (Priestly, 1978). Contrary to these results, Anzaldua-Morales & Brennan (1982) found beans canned in tomato sauce to be softer than those canned in brine, due to a possible softening effect that tomato sauce has on the beans. Davis (1976) noticed beans canned in tomato sauce to contain 100 percent split or broken beans.

1.5.2.6.5 Processing and temperature

The sterilization temperature / time combination of canned beans affects the quality of the beans. Beans canned at 121.1 °C for 14 min was noticed to be firmer than those canned at 115.6 °C for 45 min (Chang, 1988). Those canned at 121.1 °C for 60 min were softer than those canned at 115.6 °C for 80 min (Davis, 1976). Davis (1976) concluded that process temperature has a greater effect on quality than process time. The longer the processing time of beans the softer the beans were found to be, while percentage splits and drained mass were noticed to increase (Van Buren *et al.*, 1986). The shorter the cooking time, the firmer the beans and the lower the PWDWT (Heinen & Van Twisk, 1976).

1.6 INFLUENCE OF STORAGE AND PROCESSING ON CHEMICAL, STRUCTURAL AND NUTRITIONAL PROPERTIES

1.6.1 Influence of storage

1.6.1.1 Chemical properties

Storage of dry beans under poor conditions could lead to “hard-to-cook” beans (1.3.8). During prolonged storage of legumes, phytase in beans hydrolyses phytate. The latter is responsible for the chelation of divalent cations (Ca and Mg) of pectates in the middle lamella. When phytate is removed, divalent ions are replaced with monovalent cations (Na and K), which cause pectates to stay insoluble after cooking (Mattson, 1946). The degree of esterification of pectin in bean cells is significantly influenced by storage time, caused by the significant increase in pectin methylesterase activity over storage time (Mafuleka *et al*., 1991).

1.6.1.2 Structural properties

Due to the mechanism explained in 1.6.1.1, hard beans that were stored for a prolonged period, contain tougher middle lamellae between cells, which do not disrupture on soaking and cooking. Instead, hard beans separate intracellularly, causing cell walls to rupture (Aguilera & Steinsapir, 1985). Hardshell beans (1.3.8) are the consequence of prolonged stored beans. The palisade layer within the seed coat, hilum and various waterproofing substances might play a role in lignification, through their production of pigmented polyphenol complexes that might interact with proteins (Stanley & Aguilera, 1985), causing water imperability of the seed coat. Hard-to-cook defect, which is caused in improperly stored beans that imbibe water, but water is mainly found in the intercellular spaces, while that of soft beans is inside the cells (Aguilera & Rivera, 1992).

The seed coat of fresh beans contributes significantly to cooking time. In the case of beans that were subjected to an increased storage time, the contribution of the cotyledons to hardness increases, due to structural and / or biochemical changes in the cotyledons (Jackson & Varriano-Marston, 1981).

1.6.1.3 Nutritional properties

Dry beans are valuable sources of vitamin E and to a lesser extent, riboflavin (1.2.5). On storage of canned beans, vitamin retention decreases. Vitamin E experiences greater losses than riboflavin, as storage time increases (Nordstrom & Sistrunk, 1979). Storage of beans has a detrimental effect on protein quality. Bean protein becomes more susceptible to heat damage during processing when it has been stored for longer than 6 months. The protein digestibility is also affected by storage. A storage period of 3 months lowered protein digestibility, followed by a gradual increase until 6 months' storage (Molina *et al.*, 1975).

1.6.2 Influence of soaking

1.6.2.1 Chemical properties

Chemical compounds with adverse effects on human health and nutrition are classified as antinutritional factors (1.2.6). In beans these substances could be inactivated or eliminated by processing procedures, such as pre-soaking (Elkowicz & Sosulski, 1982) before canning. Conventional soaking followed by cooking was found to reduce phytate in dry beans and is more effective in the reduction of phytate compared to salt-soaked and salt-cooked beans (Iyer *et al*., 1980). Phenolic acids in dry beans are also significantly reduced during soaking and canning of beans, while saponin contents are also reduced. Non-protein nitrogen, found in beans (0.56 g.100 g^{-1} dry mass), is significantly reduced during soaking and canning of beans (Drumm *et al*., 1990). Soaking for 16 or 24 hours also lowers the protein quality of beans, once beans have been stored for six months. This indicates that proteins become more susceptible to damage during the storage period. Soaking does not affect the protein digestibility of beans (Molina *et al*., 1975).

Beans canned without soaking pre-treatment are significantly darker in colour than those that receive a soaking treatment, due to the prevention of pigments leaching into soaking water (Bolles *et al*., 1990; Occeña *et al*., 1992), with consequential better pigment retention in the cooked product (Bolles *et al*., 1990). Pigment leaching of dry beans during a 30 min hot, followed by a 30 min cold soaking period results in lighter coloured beans, while canning of Anasazi beans without a soaking / blanching process results in darker coloured beans than soaked ones (Occeña *et al*., 1992).

The level of soluble pectin present in raw beans correlates significantly (r = -0.84) with canned bean firmness, due to the pectin’s gel forming abilities when reacting with Ca (Lu & Chang, 1996). The addition of Ca to brine or soaking water also increases shear values (Larsen *et al*., 1988).

1.6.2.2 Structural properties

One of the main purposes of soaking is the tenderising effect it has on bean texture (1.4.2). Water uptake (caused by diffusion) takes place during soaking, causing beans to soften and swell (Wang *et al*., 1988), while the seed coat and cotyledons display resistance against swelling (1.3.6).

1.6.2.3 Nutritional properties

The soaking process affects the nutritional value of dry beans, mainly due to losses of substances in the soaking water. Protein losses of 17 and 18 $g.kg^{-1}$ for the F2 and F3 generations of dry beans respectively were found during soaking and cooking of these generations (Wassimi *et al*., 1988). Soaking in solutions containing high or low levels of mono- or divalent anions lowers protein quality of beans significantly, while intermediate concentrations do not have this effect (De León *et al*., 1992).

During soaking, legumes undergo a significant decrease in flatulence causing reducing sugars (1.2.2.2), such as raffinose, stachyose and verbascose, which are proportional to the time of soaking (Jood *et al*., 1985). Raffinose leaches preferentially, compared to sucrose, verbascose, and stachyose (Iyer *et al*., 1980). Soaking at 45 to 65 ° C decreases stachyose levels significantly compared to room temperature soaking (Becker *et al*., 1974).

Soaking of beans also result in mineral losses. Canned kidney beans contain less Fe, Mg, Mn, K and Zn than dry beans, due to losses during soaking, blanching and / or thermal processing (Lopez & Williams, 1988).

1.6.3 Influence of blanching

1.6.3.1 Chemical properties

The main purpose of blanching is the inactivation of enzymes, which might produce off-flavours (1.4.2). Blanching therefore is responsible for directly changing the enzymatic chemical properties of dry beans.

Blanching causes colour changes in canned beans. As with soaking (1.6.2.1), blanching of beans results in lighter coloured beans, due to greater pigment leaching (Occeña *et al*., 1992).

Blanching affects antinutritional factors in beans. Blanching reduces the original TIA of dry beans to only 14 % of its original activity (Wang & Chang, 1988).

1.6.3.2 Structural properties

Blanching causes softening and swelling of the bean structure, as in the case of soaking (1.6.2.2). Blanching decreases processing time, due to the gelatinisation of starch (Wiese & Jackson, 1993), leading to an additional advantage of blanching, as compared to soaking.

1.6.3.3 Nutritional properties

Blanching causes an average of 7 % mineral losses in broad bean. Minerals that experience losses during blanching are K, P, Fe, Zn, Cu and Mn (Kmiecik *et al*., 2000). Canned kidney beans contain less Fe, Mg, Mn, K and Zn than dry beans, due to losses during soaking, blanching and / or thermal processing (Lopez & Williams, 1988).

A combination of blanching- and soaking treatment, followed by discarding the soak water, reduces the indigestible α-galactosidases, which reduce flatus production in rats (Olson *et al*., 1982).

1.6.4 Influence of cooking

1.6.4.1 Chemical properties

As with soaking, antinutritional factors in dry beans are inactivated or eliminated by cooking (Elkowicz & Sosulski, 1982). Cooking for 30 min at 97 °C eliminates TIA of dry bean meal (Antunes & Sgarbieri, 1980). The moist heat applied probably hydrates and changes the secondary and tertiary structures of TIA and CTIA, making them more susceptible to denaturation (Iyer *et al*., 1980). Heating for 1 h also reduces TIA to less than 3 % of its original activity (Dhurandhar & Chang, 1990). Quick cooking (15 min) of dry beans reduces TIA to 8 to 12 % and CTIA to 20 % of their original activity (Iyer *et al*., 1980).

Heat treatment is more effective in the reduction of hemagglutinin activity, than in the case of TIA (Dhurandhar & Chang, 1990). Cooking navy beans at 100 °C for 10 min was found to inactivate hemagglutinin activity completely (Dhurandhar & Chang, 1990). These results were in agreement with those of Antunes & Sgarbieri (1980), who found that heating of water-soaked beans for 5 to 10 min in boiling water was sufficient to inactivate all hemagglutinin activity. The phytic acid levels of beans are only slightly decreased by cooking (Paredes-López *et al*., 1986)

Soluble pectins in dry beans are significantly increased after heat processing (Wang *et al*., 1988).

The reducing saccharides participate in Maillard reactions in the presence of heat, which contribute to the flavour of processed beans (Drumm *et al*., 1990).

1.6.4.2 Structural properties

During cooking the intercellular material within the middle lamella softens to permit the separation of adjacent cells in the beans (Rockland & Jones, 1974).

1.6.4.3 Nutritional properties

The cooking process of beans leads to protein and sugar losses. Meiners *et al*. (1976) found 1 to 3 % protein in the cooking water of beans, indicating protein losses from beans. Prolonged cooking times also lower the cooking quality of beans significantly, irrespective of the storage period after harvesting (Molina *et al*., 1975). The cooking medium affects the chemical properties of beans. Cooking of beans in water results in better protein quality than cooking in salt soaking solutions (De León *et al*., 1992). Paredes-López *et al*. (1986) found cooking to slightly increase the protein digestibility of dry beans, while Molina *et al.* (1975) found the cooking time of beans to have no significant effect on the protein digestibility. Legumes lose 4 to 10 % carbohydrates during the cooking process (Meiners *et al*., 1976).

Cooking of the soaked seeds induces significant losses of raffinose and stachyose (Jood *et al*., 1985). Drumm *et al*. (1990) confirmed these findings by measuring a decrease of 25 % and 55 % in saccharide contents of soaked and canned beans respectively, as saccharides leached from bean tissue into the canning brine. Thermal degradation of oligosaccharides to mono- and disaccharides affects the distribution of saccharides in processed beans (Drumm *et al*., 1990).

A decrease in ash content of beans after cooking indicates mineral losses to the cooking water (Meiners *et al*., 1976).

1.6.5 Influence of sterilization or thermal processing during canning

1.6.5.1 Chemical properties

Added to the effect that soaking and cooking have on antinutritional factors in beans, is the inactivating or eliminating effect that sterilization has on these factors (Elkowicz & Sosulski, 1982). Canned dry beans sterilized for 20 min at 121.1 °C or for 40 min at 115.6 °C retain less than 3 % of the initial TIA and increasing either time or temperature could further destroy TIA. The addition of Ca / EDTA to the brine reduces TIA even more with these canning procedures (Wang & Chang, 1988). Heating hydrolyses phenolic acids in dry beans, thereby reducing this component. Sterilization also causes the saponin contents to be reduced. The latter are not likely to leach into canning brine, due to low water solubility (Drumm *et al*., 1990). Non-protein nitrogen is also present (0.56 g.100 g^{-1} dry mass), but soaking and canning of beans significantly reduce levels (Drumm *et al*., 1990), as indicated in 1.6.2.1.

Phosphorous and Cu levels remain the same in canned beans, while the Na and chloride levels increase in canned beans. The latter could be attributed to the NaCl added to the filling medium of cans (Lopez & Williams, 1988).

The reducing saccharides participate in Maillard reactions in the presence of heat, which contribute to the flavour of processed beans (Drumm *et al*., 1990).

1.6.5.2 Structural properties

Commercial sterilization affects the texture of dry beans, as they continue hydration and expansion while cooked. Bean integrity might be adversely affected by swelling, depending on the compactness of the cell contents and the ability of the seed coat to accommodate the volume of the processed seeds (Heil *et al*., 1992). Beans processed at 121 °C for 30 min are firmer than those processed at 115.6 °C for 45 min (Bolles *et al*., 1990), indicating that sterilization temperature / time combinations also influence texture.

1.6.5.3 Nutritional properties

Canning decreases the protein content of dry beans, as mentioned in 1.2.1. Wang *et al*. (1988) found canning to decrease the protein content of drained beans, with the exception of one cultivar. Autoclaving at 121 °C for 15 min decreases the availability of lysine in dry bean flour and already after 7.5 min a negative effect of heat on nutritive value of protein fractions is shown (Antunes & Sgarbieri, 1980). During canning nitrogenous components, such as amino acids and small chain polypeptides, leach from bean tissue into the brine (Drumm *et al*., 1990), while crude protein also leaches into the canning medium, causing starchiness of the product (Lu & Chang, 1996).

As with all other processing procedures, thermal processing of beans causes mineral losses. Iron, Mg, Mn, K and Zn losses occur during soaking, blanching and / or thermal processing, as discussed in 1.6.2.3 and 1.6.3.3, but P and Cu levels remain the same in canned beans. The Na and chloride levels increase in canned beans, due to the NaCl added to the filling medium of cans (Lopez & Williams, 1988).

Added to the losses in raffinose and stachyose content of beans during cooking (1.6.4.3), further losses are experienced during autoclaving (Jood *et al*., 1985). Leaching of saccharides from bean tissue into the canning brine results in a decrease of 55 % in saccharide content of canned beans (Drumm *et al*, 1990). Thermal degradation of oligosaccharides to mono- and disaccharides also influences the distribution of saccharides in processed beans (Drumm *et al*., 1990).

Processing influences the total lipids and lipid fractions of dry beans, as well as the sterol content. Canning increases these components, due to the leaching of non-lipid fractions into the brine. Processing only slightly influences the fatty acid composition of lipids (Drumm *et al*., 1990).

1.7 LABORATORY OR SMALL-SCALE CANNING

More than 80 % of small white beans produced in South Africa are used for canning in tomato sauce, sold as “baked beans” (De Lange & Labuschagne, 2000). Consumers of bean products are especially aware of the texture, intactness, colour (Faris & Smith, 1964; Hosfield *et al*., 1984b), appearance and digestibility (Hosfield *et al*., 1984b). Canning characteristics of dry beans largely influence final product acceptability, necessitating the canning industry to establish definite acceptability standards in the USA (Hosfield & Ueberrsax, 1980). Developing correct processing and evaluation of canning quality procedures are therefore essential in order for South African laboratory canned beans to also meet consumer and industrial requirements.

Industrial and laboratory scale canning and quality evaluation procedures should be of equally high standards when evaluating the canning quality of beans. Laboratory canning methods enable the dry bean breeder to improve the canning quality of new cultivars through effective selection (De Lange & Labuschagne, 2000). These techniques are generally applied for the testing of dry bean cultivars before commercial release to industry for canning purposes. Laboratory testing of canning quality is necessary, since producers might reject a cultivar with poor canning quality regardless of its ability to deliver increased yields over a range of environments (Hosfield, 1991). The marketing of such beans would also increase the risk of producers not being able to sell their produce, due to the “bad name” that poor quality products might develop in the market. Chances of finding another market for small white beans with a poor canning quality are small in South Africa, since the majority of these beans are used by the canning industry (De Lange & Labuschagne, 2000).

Additionally, small-scale canning enables the breeder to make line selections as early as the F4 generations. At this stage only small quantities of seed are available for each selection, while many selections are available that have to be evaluated for canning quality (De Lange, 1999). Applying laboratory canning techniques that require small sample sizes at these stages would supply the breeder with information for line selections. The use of industrial scale techniques at these early stages is both impractical due to the large sample sizes required, but also costly, offering a third advantage for the use of small-scale techniques.

The National Dry Bean Cultivar Trials are conducted annually by the Agricultural Research Council (ARC) Grain Crops Institute (GCI) in the most important dry bean production areas of South Africa. The aim of these trials is to evaluate commercially available and new cultivars for adaptation under a variety of environmental conditions. Further, these beans are evaluated for acceptability in canning, packaging and export quality. Information obtained from these is used for decision-making on the future of existing and new cultivars, cultivar recommendations and the placing of seed orders by producers (Liebenberg *et al*., 2003).

Various small-scale canning techniques are in use. During these techniques, beans are soaked and blanched (Hosfield & Uebersax, 1980; Balasubramanian *et al*., 2000) or blanched without soaking (De Lange & Labuschagne, 2000), filled into the can together with brine (Hosfield & Uebersax, 1980; Balasubramanian *et al*., 2000) or tomato sauce (De Lange & Labuschagne, 2000), thermally processed and stored for a period to reach equilibrium in the can (Hosfield & Uebersax, 1980; Balasubramanian *et al*., 2000; De Lange & Labuschagne, 2000). Both the uptake of moisture during soaking (WU or HC) and during equilibration (PWDWT) of the beans in the can (Hosfield & Uebersax, 1980; Balasubramanian *et al*., 2000; De Lange & Labuschagne, 2000), are important measurements of canning quality. Although the consumer of the product would not directly perceive these properties, these properties influence other culinary qualities, such as VA (Walters *et al*., 1995), splits (Faris & Smith, 1964; Van Buren *et al*., 1986) and texture (Hosfield & Uebersax, 1980; Ghaderi *et al*., 1984; Occeña *et al*., 1992; Walters *et al*., 1995; Walters *et al*., 1997; Balasubramanian *et al*., 1999), which will be noticed by the consumer (Faris & Smith, 1964; Hosfield *et al*., 1984b).

Visual appearance is one of the preferences of consumers of beans, which is determined subjectively when evaluated in a laboratory (Hosfield, 1991) by means of different hedonic scales. Closely related to VA and also determined subjectively, is splitting, which determines the intactness of processed beans (Hosfield, 1991). Not only would splits of canned beans result in the exudation of starch into the canning medium, but could also lead to unwanted clumping of individual beans (Lu & Chang, 1996). Texture is used as an indication of the degree of consumer acceptance of canned beans (Ghaderi *et al*., 1984; Hosfield, 1991) as it affects the perceived stimulus of chewing (Ghaderi *et al*., 1984), while consumers of beans also have specific preferences about the colour (Hosfield, 1991).

The main differences between industrial and laboratory canning of beans are related to soaking and blanching procedures (Balasubramanian *et al*., 2000). The laboratory canning protocol used by Balasubramanian *et al*. (2000) produced equivalent texture, clumping and VA values for navy and pinto beans, compared to industrial canning protocols. The HC was however found to be poor when using the laboratory protocol, but produced a good estimate of the HC under industrial canning conditions in the absence of hard-to-cook seeds (Balasubramanian *et al*., 2000).

Currently the ARC–GCI makes use of an in house laboratory canning method and evaluation procedure (De Lange & Labuschagne, 2000) for the evaluation of the canning quality of small white beans. Other small-scale canning techniques available for dry beans are those of Hosfield & Uebersax (1980) and Balasubramanian *et al*., (2000). The shortcoming of the technique of De Lange & Labuschagne (2000) is that this technique differs significantly from other accepted techniques indicated in literature. Soaking was excluded, while the blanching period with this technique is longer (40 min at 88 °C) compared to the 30 min soaking followed by 30 min blanching of other techniques (Hosfield & Uebersax, 1980; Balasubramanian *et al*., 2000). This causes low WU values with the first technique, which will be discussed in Chapter 2, and do not nearly meet the specification of 80% WU of the USA (Hosfield *et al*., 1984a; Hosfield, 1991). Thermal processing is also longer (50 min at 121 °C) in the case of De Lange & Labuschagne (2000), compared to the 30 min at 121.1 °C of Bolles *et al*. (1990). Balasubramanian *et al*. (2000) (115.6 °C for 45 min) and Hosfield & Uebersax (1980) also heat sterilized for longer periods but at lower temperatures. The extended period of heat sterilization in combination with the high temperature used by De Lange & Labuschagne (2000) cause beans to have poor VA values, more split beans and too soft textures, which would also be discussed in

Chapter 2. The USA standard for the texture of navy beans is 72 kg.100 g^{-1} (Hosfield & Uebersax, 1980).

Both the laboratory canning techniques of Hosfield & Uebersax (1980) and Balasubramanian *et al*. (2000) were developed using beans other than small white beans, and canning in brine instead of tomato sauce. The use of tomato sauce instead of brine as a canning medium could have significantly different effects on canning quality. Tomato sauce normally has a lower pH than brine, and it is possible that this could cause the inhibition of swelling of beans in the can. The reason for this is the insoluble complexes formed by organic acids and amylose in beans or reduction in the swelling of protein and starch (Priestly, 1978). This could explain why beans canned in tomato sauce had significantly lower PWDWT (Nordstrom & Sistrunk, 1977; Priestly, 1978) and higher texture values than those canned in water (Nordstrom & Sistrunk, 1977). Contrary to these results, Anzaldua-Morales & Brennan (1982) found beans canned in tomato sauce to be softer than those canned in brine, due to a possible softening effect that tomato sauce has on the beans, while Davis (1976) noticed beans canned in tomato sauce to contain 100 percent split or broken beans. All bean types are darker after processing (Paredes-López *et al*., 1986; Bolles *et al*., 1990), but after canning in tomato sauce, no differences in colour of small white beans were observed even though some appeared greyish before canning (Heinen & Van Twisk, 1976). Can sizes used with the techniques of Hosfield & Uebersax (1980) and Balasubramanian *et al*. (2000) were 76.2 x 103.4 mm and 77.0 x 103.1 mm (396.9 g) respectively, as compared to the 73 x 110 mm (410 g) South African cans. Direct application of these techniques to South African small white beans, canned in tomato sauce is therefore not possible.

These problems necessitate the development of more suitable laboratory canning techniques for canning of South African small white beans in tomato sauce or adapting existing procedures for this type of product. Since canning quality standards for canned beans are not clearly defined in South Africa, these techniques should result in a product with standards that are comparable with those set in the USA (Hosfield & Uebersax, 1980; Hosfield *et al*., 1984a; Hosfield, 1991) and Canada

(Balasubramanian *et al*., 1999) and also meet the requirements set by industrial canners.

1.8 BREEDING ANALYSIS FOR CANNING QUALITY

Heritability (H^2) of the characteristics of a population is the proportion of the phenotypic expression of a trait that is due to the genetic causes and is calculated as follows:

H^2 = genotypic variance / phenotypic variance (Hosfield, 1991).

Heritability gives the breeder an indication of the relative importance of genetic and nongenetic factors in the expression of a specific property. Heritability would influence the method and effectiveness of selection for that property. Heritability values vary from zero (low H^2) to one (high H^2). Properties with higher H^2 are less affected by environmental factors and could often be selected without testing over multiple localities and seasons. On the other hand properties with low H^2 would be strongly affected by environment (Walters *et al*., 1995). The most important production factor of dry beans for example is yield, which is determined by more than one gene, which each has a small effect on the yield trait (Hosfield, 1991). Other factors than genotype would therefore mostly cause differences in yield of dry beans. This was illustrated by the fact that more variation was found between bean producing localities (903 to 2 8 35 ton.ha-^{1}) than between cultivars (1101 to 2 567 ton.ha^1) for dry bean yields during 2002/03 (Liebenberg *et al*., 2003).

One of the hurdles that has to be overcome when trying to improve a trait by breeding is the unpredictable effects of environment that often cause genotype x environmental (G x E) interactions (Hosfield, 1991). Significant cultivar x locality interactions suggest that cultivars do not perform consistently over localities, necessitating that cultivars be tested in time and space (Ghaderi *et al*., 1984). Season also has a significant effect on canning quality and all traits were more affected by season than by genotype. With the exception of WDWT and texture, it was reported by Hosfield *et al.* (1984a) that all canning parameters were more significantly affected by genotype x season (G x Y) interactions than genotype, indicating that strains responded non-uniformly over years.

The WU of beans during soaking was indicated to have genetic variability, but gene expression is often environment dependent and subjected to G x E interactions (Hosfield & Uebersax, 1984a). Due to the low H^2 of HC the use of the known genetic variation influencing this trait is difficult (Hosfield, 1991). The colour of beans is inherited by major genes (Moh, 1971), but the influence of environment often leads to a wide variation in whiteness values (Ghaderi *et al.*, 1984). Since significant variability in the colour of dry and cooked beans is available (Ghaderi *et al.*, 1984), breeders have enough raw materials for selection to improve the colour traits of canned beans (Hosfield, 1991). Canning characteristics, such as VA, clumping and splits are determined subjectively and therefore have a large nongenetic component affecting phenotypic expression, these traits are determined with a high enough degree of accuracy to make them useful selection criteria for breeding (Hosfield, 1991). Despite the significant effect of environment on canning quality, all canning properties (HC, WDWT, VA, solids loss and texture) were found to be moderately to highly heritable. This would suggest that these properties are affected by a few major genes rather than a large number of genes with limited effects. Subjective measurements, such as VA would have lower H^2 values due to the effect of subjective perceptions (Walters *et al.*, 1995).

Quality evaluation characteristics of dry beans, such as colour , size and shape could be sorted out quite easily in the early stages of breeding (F3 and F4), while soaking and canning characteristics should be tested at the later stages of breeding (F4 and F5) after yield problems were preliminarily sorted out. This would have a cost saving effect, since the performance soaking and canning tests on a large number of samples would be expensive. At each stage of the breeding process, beans with poor characteristics should be discarded (Ghaderi *et al.*, 1984).

1.9 OBJECTIVE OF THIS STUDY

As mentioned, the ARC–GCI annually evaluates the canning quality of small white bean cultivars submitted for testing in the National Cultivar Trials. As producers, seed companies, breeders, as well as the canning industry use these results for decision-making, the scientific accuracy and comparability of this information to those of the industry are of utmost importance. The problem is to identify whether the present laboratory canning and evaluation system would result in similar cultivar and breeding line selections as those made by industry based on canning quality. The objectives of this study were to:

1. Develop a small-scale canning technique with subsequent evaluation procedures for beans in tomato sauce that can comply with internationally accepted specifications, and can also be compared to industrially canned beans.
2. Evaluate whether this small-scale technique results in the same specifications as standard industrial scale canning procedures.
3. Evaluate whether the small-scale technique, together with multivariate analysis, can be successfully applied to classify dry bean cultivars as “choice” or “standard” grade beans.
4. Identify a possible model with multivariate analysis to predict the canning quality of beans, using the assistance of the small-scale canning technique.
5. Evaluate whether the small-scale canning technique can be successfully implemented as a method for breeding line selection based on canning quality with the assistance of the canning quality prediction model.

CHAPTER 2

EVALUATION AND STANDARDIZATION OF SMALL- SCALE CANNING TECHNIQUES AND EVALUATION PROCEDURES FOR BEANS IN TOMATO SAUCE

2.1 INTRODUCTION

Consumers of bean products are aware of the texture, intactness, colour (Faris & Smith, 1964; Hosfield *et al*., 1984b), appearance, digestibility (Hosfield *et al*., 1984b), ease of preparation (Hosfield *et al*., 1984b; Giami & Okwechime, 1993) and the saving of cooking fuel (Balasubramanian *et al*., 2000). Industrial and laboratory scale canning and quality evaluation procedures should be of equally high standards when evaluating the canning quality of beans.

The National Dry Bean Cultivar Trials are conducted annually by the ARC-GCI in the most important dry bean production areas of South Africa. The aim of these trials is to evaluate commercially available and new cultivars for adaptation under a variety of environmental conditions. Secondly, these beans are evaluated for acceptability in canning, packaging and export purposes. Information obtained from these trials is used for decision-making on the future of existing and new cultivars, cultivar recommendations and the placing of seed orders by producers (Liebenberg *et al*., 2003). The scientific accuracy and comparability of canning results to those of the industry are therefore of utmost importance.

The ARC-GCI evaluates dry beans for canning quality by means of an in-house laboratory canning technique (De Lange & Labuschagne, 2000). This laboratory technique differs from other laboratory canning techniques described in literature (Hosfield & Uebersax, 1980; Balasubramanian *et al*., 1999). With the technique of De Lange & Labuschagne (2000), soaking is excluded, while the blanching period is extended. This causes lower WU values compared to the 80 % of the USA regulations (Hosfield *et al*., 1984a; Hosfield, 1991). Thermal processing is also longer, resulting in beans to have poor VA values, more split beans and too soft textures The USA standard for the texture of navy beans is 72 kg.100 g^{-1} (Hosfield & Uebersax, 1980).

Both the techniques of Hosfield & Uebersax (1980) and Balasubramania *et al*. (2000) were developed for beans other than small white beans and brine, instead of tomato sauce. The use of tomato sauce instead of brine as a canning medium could have significantly different effects on canning quality (Davis, 1976; Nordstrom & Sistrunk, 1977; Priestly, 1978; Anzaldua-Morales & Brennan, 1982). The can sizes used in the techniques in the literature are also different from South African cans. Direct application of these techniques to South African small white beans, canned in tomato sauce is therefore not possible.

These problems necessitates the development of more suitable laboratory canning techniques for canning of South African small white beans in tomato sauce or adapting existing procedures for this type of product. Since canning quality standards for canned beans are not clearly defined in South Africa, these techniques should be comparable to the standards of the USA (Hosfield & Uebersax, 1980) and Canadian government regulations (Balasubramanian *et al*., 1999) and also meet the requirements set by industrial canners. The objectives of this chapter were to:

1. Evaluate the existing laboratory technique used by ARC-GCI by comparing it with an industrial canning technique.
2. Develop a new laboratory canning technique or modifying an existing technique and compare it with the ARC-GCI and industrial techniques.
3. Identify the laboratory canning technique that would deliver a product quality similar to that of literature standards.
4. Standardize the use of evaluation procedures according to results of the current and modified evaluation procedures.
5. Define standard values for choice grade and standard grade beans for laboratory evaluation of canning quality.

2.2 MATERIALS AND TECHNIQUES

2.2.1 Selection of dry bean cultivars

Four small white dry bean cultivars submitted for testing in the National Dry Bean Cultivar Trials of the ARC-GCI during the 2000/01 season were used. These cultivars were Helderberg, OPS-KW1, PAN 185 and Teebus. The reason for the use of only four cultivars was that these cultivars were the only ones that were commercially available during this season. More cultivars would be used in Chapter 4 where two seasons were considered, while lines selected for breeding would be considered in Chapter 5 to evaluate material with a wider genetic background. The four cultivars under study were obtained from nine localities representing four dry bean growing areas of South Africa, namely Bapsfontein, Ermelo (Gauteng / Mpumalanga area); Bethlehem, Clocolan, Harrismith, Reitz (Free State area); Cedara, Greytown (KwaZulu-Natal area) and Lichtenburg (North West / Northern Cape area). Nine localities were used to incorporate more variation in environments for the development of canning techniques, although industrial canners generally buy beans according to the most important dry bean production areas. The nine localities were chosen to give a good representation of the four main dry bean production areas. Teebus was used as reference standard for “choice grade” and Helderberg for “standard grade”, as indicated by De Lange & Labuschagne (2000). Teebus is also the reference standard used by most commercial canners. The four cultivars were planted in a randomised block design with three replicates. Four row plots (5 m long and 750 mm apart) were planted using a self-driven planter. Beans were planted at 75 mm spacing within rows. Fertilisation was applied at recommended rates for each locality. Samples were harvested manually from the middle two rows of each plot. Three replicates per cultivar were combined into one sample before receiving it for canning procedures. Therefore samples were canned in duplicate for the purpose of this chapter. All samples were kept refrigerated at 4 °C for no longer than two months before canning.

2.2.2 Application of different canning techniques

Three canning techniques were used, namely laboratory canning - (LCT), industrial canning - (ICT) and modified canning technique (MCT). The procedures are described in 2.2.2.1 tot 2.2.2.3 and summarized in Table 2.1.

Table 2.1 Summary of the canning techniques used to compare the canning quality of four small white bean cultivars from nine localities during 2000/01 using different canning procedures

Processing conditions	Canning technique		
	Laboratory canning technique LCT	Industrial canning technique ICT	Modified canning technique MCT
Dry beans mass (g)	100 g	120 g	96 g
Fill mass (g)	210 g	210 g	equivalent of 96 g of soaked beans
Soaking	none	18 h in cold water	30 min at room temperature
Blanching	40 min at 88 ˚C	8 min at 85 ˚C	80 min at 88 ˚C
Thermal processing	50 min at 121.1 ˚C	32 min at 127 ˚C	30 min at 121.1 ˚C

2.2.2.1 Laboratory canning technique (LCT)

The in-house technique used by the ARC-GCI for canning quality evaluation of small white beans was as follows: Samples of 100 g dry beans were placed in nylon mesh bags and blanched for 40 min at 88 °C, followed by cooling in tap water. Samples of 100 g beans were used in order to obtain at least 210 g blanched beans after the blanching period. To determine the WU during soaking / blanching, samples were drained on a 500 µm mesh sieve placed at a 15 ° angle for 2 min. The percentage WU was determined as follows (De Lange & Labuschagne, 2000):

% WU = ((mass blanched beans (g) – mass of dry beans (g)) / mass of dry beans (g)) x 100

Each can (73 x 110 mm one piece cans and 73 mm ends) with a capacity of 410 g was filled with 210 g blanched beans and 200 g tomato sauce and sealed with a Dixie Automatic Can Sealer (Dixie Canner Co., Athens, GA, U.S.A). The sealed cans were heat sterilized in a Huxley vertical autoclave (model HL30, 50 L, 50 Hz) at 121.1 °C

for 50 min, followed by instant cooling in tap water. After canning, a storage period of two weeks was allowed for the beans and the moisture in the tomato sauce to reach equilibrium (De Lange, 1999).
Distilled water with added calcium chloride dihydrate (at 10 ppm) was used both for blanching and in the canning medium, instead of tap water as described by Balasubramanian *et al*. (1999), for uniform water quality.

The in-house tomato sauce recipe of the ARC-GCI was used by cooking the following: 876 g tomato puree, 246 g white sugar, 118 g brown sugar, 65 g salt and 325 g water (distilled water supplemented with 10 ppm $CaCl_2.2H_2O$).

2.2.2.2 Industrial canning technique (ICT)

An ICT with an overnight soaking step was used for canning in the laboratory. This technique is not a standard technique for industrial canning, but an example of one of the many techniques available. Samples of 120 g dry beans were placed in nylon mesh bags and soaked for 18 h in cold water. Distilled water with the same levels of $CaCl_2.2H_2O$ was used as in 2.2.2.1. Soaking was followed by blanching for 8 min at 85 °C in fresh distilled water, with $CaCl_2.2H_2O$ added. Cooling of samples and draining was done as in 2.2.2.1. The percentage WU was determined as in 2.2.2.1 after soaking and blanching.

The tomato sauce used was the same as in 2.2.2.1. Each can was filled with 210 g blanched beans and 200 g tomato sauce, and sealed. The sealed cans were heat sterilized in a vertical autoclave at 127 °C for 32 min, followed by cooling in tap water (2.2.2.1). Storage was the same as in 2.2.2.1.

2.2.2.3 Modified canning technique (MCT)

The canning technique described by Balasubramanian *et al*. (1999) for the canning of navy, black and pinto beans was used, replacing the brine with tomato sauce. Can sizes were as in 2.2.2.1 (410 g), instead of the 14 oz (396.9 g) cans used by

Balasubramanian *et al*. (1999). Samples of 96 g small white beans (same as for navy beans) were placed in nylon mesh bags, soaked for 30 min at room temperature, and blanched for 30 min at 88 °C. Water hardness was as described in 2.2.2.1 and the same procedures for the cooling, draining and determining WU were used as in 2.2.2.1.

The soaked and blanched beans (soaked beans equivalent to the 96 g of dry sample used) were transferred to cans (Balasubramanian *et al*., 1999), filled to a mass of 410 g with tomato sauce and sealed as described in 2.2.2.1. The sealed cans were heat sterilized in a vertical autoclave (2.2.2.1) at 121.1 °C for 30 min as described by Bolles *et al*. (1990). Cooling and storing procedures were as described in 2.2.2.1.

2.2.3 Canning quality evaluation procedures of laboratory canned beans

Two canning evaluation procedures were used for the evaluation of beans, namely the laboratory canning evaluation procedure (LCEP) and the modified canning evaluation procedure (MCEP), which are described in 2.2.3.1 and 2.2.3.2. The differences in the evaluation parameters used with the LCEP and MCEP are summarized in Table 2.2.

Table 2.2 Summary of the canning evaluation procedures used to compare the canning quality four small white bean cultivars from nine localities during 2000/01 using different evaluation techniques

Canning parameters	Canning evaluation procedures	
	Laboratory canning evaluation procedure (LCEP)	Modified canning evaluation procedure (MCEP)
Water uptake (WU)	$WU = \frac{\text{Mass of soaked beans -Mass of dry beans}}{\text{Mass of dry beans}} \times 100$ WU of 80 % is considered optimum (Hosfield, 1991).	
Hydration coefficient (HC)		$HC = \frac{\text{Mass of soaked beans}}{\text{Mass of dry beans}}$ HC of 1.8 is considered optimum (Hosfield, 1991).
Percentage washed drained weight (PWDWT)	$PWDWT = \frac{\text{Washed drained weight}}{\text{Mass of can contents}} \times 100$ PWDWT of 60 % is considered optimum (Balasubramanian *et al*., 1999).	$PWDWT = \frac{\text{Washed drained weight}}{\text{Mass of can contents}} \times 100$ PWDWT of 60 % is considered optimum (Balasubramanian *et al*., 1999).
Visual appearance (VA)	Presence of loose seed coats, intactness, uniformity in size and colour, sauce consistence and colour. Value of 10 = intact beans, no free seed coats, uniform size and colour, bright shiny colour. Value of 1 = broken beans, loose seed coats, dull colour, dull and thick tomato sauce (De Lange & Labuschagne, 2000).	Presence of loose seed coats, intactness, uniformity in size and colour, sauce consistence and colour Value of 5 = intact beans, no free seed coats, uniform size and colour, bright shiny colour. Value of 1 = broken beans, loose seed coats, dull colour, dull and thick tomato sauce (Balasubramanian *et al*., 1999)
Texture	Determined on 100 g of beans with a FTC Texture Press equipped with load cell. Measured in kg.100 g^{-1}.12 s^{-1} and kg.s $^{-1}$ (De Lange & Labuschagne, 2000). Value of 72 kg.100 g^{-1} is considered optimum for navy beans in USA (Hosfield & Uebersax, 1980).	Determined on 100 g of beans with a FTC Texture Press equipped with load cell. Measured in kg.100 g^{-1}.12 s^{-1} (De Lange & Labuschagne, 2000). Value of 72 kg.100 g^{-1} is considered optimum for navy beans in USA (Hosfield & Uebersax, 1980).
Splits	Beans with cracks, splits and loose skins evaluated on a scale from 1 to 10. Value of 1 = completely broken and mushy beans. Value of 10 = beans without cracks, splits or loose skins (De Lange & Labuschagne, 2000).	Completely broken beans and skins expressed as a actual percentage in 100 g sample.
Size		Seed size within bean sample evaluated on 1 to 7 scale. Uniformity in size and exceptionally large or small beans considered. Value of 1 = exceptionally large or small seeds, unevenly sized. Value of 7 = beans of regular size, evenly sized.
Clumping		Degree of clumping of beans in can on 1 to 3 scale. Value of 1 = beans solidly clumped to bottom of can. Value of 3 = no clumping, easily decanted (Balasubramanian *et al*., 1999).
Colour		Colour of washed drained beans measure on Hunter Lab Colorquest (45/0) (Balasubramanian *et al*., 1999).
Viscosity		Viscosity of tomato sauce measured with a Brookfield viscometer with no. 3 spindle at 100 rpm (Balasubramanian *et al*., 1999).

2.2.3.1 Laboratory canning evaluation procedure (LCEP)

Small white beans canned with the LCT, ICT and MCT were evaluated for canning quality, using the evaluation procedures described by De Lange & Labuschagne (2000), which is also the in-house technique used by ARC-Grain Crops Institute and is laid out below.

2.2.3.1.1 Percentage washed drain weight (PWDWT)

Cans were opened after the storage period and beans were drained and washed in tap water for 2 min on a 1000 μm sieve to remove the tomato sauce (De Lange & Labuschagne, 2000).

Washed drained mass (WDM) was determined, as was used by De Lange & Labuschagne (2000), calculated as the mass (g) gained by the beans in the can during the storage period of two weeks. Instead of using the WDM, the PWDWT was calculated from WDM to compare the canning techniques on the same basis, since the original mass of beans in the can was different for the MCT than for the LCT and ICT. The PWDWT was calculated as follows (Balasubramanian *et al.*, 1999):

$$\text{PWDWT} = (\text{WDWT (g)} / \text{Mass of can contents (g)}) \times 100$$

2.2.3.1.2 Visual appearance (VA)

Visual appearance was determined subjectively on washed and drained beans on a scale from 1 to 10, as described by De Lange & Labuschagne (2000). Criteria that were taken into account were the presence of loose or free seed coats, individual bean integrity, uniformity in size and colour and sauce consistence and colour. A score of 1 indicated broken beans with loose seed coats and a dull colour, while tomato sauce was dull and thick in appearance. At the other end, a score of 10 indicated intact beans, with skins still attached and a clear and shiny surface colour, with colour uniformity. Thus, high values are the desired trait.

2.2.3.1.3 Splits

Bean splitting was evaluated subjectively on washed drained beans on a scale from 1 to 10 (with 1 indicating the maximum and 10 the minimum number of split beans) (De Lange & Labuschagne, 2000). Beans considered as split beans were those with cracks, broken beans and loose skins. A score of 1 indicated completely broken, mushy beans, while 10 indicated intact beans without any cracks or loose skins. Again, high values are the desired trait.

2.2.3.1.4 Texture

The texture of beans was determined, using 100 g of washed drained beans, by means of a FTC Texture Press (model TP-1A Shear, Food Technology Corporation, Rockville, USA), equipped with a load cell and a multiblade system. The samples were placed inside the load cell and force applied until the blades went through the bean sample. Texture data were stored electronically at 0.1-second intervals for 12 seconds. Texture data were indicated by a texture curve, with the maximum resistance at the peak of the curve. Data recorded were the maximum resistance experienced in the load cell (kg.100 g^{-1}.12 s^{-1}) (TXT1), as well as the total resistance, which were calculated from surface area underneath the graph (kg.s^{-1}) (TXT2) (De Lange & Labuschagne, 2000).

2.2.3.1.5 Statistical analysis

Analysis of Variance (ANOVA) was carried out on each canning quality parameter to identify significant differences among techniques using Costat (Cohort Version 3.02). A randomised block ANOVA was used and the R^2-values, root mean square error (RMSE) and coefficient of variation (CV) calculated as follows:

R^2 = Sum square model / Sum square total

RMSE = Square root of mean square error

CV = Square root of mean sum square as percentage of mean value of all data

The percentage contribution of each factor to the variance was determined by a variance component analysis (VCA) using Statgraphics 5 Plus.

2.2.3.2 Modified canning evaluation procedure (MCEP)

Based on results obtained with the LCEP, comparison of evaluation procedures was only done for beans canned with the MCT. These beans were also evaluated according to the MCEP to enable the comparison of the LCEP and MCEP.

2.2.3.2.1 Hydration coefficient (HC)

The HC (Hosfield & Uebersax, 1980) was used instead of the WU that is used in the LCEP (De Lange & Labuschagne, 2000). The HC indicates the increase in dry bean mass due to water uptake during soaking, relative to the dry state (Hosfield *et al*., 1984b). Samples were drained as described for the LCEP. The HC was calculated by weighing the drained samples and using the following equation (Hosfield & Uebersax, 1980):

HC = Mass of soaked beans (g) / Mass of dry beans (g)

A HC value of 1.80 is therefore usually considered optimal for dry beans (Hosfield *et al*., 1984a; Hosfield, 1991).

2.2.3.2.2 Percentage washed drained weight (PWDWT)

The PWDWT was determined as for the LCEP (2.3.1.1).

2.2.3.2.3 Visual appearance (VA)

Visual appearance of the canned washed drained beans was determined subjectively on a scale from 1 to 5 (Hosfield & Uebersax, 1980) instead of the 1 to 10 scale used for the LCEP (De Lange & Labuschagne, 2000). Washed and drained beans were visually evaluated and criteria that were taken into account were the presence of loose or free seed coats, individual bean integrity, uniformity in size and colour and sauce consistency and colour. A score of 1 indicated beans of poor appearance, while a score of 5 indicated excellent appearance. Thus, high values are the required trait.

2.2.3.2.4 Splits

Splits were determined as the actual percentage of split beans found in a sample, as was recommended by industry. Only completely broken beans and loose skins were considered as splits. Faris & Smith (1964) determined the actual percentage of splits by canning 100 seeds and calculating the percentage broken seeds after canning. This technique was modified to calculate the percentage splits on a mass basis by removing and weighing all the split beans from a 100 g sample, since the use of the total sample from the can is a time-consuming process when many samples are considered.

2.2.3.2.5 Texture

Texture was determined as for the LCEP, but only TXT1 was used, based on results from 2.2.3.1.4.

2.2.3.2.6 Seed size

Seed size within each bean sample was evaluated visually on a scale from 1 to 7. Washed and drained beans were mainly evaluated for uniformity in size, while exceptionally large or small sized samples were also considered. Beans with a size value of 7 would have been samples with uniformity in seed size and beans of regular size, while those with a score of 1 would have been exceptionally large, small or uneven in seed size. Thus, high values are the desired trait.

2.2.3.2.7 Clumping

Determination of the degree of clumping of beans was done on a scale from 1 to 3. Beans were decanted from the opened cans. A score of 1 indicated solid clumping of beans at the bottom of the can, while a value of 3 indicated no clumping. Beans with a value of 2 experienced clumping, but were easily decanted. (Balasubramanian *et al.*, 1999). High CL values are thus the desired trait.

2.2.3.2.8 Colour of canned beans

The colour of canned washed drained beans was measured with a HunterLab colour meter (Colorquest 45/0) (Hunter Associates Laboratory Inc., Reston, VA) (Balasubramanian *et al.*, 1999). The sample cup (64 mm diameter; 37 mm height) was filled to the top with washed drained beans. The sample cup was dropped once from about two centimetres above the working surface to distribute the sample evenly. Five repacks per samples were done. The L-, a_L- and b_L-values were recorded. The L-value indicates the spectrum between white (100) and black (0), a_L-value indicates red (+) and green (-) and b_L-value indicates yellow (+) and blue (-) (Hosfield *et al.*, 1984b; Chung *et al.*, 1995).

2.2.3.2.9 Viscosity of tomato sauce

Viscosity of the tomato sauce of canned beans was not determined, due to a lack of enough samples. Viscosity measurements were done by Balasubramanian *et al.* (1999) on the brine of canned samples and would be performed in Chapter 4 on the tomato sauce of cultivar evaluation samples.

2.2.3.2.10 Statistical analysis

Analysis of variance was conducted for data from the LCEP and MCEP on each canning quality parameter to identify significant differences among cultivars, localities and for different evaluation techniques, using Costat (Cohort Version 3.02). A randomised block ANOVA was used. The R^2-values, RMSE and CV were calculated as in 2.2.3.1.5.

2.3 RESULTS AND DISCUSSION

2.3.1 Application of different canning techniques

The WU, PWDWT, VA, splits and texture (TXT1 & TXT2) values of four small white beans from nine localities, that were canned according to the laboratory, industrial and modified literature techniques, are provided in Tables 2.3.1 to 2.8.3. All canning quality parameters were significantly different for cultivars, localities and canning techniques (Table 2.9). Most of the variation in data was caused by the canning techniques as indicated by the higher F-values. No significant differences were found between sample replicates, as the same samples were canned in duplicate. The significant differences ($P < 0.01$) recorded between canning techniques for all canning quality parameters were an indication that an acceptable canning technique should be selected from the three, that produces canned beans with similar quality properties to those provided by industry.

Table 2.10 shows the R^2-values, root mean square errors (RMSE) and coefficients of variation (CV) for canning parameters, which should approach 1.0, 0 and 0 respectively. All R^2-values were close to 1.0 and significant ($P < 0.01$). All RMSE values were lower than 5.0, except for TXT2. All CV values were lower than 10, which were considered acceptable.

Table 2.3.1 Percentage water uptake of four small white bean cultivars (2000/01 season) from nine localities during soaking (laboratory canning technique)

Cultivar (n =4)	Replicate (n =2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	72.32	75.30	74.21	75.93	72.83	66.86	73.45	75.49	61.68	72.01
Helderberg	2	75.65	72.13	72.05	73.81	69.56	63.88	75.62	76.20	61.82	71.19
OPS-KW1	1	71.18	67.12	64.19	63.41	74.96	52.31	72.06	76.00	62.75	67.11
OPS-KW1	2	72.29	68.98	65.89	63.95	69.18	50.94	70.15	75.74	62.46	66.62
PAN 185	1	71.19	69.47	73.54	78.83	71.36	66.04	78.14	77.16	63.90	72.18
PAN 185	2	72.27	64.74	71.02	79.34	74.17	69.38	77.75	76.84	64.91	72.27
Teebus	1	58.03	52.51	64.54	59.84	64.39	49.49	34.31	65.73	48.08	55.21
Teebus	2	59.19	55.80	61.06	58.73	60.28	49.63	34.68	63.83	50.44	54.85
Mean		69.02	65.76	68.31	69.23	69.59	58.57	64.52	73.37	59.51	
Min		58.03	52.51	61.06	58.73	60.28	49.49	34.31	63.83	48.08	
Max		75.65	75.30	74.21	79.34	74.96	69.38	78.14	77.16	64.91	
Range		17.62	22.79	13.15	20.61	14.68	19.88	43.83	13.33	16.83	

%CV = 1.04

Table 2.3.2 Percentage water uptake of four small white bean cultivars (2000/01 season) from nine localities during soaking (industrial canning technique)

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	88.87	89.74	89.79	97.19	87.93	93.17	90.12	90.16	75.87	89.20
Helderberg	2	89.17	90.96	89.28	96.55	86.67	93.57	91.34	88.56	73.82	88.88
OPS-KW1	1	87.56	90.15	90.07	91.33	86.78	98.08	90.59	88.36	79.33	89.14
OPS-KW1	2	88.66	89.69	90.11	92.79	85.63	97.12	90.94	88.15	80.20	89.25
PAN 185	1	85.87	88.92	87.53	96.50	86.40	94.18	90.43	88.40	76.59	88.31
PAN 185	2	87.27	89.51	87.37	97.10	85.60	93.21	91.43	87.57	75.49	88.28
Teebus	1	78.23	79.97	82.22	80.76	83.88	82.20	75.50	82.95	73.70	79.93
Teebus	2	77.64	80.34	82.42	78.58	83.74	82.97	75.52	84.23	72.63	79.78
Mean		85.41	87.41	87.35	91.35	85.83	91.81	86.98	87.30	75.95	
Min		77.64	79.97	82.22	78.58	83.74	82.20	75.50	82.95	72.63	
Max		89.17	90.96	90.11	97.19	87.93	98.08	91.43	90.16	80.20	
Range		11.53	10.99	7.89	18.62	4.19	15.89	15.94	7.21	7.57	

%CV = 0.81

Table 2.3.3 **Percentage water uptake of four small white bean cultivars (2000/01 season) from nine localities during soaking (modified canning technique)**

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	84.56	85.39	81.41	89.05	83.62	84.28	84.83	82.87	82.73	84.31
Helderberg	2	83.70	85.35	82.90	88.13	82.74	84.42	85.12	84.24	82.81	84.38
OPS-KW1	1	83.51	85.66	81.84	80.77	84.22	84.45	82.31	83.01	82.83	83.18
OPS-KW1	2	83.87	84.94	83.00	79.51	85.22	84.31	82.20	82.71	82.90	83.18
PAN 185	1	83.95	85.89	84.27	83.02	86.01	83.82	85.43	83.33	83.67	84.38
PAN 185	2	84.98	85.47	83.17	80.92	81.19	83.15	85.41	82.94	83.44	83.41
Teebus	1	74.97	78.65	74.22	77.23	79.49	70.99	72.68	73.51	73.09	74.98
Teebus	2	74.12	79.19	72.35	76.68	79.82	72.92	73.39	73.96	73.56	75.11
Mean		81.71	83.82	80.39	81.91	82.79	81.04	81.42	80.82	80.63	
Min		74.12	78.65	72.35	76.68	79.49	70.99	72.68	73.51	73.09	
Max		84.98	85.89	84.27	89.05	86.01	84.45	85.43	84.24	83.67	
Range		10.86	7.24	11.93	12.37	6.52	13.46	12.75	10.74	10.58	

%CV = 1.04

Table 2.4.1 **Percentage washed drained weights of four canned small white bean cultivars (2000/01 season) from nine localities (laboratory canning technique)**

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	69.89	72.92	72.82	72.9	73.93	76.52	71.35	74.35	69.7	72.71
Helderberg	2	70.19	73.23	73.36	73.22	76.19	74.61	70.95	74.35	70.3	73.15
OPS-KW1	1	91.98	76.59	78.8	74.86	75.08	75.9	72.93	69.1	73.1	74.26
OPS-KW1	2	70.38	76.64	77.8	76.97	76.44	76.1	73.56	69.44	73.8	74.57
PAN 185	1	71.51	72.79	71.32	71.79	74.6	75.8	71.1	68.95	69.9	71.98
PAN 185	2	69.57	73.92	73.03	73.19	74.32	74.36	70.51	69.5	70.3	72.08
Teebus	1	72.73	74.75	76.24	75.12	78.91	73.15	69.39	76.88	71.7	74.32
Teebus	2	73.34	73.99	74.78	76.98	78.84	75.16	69.34	75.31	71.2	74.33
Mean		71.2	74.35	75.02	74.38	76.04	75.2	71.14	72.24	771	
Min		69.57	72.79	71.32	71.79	73.93	73.15	69.34	68.95	69.7	
Max		73.34	76.64	78.8	76.98	78.91	76.52	73.56	76.88	73.8	
Range		3.78	3.86	7.48	5.19	4.98	3.38	4.22	7.93	4.02	

%CV = 1.42

Table 2.4.2 Percentage washed drained weights of four canned small white bean cultivars (2000/01 season) from nine localities (industrial canning technique)

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	66.98	68.16	70.34	67.41	45.84	60.93	56.26	43.27	56.54	58.46
Helderberg	2	66.50	66.09	71.01	67.49	45.53	60.61	56.68	43.64	57.32	57.66
OPS-KW1	1	67.00	68.92	69.00	68.25	45.56	59.13	55.60	43.31	58.78	56.54
OPS-KW1	2	67.71	68.90	71.22	70.90	45.28	53.97	55.98	43.26	57.98	57.32
PAN 185	1	69.05	68.71	72.00	68.13	45.46	58.97	57.21	43.40	57.71	58.78
PAN 185	2	68.49	67.79	73.19	71.38	45.27	59.94	56.68	43.33	57.17	57.98
Teebus	1	73.32	73.11	73.67	75.91	44.85	58.31	57.55	41.05	58.46	57.71
Teebus	2	72.86	73.64	72.26	76.57	44.81	58.06	56.76	41.19	57.66	57.17
Mean		68.99	69.42	71.59	70.75	45.32	58.74	56.59	42.81	57.70	
Min		66.50	66.09	69.00	67.41	44.81	53.97	55.60	41.05	56.54	
Max		73.32	73.64	73.67	76.57	45.84	60.93	57.55	43.64	58.78	
Range		6.82	7.55	4.66	9.15	1.02	6.97	1.95	2.59	2.24	

%CV = 1.60

Table 2.4.3 Percentage washed drained weights of four canned small white bean cultivars (2000/01 season) from nine localities (modified canning technique)

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	56.75	59.12	60.10	57.97	56.62	60.93	56.26	58.64	56.54	58.10
Helderberg	2	56.96	58.71	60.33	57.39	57.26	60.61	56.68	58.00	57.32	58.14
OPS-KW1	1	55.70	59.00	59.28	56.35	56.62	59.13	55.60	58.59	58.78	57.67
OPS-KW1	2	56.67	58.68	56.70	56.34	56.07	53.97	55.98	57.61	57.98	56.67
PAN 185	1	56.59	57.84	60.35	57.87	56.20	58.97	57.21	56.95	57.71	57.74
PAN 185	2	55.93	58.29	57.44	57.88	56.44	59.94	56.68	57.45	57.17	57.47
Teebus	1	59.81	59.60	57.04	58.70	59.60	58.31	57.55	58.30	58.46	58.60
Teebus	2	59.49	60.06	57.02	58.69	59.29	58.06	56.76	58.72	57.66	58.42
Mean		57.24	58.91	58.54	57.65	57.26	58.74	56.59	58.03	57.70	
Min		55.70	57.84	56.70	56.34	56.07	53.97	55.60	56.95	56.54	
Max		59.81	60.06	60.35	58.70	59.60	60.93	57.55	58.72	58.78	
Range		4.11	2.21	3.65	2.36	3.52	6.97	1.95	1.77	2.24	

%CV = 1.42

Table 2.5.1 Visual appearance (scale 1 to 10) of four canned small white bean cultivars (2000/01 season) from nine localities canned with the laboratory canning technique and evaluated with the laboratory canning evaluation procedure

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	6.00	6.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	6.78
Helderberg	2	6.00	6.00	7.00	5.00	7.00	7.00	7.00	7.00	7.00	6.56
OPS-KW1	1	7.00	7.00	7.00	6.00	6.00	7.00	6.00	7.00	8.00	6.78
OPS-KW1	2	7.00	7.00	7.00	6.00	7.00	8.00	6.00	6.00	8.00	6.89
PAN 185	1	7.00	6.00	7.00	8.00	6.00	7.00	7.00	6.00	7.00	6.78
PAN 185	2	7.00	6.00	7.00	7.00	6.00	7.00	7.00	6.00	7.00	6.67
Teebus	1	7.00	8.00	9.00	7.00	7.00	7.00	7.00	8.00	9.00	7.67
Teebus	2	7.00	7.00	8.00	6.00	8.00	8.00	7.00	8.00	9.00	7.56
Mean		6.75	6.63	7.38	6.50	6.75	7.25	6.75	6.88	7.75	
Min		6.00	6.00	7.00	5.00	6.00	7.00	6.00	6.00	7.00	
Max		7.00	8.00	9.00	8.00	8.00	8.00	7.00	8.00	9.00	
Range		1.00	2.00	2.00	3.00	2.00	1.00	1.00	2.00	2.00	

%CV = 4.27

Table 2.5.2 Visual appearance (scale 1 to 10) of four canned small white bean cultivars (2000/01 season) from nine localities canned with the industrial canning technique and evaluated with the laboratory canning evaluation procedure

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	6.00	6.00	7.00	5.00	5.00	6.00	6.00	6.00	6.00	5.89
Helderberg	2	6.00	6.00	6.00	5.00	5.00	6.00	6.00	6.00	6.00	5.78
OPS-KW1	1	6.00	6.00	7.00	5.00	6.00	6.00	6.00	6.00	6.00	6.00
OPS-KW1	2	6.00	6.00	7.00	5.00	6.00	5.00	6.00	6.00	6.00	5.89
PAN 185	1	6.00	6.00	6.00	5.00	5.00	5.00	6.00	6.00	6.00	5.67
PAN 185	2	6.00	6.00	6.00	5.00	5.00	6.00	7.00	6.00	6.00	5.89
Teebus	1	7.00	7.00	6.00	5.00	7.00	7.00	7.00	6.00	7.00	6.56
Teebus	2	6.00	7.00	6.00	6.00	6.00	7.00	7.00	6.00	7.00	6.44
Mean		6.13	6.25	6.38	5.13	5.63	6.00	6.38	6.00	6.25	
Min		6.00	6.00	6.00	5.00	5.00	5.00	6.00	6.00	6.00	
Max		7.00	7.00	7.00	6.00	7.00	7.00	7.00	6.00	7.00	
Range		1.00	1.00	1.00	1.00	2.00	2.00	1.00	0.00	1.00	

%CV = 5.25

Table 2.5.3 Visual appearance (scale 1 to 10) of four canned small white bean cultivars (2000/01 season) from nine localities canned with the modified canning technique and evaluated with the laboratory canning evaluation procedure

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	9.00	9.00	9.00	10.00	9.00	9.00	9.00	10.00	9.00	9.22
Helderberg	2	9.00	9.00	9.00	8.00	9.00	8.00	9.00	9.00	9.00	8.78
OPS-KW1	1	10.00	8.00	9.00	10.00	10.00	9.00	8.00	9.00	9.00	9.11
OPS-KW1	2	9.00	8.00	9.00	9.00	10.00	9.00	8.00	9.00	9.00	8.89
PAN 185	1	9.00	9.00	9.00	9.00	10.00	9.00	8.00	9.00	8.00	8.89
PAN 185	2	10.00	9.00	9.00	8.00	10.00	10.00	9.00	9.00	9.00	9.22
Teebus	1	10.00	9.00	10.00	9.00	10.00	9.00	9.00	10.00	10.00	9.56
Teebus	2	10.00	10.00	9.00	9.00	10.00	9.00	10.00	10.00	10.00	9.67
Mean		9.50	8.88	9.13	9.00	9.75	9.00	8.75	9.38	9.13	
Min		9.00	8.00	9.00	8.00	9.00	8.00	8.00	9.00	8.00	
Max		10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	
Range		1.00	2.00	1.00	2.00	1.00	2.00	2.00	1.00	2.00	

%CV = 4.26

Table 2.6.1 Splits (scale 1 to 10) of four canned small white bean cultivars (2000/01 season) from nine localities canned with the laboratory canning technique and evaluated with the laboratory canning evaluation procedure

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	8.00	8.00	6.00	8.00	8.00	6.00	8.00	8.00	8.00	7.56
Helderberg	2	6.00	8.00	6.00	6.00	8.00	6.00	8.00	8.00	8.00	7.11
OPS-KW1	1	8.00	8.00	6.00	6.00	8.00	8.00	6.00	8.00	8.00	7.33
OPS-KW1	2	8.00	8.00	6.00	6.00	8.00	8.00	6.00	6.00	8.00	7.11
PAN 185	1	6.00	6.00	8.00	8.00	6.00	8.00	8.00	6.00	8.00	7.11
PAN 185	2	8.00	6.00	8.00	8.00	6.00	8.00	8.00	6.00	8.00	7.33
Teebus	1	6.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	7.78
Teebus	2	6.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	7.78
Mean		7.00	7.50	7.00	7.25	7.50	7.50	7.50	7.25	8.00	
Min		6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	8.00	
Max		8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	
Range		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	0.00	

%CV = 9.49

Table 2.6.2 Splits (scale 1 to 10) of four canned small white bean cultivars (2000/01 season) from nine localities canned with the industrial canning technique and evaluated with the laboratory canning evaluation procedure

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Helderberg	2	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
OPS-KW1	1	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
OPS-KW1	2	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
PAN 185	1	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
PAN 185	2	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Teebus	1	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Teebus	2	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Mean		4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	
Min		4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	
Max		4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	
Range		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

%CV = not available (no difference between samples)

Table 2.6.3 Splits (scale 1 to 10) of four canned small white bean cultivars (2000/01 season) from nine localities canned with the modified canning technique and evaluated with the laboratory canning evaluation procedure

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Helderberg	2	10.00	10.00	10.00	6.00	10.00	8.00	8.00	10.00	10.00	9.11
OPS-KW1	1	10.00	8.00	10.00	10.00	10.00	8.00	8.00	10.00	6.00	8.89
OPS-KW1	2	10.00	6.00	8.00	10.00	10.00	10.00	8.00	10.00	6.00	8.67
PAN 185	1	10.00	10.00	10.00	8.00	10.00	10.00	8.00	10.00	6.00	9.11
PAN 185	2	10.00	10.00	8.00	6.00	10.00	10.00	10.00	10.00	8.00	9.11
Teebus	1	10.00	10.00	10.00	8.00	10.00	8.00	10.00	10.00	10.00	9.56
Teebus	2	10.00	10.00	10.00	8.00	10.00	10.00	10.00	10.00	10.00	9.78
Mean		10.00	9.25	9.50	8.25	10.00	9.25	9.00	10.00	8.25	
Min		10.00	6.00	8.00	6.00	10.00	8.00	8.00	10.00	6.00	
Max		10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	
Range		0.00	4.00	2.00	4.00	0.00	2.00	2.00	0.00	4.00	

%CV = 9.49

Table 2.7.1 Texture (kg.100 g^{-1}.12 s^{-1}) of four canned small white bean cultivars (2000/01 season) from nine localities (laboratory canning technique)

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	86.80	53.00	41.70	51.20	62.30	44.30	51.70	44.40	43.90	53.26
Helderberg	2	87.20	50.40	43.30	51.40	55.70	45.00	52.10	44.40	47.80	53.03
OPS-KW1	1	65.90	49.70	47.20	62.60	57.20	52.50	54.90	53.00	39.50	53.61
OPS-KW1	2	67.00	48.80	48.90	59.50	53.80	52.50	57.60	54.80	40.80	53.74
PAN 185	1	70.40	58.10	47.80	51.90	61.90	50.80	42.60	48.40	49.80	53.52
PAN 185	2	70.30	51.50	48.20	54.30	57.00	49.30	44.20	57.20	49.80	53.53
Teebus	1	63.90	53.30	61.90	59.00	49.10	52.70	75.20	38.70	43.90	55.30
Teebus	2	73.20	51.90	57.00	58.90	55.70	53.70	85.20	46.00	59.50	60.12
Mean		73.09	52.09	49.50	56.10	56.59	50.10	57.94	48.36	46.88	
Min		63.90	48.80	41.70	51.20	49.10	44.30	42.60	38.70	39.50	
Max		87.20	58.10	61.90	62.60	62.30	53.70	85.20	57.20	59.50	
Range		23.30	9.30	20.20	11.40	13.20	9.40	42.60	18.50	20.00	

%CV = 6.01

Table 2.7.2 Texture (kg.100 g^{-1}.12 s^{-1}) of four canned small white bean cultivars (2000/01 season) from nine localities (industrial canning technique)

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	55.40	44.50	34.90	41.70	51.00	43.60	41.20	43.90	37.30	43.72
Helderberg	2	49.10	49.60	40.80	40.30	50.10	43.30	41.40	45.70	39.40	44.41
OPS-KW1	1	53.40	52.20	39.30	41.50	56.70	39.20	43.20	48.70	45.30	46.61
OPS-KW1	2	53.90	48.50	38.60	41.40	56.70	43.60	47.20	52.00	43.80	47.30
PAN 185	1	51.60	44.70	38.20	36.00	50.80	45.60	48.00	46.10	41.00	44.67
PAN 185	2	51.80	45.20	37.90	40.40	52.10	42.00	45.60	46.90	40.60	44.72
Teebus	1	42.60	40.30	41.80	36.20	41.20	43.10	41.30	39.60	38.10	40.47
Teebus	2	45.10	41.90	43.30	38.70	43.50	45.30	46.40	43.60	41.20	43.22
Mean		50.36	45.86	39.35	39.53	50.26	43.21	44.29	45.81	40.84	
Min		42.60	40.30	34.90	36.00	41.20	39.20	41.20	39.60	37.30	
Max		55.40	52.20	43.30	41.70	56.70	45.60	48.00	52.00	45.30	
Range		12.80	11.90	8.40	5.70	15.50	6.40	6.80	12.40	8.00	

%CV = 4.30

Table 2.7.3 **Texture (kg.100 g^{-1}.12 s^{-1}) of four canned small white bean cultivars (2000/01 season) from nine localities (modified canning technique)**

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	93.70	67.30	80.30	75.00	94.20	55.30	69.80	65.30	85.70	76.29
Helderberg	2	100.30	64.60	60.60	79.10	88.10	62.00	65.10	65.70	82.60	74.23
OPS-KW1	1	100.80	73.10	68.50	93.90	87.90	77.20	69.30	63.80	66.00	77.83
OPS-KW1	2	90.30	69.90	58.70	89.90	87.40	80.50	77.00	62.80	74.10	76.73
PAN 185	1	102.30	78.40	63.50	74.00	89.30	75.70	60.20	71.20	69.80	76.04
PAN 185	2	102.90	69.00	66.40	73.60	92.10	78.60	61.60	64.70	74.30	75.91
Teebus	1	59.40	57.40	84.30	68.90	68.20	71.80	58.20	72.70	80.10	69.00
Teebus	2	61.20	56.50	81.70	73.10	69.60	80.90	67.90	65.70	86.10	71.41
Mean		88.86	67.03	70.50	78.44	84.60	72.75	66.14	66.49	77.34	
Min		59.40	56.50	58.70	68.90	68.20	55.30	58.20	62.80	66.00	
Max		102.90	78.40	84.30	93.90	94.20	80.90	77.00	72.70	86.10	
Range		43.50	21.90	25.60	25.00	26.00	25.60	18.80	9.90	20.10	

%CV = 6.01

Table 2.8.1 **Texture (kg.s^{-1}) of four canned small white bean cultivars (2000/01 season) from nine localities (laboratory canning technique)**

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	277.70	161.50	138.40	179.00	181.60	162.10	182.60	145.40	149.60	175.32
Helderberg	2	249.80	166.10	139.30	165.70	178.20	145.90	164.20	145.40	153.10	167.52
OPS-KW1	1	220.50	167.70	177.50	191.80	175.80	164.50	174.00	162.10	135.50	174.38
OPS-KW1	2	220.90	166.60	156.60	191.80	185.30	162.40	191.70	191.40	128.00	177.19
PAN 185	1	206.00	175.50	159.10	175.50	172.60	166.60	123.70	178.70	160.30	168.67
PAN 185	2	221.50	173.20	146.20	183.90	178.20	163.60	145.80	170.00	161.60	171.56
Teebus	1	206.90	165.90	189.70	157.00	156.80	153.60	235.10	119.50	119.80	167.14
Teebus	2	229.00	191.90	198.70	156.90	162.20	176.80	260.90	164.10	153.70	188.24
Mean		229.04	171.05	163.19	175.20	173.84	161.94	184.75	159.58	145.20	
Min		206.00	161.50	138.40	156.90	156.80	145.90	123.70	119.50	119.80	
Max		277.70	191.90	198.70	191.80	185.30	176.80	260.90	191.40	161.60	
Range		71.70	30.40	60.30	34.90	28.50	30.90	137.20	71.90	41.80	

%CV = 5.99

Table 2.8.2 Texture (kg.s^{-1}) of four canned small white bean cultivars (2000/01 season) from nine localities (industrial canning technique)

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	190.30	157.90	119.80	153.50	170.10	156.00	143.10	161.50	132.20	153.82
Helderberg	2	176.90	187.40	152.10	139.40	170.00	155.80	141.10	161.70	130.80	157.24
OPS-KW1	1	182.10	188.70	135.50	144.10	190.40	148.70	143.10	180.40	160.10	163.68
OPS-KW1	2	199.90	169.80	131.20	141.30	197.70	156.30	174.10	191.20	159.50	169.00
PAN 185	1	185.40	165.20	132.90	137.00	177.50	173.10	164.50	167.10	151.70	161.60
PAN 185	2	184.10	161.00	132.90	138.60	185.20	160.40	168.90	167.60	145.00	160.41
Teebus	1	159.10	136.10	131.40	116.00	149.40	152.60	144.50	126.20	142.10	139.71
Teebus	2	158.00	149.90	150.20	130.50	165.70	161.40	158.30	157.70	138.80	152.28
Mean		179.48	164.50	135.75	137.55	175.75	158.04	154.70	164.18	145.03	
Min		158.00	136.10	119.80	116.00	149.40	148.70	141.10	126.20	130.80	
Max		199.90	188.70	152.10	153.50	197.70	173.10	174.10	191.20	160.10	
Range		41.90	52.60	32.30	37.50	48.30	24.40	33.00	65.00	29.30	

%CV = 5.83

Table 2.8.3 Texture (kg.s^{-1}) of four canned small white bean cultivars (2000/01 season) from nine localities (modified canning technique)

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	310.80	188.30	229.30	237.40	269.20	184.30	221.70	208.70	248.60	233.14
Helderberg	2	320.60	182.70	204.30	240.40	270.40	186.80	211.70	203.40	245.20	229.50
OPS-KW1	1	330.80	198.30	210.30	292.60	273.50	258.60	235.10	200.30	203.70	244.80
OPS-KW1	2	280.40	215.80	200.30	277.30	293.90	239.10	248.90	201.60	218.40	241.74
PAN 185	1	342.20	240.30	194.80	246.40	291.40	200.90	205.60	231.60	213.60	240.76
PAN 185	2	315.60	220.90	199.60	227.10	300.30	204.20	216.10	203.80	221.00	234.29
Teebus	1	209.70	192.70	232.80	214.30	194.50	234.00	188.90	229.80	196.00	210.30
Teebus	2	215.00	183.60	218.70	238.50	202.80	265.80	226.40	200.20	234.20	220.58
Mean		290.64	202.83	211.26	246.75	262.00	221.71	219.30	209.93	222.59	
Min		209.70	182.70	194.80	214.30	194.50	184.30	188.90	200.20	196.00	
Max		342.20	240.30	232.80	292.60	300.30	265.80	248.90	231.60	248.60	
Range		132.50	57.60	38.00	78.30	105.80	81.50	60.00	31.40	52.60	

%CV = 5.99

Table 2.9 Mean, minimum, and maximum values and F-values pertaining to main effects of the canning quality of four small white bean cultivars (2000/01 season) from nine localities canned with the laboratory, industrial and modified canning techniques

Canning quality	Mean	Minimum	Maximum	F-values		
				Cultivar (df = 3)	Locality (df = 8)	Canning technique (df = 2)
Water uptake (%)	78.21	34.31	98.08	1252.24 ***	122.23 ***	5969.23 ***
Washed drained weight (%)	63.83	41.05	78.80	32.57 ***	444.99 ***	6417.34 ***
Visual appearance (scale 1 to 10)	7.41	5.00	10.00	48.94 ***	9.21 ***	1403.59 ***
Splits (scale 1 tot 10)	6.89	4.00	10.00	7.33 ***	2.78 **	1559.24 ***
Texture (**kg.100 g^{-1}.12 s^{-1}**)	57.86	34.90	102.90	6.06 ***	69.83 ***	1482.44 ***
Texture (kg.s^{-1})	187.62	116.00	342.20	16.39 ***	68.39 ***	806.43 ***

***$P < 0.01$; **$P < 0.05$; ns > P 0.05

Table 2.10 R^2-values, root mean square errors and coefficients of variation pertaining to canning quality parameters of four small white bean cultivars (2000/01 season) from nine localities canned with the laboratory, industrial and modified canning techniques

Canning quality	**#R^2**	**Root mean square error**	**Coefficient of variation**
Water uptake (%)	0.99 ***	1.15	1.48
Washed drained weight (%)	1.00 ***	0.89	1.40
Visual appearance (scale 1 to 10)	0.97 ***	0.38	5.11
Splits (scale 1 tot 10)	0.97 ***	0.57	8.37
Texture (kg.100 g^{-1}.12 s^{-1})	0.98 ***	3.40	5.87
Texture (kg.s^{-1})	0.97 ***	11.72	6.25

R^2 = Sum square model/Sum square total

*** $P < 0.01$; **$P < 0.05$; ; ns > P 0.05

Table 2.11 The percentage contribution of cultivar, locality, technique and replicate to the variance in the canning quality parameters of four small white bean cultivars (2000/01 season) from nine localities canned with the laboratory, industrial and modified canning techniques

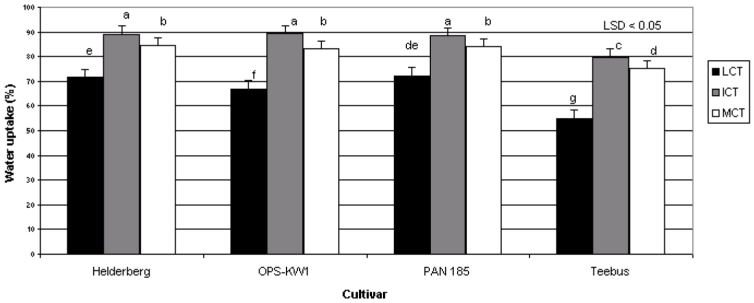
Canning quality	**Percent variability contribution**			
	Cultivar	**Locality**	**Technique**	**Replicate**
Water uptake (%)	16.30	0.00	82.86	0.84
Washed drained weight (%)	0.00	0.00	99.27	0.73
Visual appearance (scale 1 to 10)	0.50	0.00	94.96	4.54
Splits (scale 1 tot 10)	0.00	0.00	95.84	4.16
Texture (kg.100 g^{-1}.12 s^{-1})	0.00	0.00	96.06	3.94
Texture (kg .s^{-1})	0.00	0.00	93.32	6.68

Table 2.11 indicates the percentage contribution of cultivar, locality, technique and replicate to the variance. Canning technique showed the largest contribution in the case of all canning parameters, indicating that most of the variation in the data could be explained by the different canning techniques used. This was also confirmed by the higher F-values found for canning technique (Table 2.9). Cultivar only contributed significantly to the variation in the case of WU (Table 2.11). Canning technique was also found to affect WU to a lower extent than in the case of other parameters. Water uptake is therefore a different kind of parameter than the others, which should be considered when WU as a canning parameter are used. Locality did not contribute to variance, while the contribution of replicates was low, as samples were canned in duplicate.

Figures 2.1 to 2.3 and 2.5 to 2.7 display the effect of different canning techniques on the canning quality parameters of the four cultivars.

2.3.1.1 Water uptake

The WU of cultivars using different soaking techniques is provided in Figure 2.1. The ICT displayed significantly higher WU than the other two techniques for all cultivars. This could be explained by the long soaking period of 18 hours that was used for this technique. Wang *et al*. (1988) noticed that most beans were already saturated after 10 h of soaking and water absorption reached a plateau after 14 h. Canning according to MCT also led to higher WU levels ($P < 0.05$) than with the LCT, due to the longer total soaking period with the former in the case of all four cultivars. The lower WU levels with the MCT compared to the ICT, were in agreement with the lower WU found by Balasubramanian *et al*. (2000) for a laboratory canning protocol. Water uptake with laboratory techniques was indicated to be lower, but HC values were indicated to still be a good estimate of actual HC under industrial canning conditions (Balasubramanian *et al*., 2000). Hosfield *et al*. (1984a) and Hosfield (1991) reported that uncooked beans should undergo a mass increase of at least 80 % during soaking. All cultivars displayed higher than 80 % WU with both the ICT and the MCT, except for Teebus which displayed slightly lower values with the MCT. In the present study, levels of WU were also lower than 80 % in the case of the LCT for all cultivars. Water uptake by Teebus was lower than by the other cultivars in the case of all canning techniques, which indicated that lower WU was due to a cultivar-specific property. This was also confirmed by the 16.30 % contribution that cultivar made to WU (Table 2.11). In the commercial canning industry the soaking time of cultivars with lower WU, such as Teebus, are lengthened to ensure that sufficient WU takes place before canning.

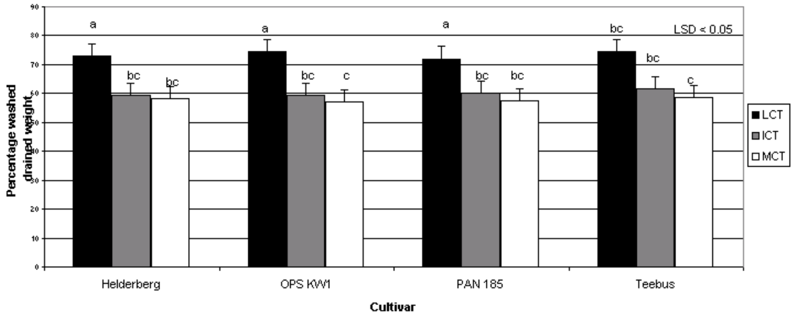


#LCT = laboratory canning technique; ICT = Industrial canning technique; MCT = modified canning technique

Figure 2.1 Water uptake of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities canned with different canning techniques (Different letters indicate significant differences at *P* = 0.05).

2.3.1.2 Percentage washed drained weight

The PWDWT of the four small white bean cultivars canned according to different techniques, is shown in Figure 2.2. Water uptake takes place inside the can during the first seven days after canning, due to increased water migration within the can (Bolles *et al*., 1982). Bean cultivars from the MCT were noticed to have significantly lower PWDWT values for all cultivars than with the LCT. Low water absorption levels in the can were found to be a possible indication of excessive solid loss during processing, while high water absorption levels indicated large swelling capacities (Hosfield, 1991). The latter could be a possible cause of bean splits. Balasubramanian *et al*. (1999) found that the PWDWT of navy beans, canned in brine, varied between 60.9 and 62.1 % for a laboratory canning technique and according to Canadian government regulations, the PWDWT should be at least 60 % of dry beans for a 14 oz can (Balasubramanian *et al*., 1999). Drained weight of dry beans relates to "processors yield" (Varner & Uebersax, 1995), as it would require a lower mass of dry beans with a higher WDWT to fill a can than in the case of beans with a lower WDWT (Hosfield, 1991). Teebus (reference standard) (Figure 2.2), canned with the MCT, had lower PWDWT values compared to values found by Balasubramanian *et al*. (1999) (60.9 and 62.1 %). This was probably due to the tomato sauce canning medium that was used with the MCT. Beans canned in tomato sauce were noticed to have significantly lower PWDWT and higher texture values than those canned in water. Tomato sauce had lower pH values, that could have caused the inhibition of swelling, perhaps caused by insoluble complexes that were formed by organic acids and amylose in the beans (Nordstrom & Sistrunk, 1977). The osmotic pressure of tomato sauce could also have been higher than that of brine, since increased levels of solids are present in the latter. Despite the lowering effect of the tomato sauce on the PWDWT values, Teebus still had values (mean = 58.51 %) comparable to that of Canadian regulations (60 %) when canned with the MCT.



#LCT = laboratory canning technique; ICT = Industrial canning technique; MCT = modified canning technique

Figure 2.2 Percentage washed drained weight of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities canned with different canning techniques (Different letters indicate significant differences at *P* = 0.05).

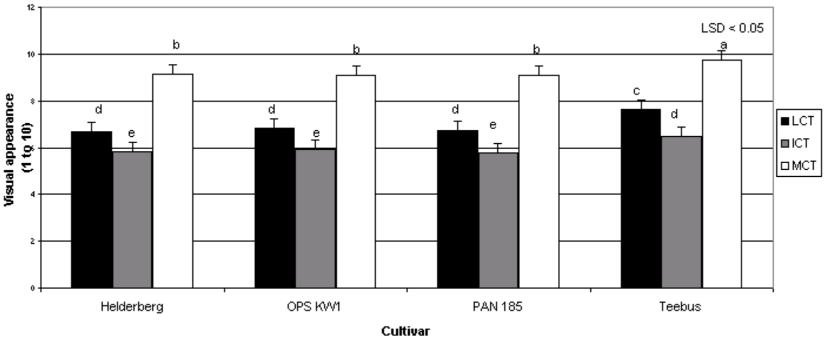
On opening the cans of the LCT treatment beans appeared very dry, clumped, with almost no free tomato sauce left in the can. The dry appearance of these beans could have been caused by more water migration from the canning medium into the beans, as these beans displayed higher PWDWT values than those recorded in literature (Balasubramanian *et al*., 1999). As mentioned, a high PWDWT value is an indication of the large swelling capacity of beans (Hosfield, 1991). Despite the tomato sauce medium, beans canned with the ICT displayed PWDWT values that were in line with those of Balasubramanian *et al*. (1999), but the excessive splitting of these beans (discussed in 2.3.1.4) could in turn have been caused by excessive swelling in the can.

2.3.1.3 Visual Appearance (scale 1 to 10)

Figure 2.3 displays the VA values of small white bean cultivars canned according to the three different techniques. All four bean cultivars canned with the MCT displayed significantly higher VA values than those of the other two techniques. Teebus (reference standard) displayed higher VA values than the other cultivars, with all canning techniques, but VA was significantly better when Teebus was canned with the MCT. These beans had almost no loose or free seed coats, individual beans were visible, shiny and the colour and size were uniform (Figure 2.4c). Helderberg, which serves as the reference standard for “standard grade” canned beans, was not significantly different in VA than either OPS-KW1 or PAN 185 with all canning techniques, but its VA was lower than that of Teebus. Helderberg also displayed significantly better VA values, when canned with the MCT.

Beans canned using the ICT appeared poor and totally unacceptable, with VA significantly lower than that of the MCT for all cultivars (Figure 2.3). These beans were mushy, showed bean breakdown and free skins, and were clumped in the can with dull appearance (Figure 2.4b). As mentioned in 2.3.1.2 a possible cause for this could have been excessive swelling, which was indicated by the high PWDWT (Figure 2.3). The beans could have been over-processed in the ICT. Industrial techniques are used in large canning plants, where large rotating retorts are used, compared to the stationery autoclave with a capacity of 45 cans that was used in the laboratory. Another reason for the poor appearance of these beans, could have been the long soaking period (18 h), that would likely result in high microbial counts and high levels of enzymatic activity within the beans (amylases, proteases and cellulases).

The lower VA values ($P < 0.05$) of the bean cultivars canned with the LCT compared to those of the MCT, could be attributed to dryness, dullness, discoloration and clumping of these beans (Figure 2.4a). This could have been caused by excessive water migration into the beans from the tomato sauce (high PWDWT), as discussed in 2.3.1.2. When the reference standard for choice (Teebus) and standard (Helderberg) grade beans are considered, the MCT would be the preferred technique for canning to preserve the good appearance of the beans after canning.



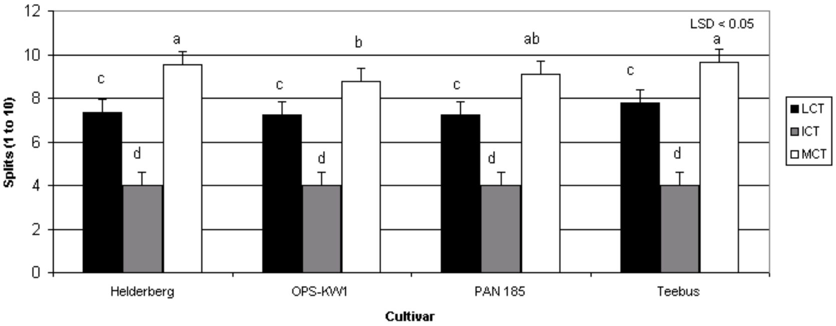
#LCT = laboratory canning technique; ICT = Industrial canning technique; MCT = modified canning technique

Figure 2.3 **Visual appearance (scale 1 to 10) of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities canned with different canning techniques (Different letters indicate significant differences at *P* = 0.05).**

Figure 2.4 **Visual appearance of Teebus 14 days after canning using a) laboratory canning -, b) industrial canning- and c) modified canning techniques.**

2.3.1.4 Splits (scale 1 to 10)

Significantly higher scores for beans splits were found when canned with the MCT compared to those of the other two canning techniques. Not only would splitting of canned beans result in the exudation of starch into the canning medium, causing graininess of the sauce, but also could lead to clumping of individual beans (Lu &Chang, 1996). This also explains why beans canned according to the MCT displayed better VA values than the other beans (2.3.1.3). Split values of Helderberg (reference standard for standard grade) for all canning techniques were not significantly different from Teebus in split values (Figure 2.5).



#LCT = laboratory canning technique; ICT = Industrial canning technique; MCT = modified canning technique

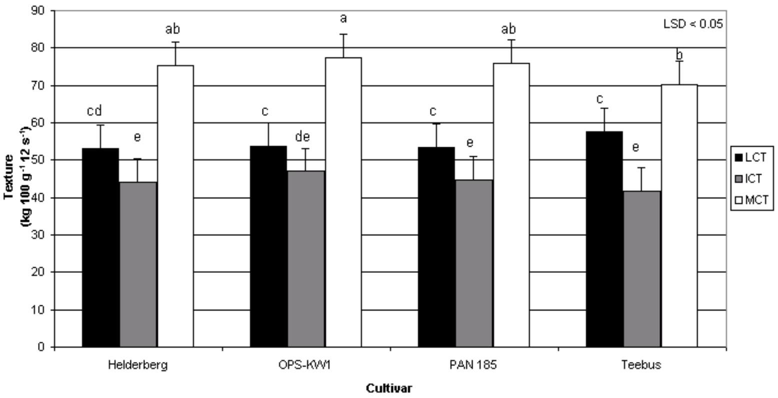
Figure 2.5 Splits (scale 1 to 10) of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities canned with different canning techniques (Different letters indicate significant differences at *P* = 0.05).

Beans canned using the ICT displayed significantly higher WU values (2.3.1.1) than the other beans, but also had lower split values ($P < 0.05$) (Figure 2.5). The breakage of the reference standard (Teebus) was significantly more severe for beans canned by the ICT, than those canned with the other techniques. Again, over-processing could have caused splits or high WU levels (Figure 2.1), since it was reported that beans that weigh more, due to greater WU levels, have a higher tendency to split (Forney *et al.*, 1990).

Bean cultivars canned with the LCT, displayed lower split values than those of the MCT, while breakdown was not as severe as in the case of the ICT (Figure 2.5). Excessive swelling due to the higher PWDWT values of these beans could have caused more splitting than with the MCT.

2.3.1.5 Texture

In the USA the cultivar Sanilac (navy bean) with a TXT1 value of 72 kg.100 g^{-1} is considered the industrial standard for canning quality (Hosfield & Uebersax, 1980). The reference standard (Teebus) had values for TXT1 closest to those of Sanilac (Figure 2.6), when canned with the MCT. Helderberg (standard grade) and PAN 185 also displayed values closer to the USA standard, when canned with the MCT, since these cultivars did not differ significantly from Teebus in texture values.

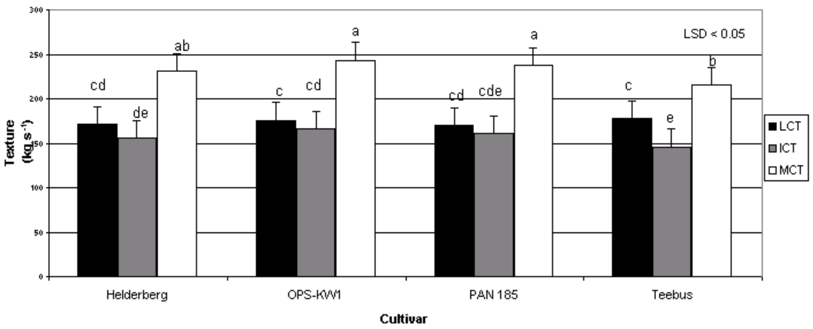


LCT = laboratory canning technique; ICT = Industrial canning technique; MCT = modified canning technique

Figure 2.6 Texture (kg.100 g^{-1}.12 s^{-1}) of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities canned with different canning techniques (Different letters indicate significant differences at *P* = 0.05).

From Figure 2.6 it is noticed that beans from the ICT were significantly softer than those of the MCT and LCT. Beans should soften during processing, but not to such a degree that individual integrities are lost (Hosfield & Uebersax, 1980). Beans canned using the ICT were therefore too soft, as these beans displayed extreme breakage (2.3.1.3). As mentioned in 2.3.1.3 the long soaking period (18 h) of the ICT, would have likely resulted in high microbial counts and high levels of enzymatic activity within the beans (amylases, proteases and cellulases). This would have likely resulted in “over-softening” of the beans.

The TXT1 and TXT2 values (Figures 2.6 & 2.7) of the MCT bean cultivars were significantly higher than those of the other two techniques. The TXT1 values (Figure 2.6) of cultivars canned using the MCT were all within the range 59.1 to 89.9 kg.100 g^{-1}.12 s^{-1} found by Hosfield & Uebersax (1980), although no small white bean cultivars were among those canned to obtain these values. Beans that were canned in tomato sauce were found to have significantly higher texture values than those canned in water (Nordstrom & Sistrunk, 1977), which explains why texture values were on the higher side of the range found by Hosfield & Uebersax (1980).



#LCT = laboratory canning technique; ICT = Industrial canning technique; MCT = modified canning technique

Figure 2.7 Texture (kg.s^{-1}) of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities canned with different canning techniques (Different letters indicate significant differences at *P* = 0.05).

Table 2.10 indicates that TXT2 had higher RMSE values (> 5) compared to TXT1, which indicates that TXT1 provides a better estimate of the texture of beans. Only TXT1 values are therefore considered in the rest of the study and would be referred to as texture.

2.3.2 Canning quality evaluation procedures of laboratory canned beans

Evaluation results of beans evaluated with the LCEP were provided in Tables 2.3.3 (WU), 2.4.3 (PWDWT), 2.5.3 (VA), 2.6.3 (splits), 2.7.3 (texture). The results of the MCEP are indicated in Tables 2.12.1 to 2.12.7. Results for PWDWT and texture were the same as for LCEP and the MCEP. The mean, minimum, maximum and F-values values for the different canning quality parameters are indicated for the LCEP and MCEP in Tables 2.13 and 2.14 respectively. Significant differences between cultivars, localities and cultivar x locality interaction were found for all canning quality parameters, except for differences between cultivar splits (%) and cultivar x locality for splits (%), VA (scale 1 to 5) and b_L-values (Table 2.14). No significant differences were found between replicates for any canning quality parameter, as samples were merely canned in duplicate (Tables 2.13 & 2.14). Table 2.15 provides the R^2-values, RMSE and CV for small white bean cultivars evaluated for canning quality according to the LCEP and MCEP. Table 2.16 indicates the correlation coefficients between different canning evaluation properties.

Table 2.12.1 Visual appearance (scale 1 to 5) of four small white bean cultivars (2000/01 season) from nine localities canned with the industrial canning technique and evaluated with the modified canning evaluation procedure

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	4.00	4.00	4.00	5.00	4.00	4.00	4.00	5.00	4.00	4.22
Helderberg	2	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
OPS-KW1	1	5.00	4.00	5.00	5.00	5.00	5.00	4.00	4.00	5.00	4.67
OPS-KW1	2	4.00	4.00	5.00	4.00	5.00	5.00	4.00	4.00	5.00	4.44
PAN 185	1	4.00	4.00	4.00	4.00	5.00	4.00	4.00	4.00	4.00	4.11
PAN 185	2	5.00	4.00	5.00	4.00	5.00	5.00	4.00	4.00	4.00	4.44
Teebus	1	5.00	4.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	4.89
Teebus	2	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Mean		4.50	4.13	4.63	4.50	4.75	4.63	4.25	4.38	4.50	
Min		4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	
Max		5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
Range		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	

%CV = 7.56

Table 2.12.2 Percentage splits of four small white bean cultivars (2000/01 season) from nine localities canned with the industrial canning technique and evaluated with the modified canning evaluation procedure

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	0.00	0.53	0.23	0.95	0.00	0.86	0.57	0.21	0.00	0.37
Helderberg	2	0.00	0.00	0.00	3.42	0.00	1.58	1.42	0.21	0.00	0.74
OPS-KW1	1	0.00	1.16	1.09	0.25	0.00	1.18	1.70	0.55	2.30	0.91
OPS-KW1	2	0.00	3.96	2.64	0.40	0.00	0.62	1.16	0.00	0.50	1.03
PAN 185	1	0.14	0.23	0.12	1.37	0.39	0.56	1.57	0.00	0.00	0.49
PAN 185	2	0.00	0.00	1.69	2.03	0.00	0.96	0.49	0.85	1.40	0.82
Teebus	1	0.00	0.35	0.21	1.15	0.00	1.17	0.00	0.00	0.40	0.36
Teebus	2	0.00	0.69	0.37	1.16	0.40	0.00	0.75	0.00	0.10	0.38
Mean		0.02	0.86	0.79	1.34	0.10	0.86	0.96	0.23	0.59	
Min		0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	0.00	
Max		0.14	3.96	2.64	3.42	0.40	1.58	1.70	0.85	2.30	
Range		0.14	3.96	2.64	3.17	0.40	1.58	1.70	0.85	2.30	

%CV = 102.41

Table 2.12.3 Size (scale 1 to 7) of four small white bean cultivars (2000/01 season) from nine localities canned with the industrial canning technique and evaluated with the modified canning evaluation procedure

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	5.00	6.00	6.00	6.00	6.00	5.00	6.00	6.00	6.00	5.78
Helderberg	2	5.00	6.00	6.00	5.00	6.00	5.00	6.00	6.00	6.00	5.67
OPS-KW1	1	6.00	6.00	6.00	6.00	7.00	6.00	7.00	5.00	7.00	6.22
OPS-KW1	2	6.00	6.00	7.00	6.00	7.00	5.00	6.00	5.00	7.00	6.11
PAN 185	1	6.00	6.00	7.00	5.00	6.00	5.00	6.00	6.00	6.00	5.89
PAN 185	2	6.00	6.00	7.00	5.00	7.00	6.00	6.00	6.00	6.00	6.11
Teebus	1	7.00	7.00	6.00	7.00	7.00	7.00	7.00	7.00	7.00	6.89
Teebus	2	7.00	7.00	6.00	7.00	7.00	7.00	7.00	7.00	7.00	6.89
Mean		6.00	6.25	6.38	5.88	6.63	5.75	6.38	6.00	6.50	
Min		5.00	6.00	6.00	5.00	6.00	5.00	6.00	5.00	6.00	
Max		7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	
Range		2.00	1.00	1.00	2.00	1.00	2.00	1.00	2.00	1.00	

%CV = 4.73

Table 2.12.4 Clumping (scale 1 to 3) of four small white bean cultivars (2000/01 season) from nine localities canned with the industrial canning technique and evaluated with the modified canning evaluation procedure

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	3.00	3.00	2.00	3.00	3.00	3.00	3.00	2.00	2.00	2.67
Helderberg	2	3.00	3.00	2.00	3.00	3.00	3.00	3.00	2.00	3.00	2.78
OPS-KW1	1	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.00	3.00	2.89
OPS-KW1	2	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
PAN 185	1	3.00	3.00	2.00	3.00	3.00	3.00	3.00	2.00	3.00	2.78
PAN 185	2	3.00	3.00	2.00	3.00	3.00	3.00	3.00	3.00	3.00	2.89
Teebus	1	3.00	3.00	2.00	3.00	3.00	3.00	3.00	3.00	3.00	2.89
Teebus	2	3.00	3.00	2.00	3.00	3.00	3.00	3.00	3.00	3.00	2.89
Mean		3.00	3.00	2.25	3.00	3.00	3.00	3.00	2.50	2.88	
Min		3.00	3.00	2.00	3.00	3.00	3.00	3.00	2.00	2.00	
Max		3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	
Range		0.00	0.00	1.00	0.00	0.00	0.00	0.00	1.00	1.00	

%CV = 6.96

Table 2.12.5 **L-values of four small white bean cultivars (2000/01 season) from nine localities canned with the industrial canning technique and evaluated with the modified canning evaluation procedure**

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	40.01	40.33	41.23	42.01	43.57	38.75	41.52	44.10	41.66	41.46
Helderberg	2	39.72	40.40	41.26	43.08	44.23	39.25	40.13	43.20	41.77	41.45
OPS-KW1	1	39.02	40.16	41.19	39.01	41.66	38.31	37.85	42.77	40.42	40.04
OPS-KW1	2	37.85	40.90	41.07	38.29	41.77	39.88	38.19	42.41	41.32	40.19
PAN 185	1	39.85	41.35	41.38	40.79	43.55	38.69	38.12	43.30	40.35	40.82
PAN 185	2	40.18	38.90	41.14	39.94	42.72	38.38	38.91	41.25	40.37	40.20
Teebus	1	38.64	39.70	41.50	40.73	42.26	38.81	37.47	41.52	40.28	40.10
Teebus	2	39.00	39.57	41.86	40.33	42.02	39.58	38.97	42.39	41.03	40.53
Mean		39.28	40.16	41.33	40.52	42.72	38.96	38.90	42.62	40.90	
Min		37.85	38.90	41.07	38.29	41.66	38.31	37.47	41.25	40.28	
Max		40.18	41.35	41.86	43.08	44.23	39.88	41.52	44.10	41.77	
Range		2.33	2.45	0.79	4.79	2.57	1.57	4.05	2.85	1.49	

%CV = 1.55

Table 2.12.6 **The a_L-values of four small white bean cultivars (2000/01 season) from nine localities canned with the industrial canning technique and evaluated with the modified canning evaluation procedure**

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	10.01	11.15	11.07	9.83	10.58	11.47	10.72	10.19	9.52	10.50
Helderberg	2	10.24	11.20	11.06	10.26	10.45	11.20	10.71	10.20	9.90	10.58
OPS-KW1	1	10.53	11.32	11.46	11.40	10.89	11.06	11.23	11.02	10.78	11.08
OPS-KW1	2	10.77	10.84	11.15	11.58	10.54	10.94	11.30	10.63	10.15	10.88
PAN 185	1	10.17	10.85	11.14	11.06	10.06	11.25	11.45	10.09	10.37	10.72
PAN 185	2	10.12	10.79	10.74	11.22	10.10	11.27	11.34	11.08	10.27	10.77
Teebus	1	11.16	11.39	10.87	10.46	11.12	11.62	11.97	10.88	10.70	11.13
Teebus	2	11.09	11.41	11.28	10.51	10.67	11.76	11.89	10.82	10.52	11.11
Mean		10.51	11.12	11.10	10.79	10.55	11.32	11.33	10.61	10.28	
Min		10.01	10.79	10.74	9.83	10.06	10.94	10.71	10.09	9.52	
Max		11.16	11.41	11.46	11.58	11.12	11.76	11.97	11.08	10.78	
Range		1.15	0.62	0.72	1.75	1.06	0.82	1.26	0.99	1.26	

%CV = 1.97

Table 2.12.7 The b_L-values of four small white bean cultivars (2000/01 season) from nine localities canned with the industrial canning technique and evaluated with the modified canning evaluation procedure

Cultivar (n = 4)	Replicate (n = 2)	Bapsfontein	Bethlehem	Cedara	Clocolan	Ermelo	Greytown	Harrismith	Lichtenburg	Reitz	Mean (n = 9)
Helderberg	1	16.52	16.57	17.15	16.52	17.66	15.98	16.79	17.55	16.26	16.78
Helderberg	2	16.61	16.85	17.00	17.10	17.86	16.18	16.16	17.37	16.47	16.84
OPS-KW1	1	16.00	16.39	17.13	15.98	16.85	15.93	15.30	17.37	15.88	16.31
OPS-KW1	2	15.72	16.30	16.97	15.81	16.65	16.60	15.67	17.28	15.72	16.30
PAN 185	1	16.42	16.96	17.31	16.66	17.52	16.15	15.90	17.40	16.17	16.72
PAN 185	2	16.62	16.24	16.91	16.58	17.16	16.28	16.19	17.23	16.13	16.59
Teebus	1	16.67	16.63	17.27	16.44	17.40	16.46	16.07	17.26	16.36	16.73
Teebus	2	16.67	16.60	17.66	16.39	17.04	16.64	16.70	17.56	16.44	16.86
Mean		16.40	16.57	17.18	16.44	17.27	16.28	16.10	17.38	16.18	
Min		15.72	16.24	16.91	15.81	16.65	15.93	15.30	17.23	15.72	
Max		16.67	16.96	17.66	17.10	17.86	16.64	16.79	17.56	16.47	
Range		0.95	0.72	0.75	1.29	1.21	0.71	1.49	0.33	0.75	

%CV = 1.36

Table 2.13 Mean, minimum and maximum values and F-values pertaining to canning quality parameters of four small white bean cultivars (2000/01 season) from nine localities evaluated according to the laboratory canning evaluation procedure

Canning quality	Mean	Minimum	Maximum	F-values			
				Cultivar (df = 3)	Locality (df = 8)	Cultivar x Locality (df = 24)	Replicates (df = 1)
Water uptake (%)	81.62	70.99	89.05	485.77***	13.60***	9.40***	0.90^{ns}
Washed drained weight (%)	57.85	53.97	60.93	9.20***	7.16***	3.53***	3.41^{ns}
Visual appearance (scale 1 to 10)	9.26	8.00	10.00	11.63***	5.89***	2.27*	0.49^{ns}
Splits (scale 1 tot 10)	9.28	6.00	10.00	3.92*	4.91***	2.52**	1.15^{ns}
Texture (kg.100 g^{-1}.12 s^{-1})	74.68	55.30	102.90	8.60***	26.88***	9.91**	0.04^{ns}

*** $P < 0.01$; ** $P < 0.05$; * $P < 0.1$; ; ns > P 0.05

Table 2.14 **Mean, minimum and maximum values and F-values pertaining to canning quality parameters of four small white bean cultivars (2000/01 season) from nine localities evaluated according to the modified canning evaluation procedure**

Canning quality	Mean	Minimum	Maximum	F-values			
				Cultivar (df = 3)	Locality (df = 8)	Cultivar x Locality (df = 24)	Replicates (df = 1)
Hydration coefficient	1.82	1.71	1.89	486 ***	13.6 ***	9.4 ***	0.9^{ns}
Visual appearance (1 to 5)	4.47	4.00	5.00	20.9 ***	2.67 *	1.58^{ns}	5.94^{ns}
Splits (%)	0.64	0.00	3.96	2.64^{ns}	3.66 **	1.57^{ns}	1.86^{ns}
Size (1 to 7)	6.19	5.00	7.00	52.1 ***	8.43 ***	5.4 ***	2.73^{ns}
Clumping	2.85	2.00	3.00	4.12 *	15.7 ***	2.53 **	3.18^{ns}
L-value	40.60	37.47	43.08	16 ***	42.1 ***	2.4 **	0.01^{ns}
a_L-value	10.85	9.52	11.97	25.5 ***	26.7 ***	4.63 ***	0.21^{ns}
b_L-value	16.64	15.30	17.86	19 ***	38.3 ***	1.75^{ns}	0.06^{ns}

***$P < 0.01$; ** $P < 0.05$; * $P < 0.1$; ; ns > P 0.05

Table 2.15 **R^2–values, root mean square errors and coefficients of variation pertaining to canning quality parameters of four small white bean cultivars (2000/01 season) from nine localities canned with the laboratory- and modified canning evaluation procedure**

Canning quality	$^{\#}R^2$	Root mean square error	Coefficient of variation (%)
Laboratory canning evaluation procedure (LCEP)			
Water uptake (%)	0.98***	0.85	1.04
Washed drained weight (%)	0.83***	0.82	1.42
Visual appearance (scale 1 to 10)	0.80***	0.40	4.26
Splits (scale 1 tot 10)	0.76***	0.88	9.49
Texture (kg.100 g^{-1}.12 s^{-1})	0.93***	4.48	6.01
Modified canning evaluation procedure (MCEP)			
Hydration coefficient	0.98***	0.01	0.47
Washed drained weight (%)	0.83***	0.82	1.42
Visual appearance (scale 1 to 5)	0.78***	0.34	7.56
Size	0.91***	0.29	4.73
Splits (%)	0.69*	0.65	102.41
Texture (kg.100 g^{-1}.12 s^{-1})	0.93***	4.48	6.01
Clumping (scale 1 to 3)	0.85***	0.20	6.96
L-value	0.93***	0.63	1.55
a_L-value	0.92***	0.21	1.97
b_L-value	0.92***	0.23	1.36

\# R^2 = Sum square model / Sum square total

*** $P < 0.01$; ** $P < 0.05$; * $P < 0.1$; ; ns > P 0.05

Table 2.16 **Linear correlations between the difference canning quality parameters of four small white bean cultivars (2000/01 season) from nine localities evaluated with the laboratory and modified canning evaluation procedures**

Parameter	WU	HC	PWDWT	VA1	VA2	SPLT1	SPLT2	Texture	Size	Clumping	L-value	a_L-value	b_L-value
WU	1												
HC	1.00 ***	1											
PWDWT	-0.15 ns	-0.15 ns	1										
VA1	-0.40 ***	-0.40 ***	-0.07 ns	1									
VA2	-0.52 ***	-0.52 ***	-0.01 ns	0.66 ***	1								
SPLT1	-0.16 ns	-0.16 ns	-0.03 ns	0.67 ***	0.10 ns	1							
SPLT2	0.22 ns	0.22 ns	0.06 ns	-0.59 ***	-0.09 ns	-0.76 ***	1						
TXT1	0.11 ns	0.11 ns	-0.57 ***	0.28 *	0.07 ns	0.19 ns	-0.29 *	1					
Size	-0.54 ***	-0.54 ***	0.11 ns	0.38 ***	0.59 ***	0.03 ns	-0.12 ns	-0.18 ns	1				
Clumping	0.03 ns	0.03 ns	-0.13 ns	-0.07 ns	0.09 ns	-0.18 ns	0.16 ns	0.11 ns	0.06 ns	1			
L-value	0.16 ns	0.16 ns	-0.04 ns	0.25 ***	0.02 ns	0.11 ns	-0.11 ns	0.10 ns	-0.03 ns	-0.40 ***	1		
a_L-value	-0.38 **	-0.38 **	0.30 *	-0.18 ns	0.06 ns	0.03 ns	0.15 ns	-0.45 ***	0.14 ns	0.16 ns	-0.57 ***	1	
b_L-value	-0.11 ns	-0.11 ns	0.11 ns	0.38 ***	0.10 ns	0.38 ***	-0.26 *	-0.02 ns	0.00 ns	-0.43 ***	0.81 ***	-0.18 ns	1

WU =Water uptake

HC = Hydration coefficient

PWDWT = Percentage washed drained weight

VA1 = Visual appearance (1 to 10)

VA2 = Visual appearance (1 to 5)

SPLT1 = Splits (1 to 10)

SPLT2 = Splits (%)

*** $P < 0.01$; ** $P < 0.05$; * $P < 0.01$; ;   ns > P 0.05

2.3.2.1 Water uptake vs. hydration coefficient

The mean values for WU (mean = 81.6) and HC (mean = 1.82) (Table 2.13 & 2.14) were slightly higher than the required values for WU and HC of 80 % and 1.80 respectively, as suggested by Hosfield *et al*. (1984a). Water uptake was found to correlate significantly with HC (r = 1.0, $P < 0.01$) (Table 2.16). This could be explained by the fact that WU and HC are alternatives for expressing water absorbed during soaking and / or blanching.

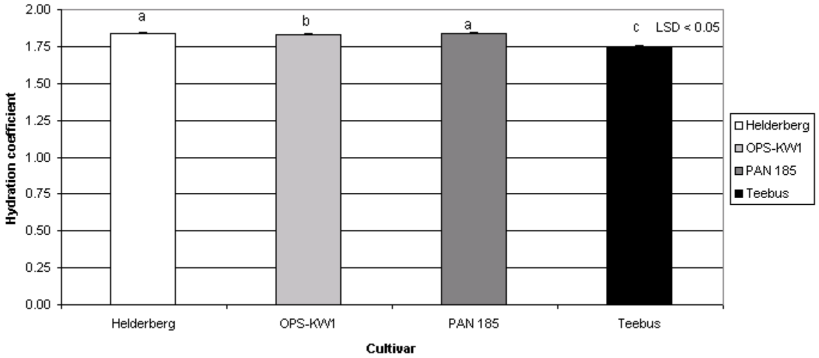


Figure 2.8 Hydration coefficient of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities (Different letters indicate significant differences at *P* = 0.05).

Despite the significant correlation between HC and WU, HC is more frequently used in literature than WU for laboratory canning. Both the RMSE and CV were lower in the case of HC and both RMSE and CV should approach zero (Table 2.15). Hydration coefficient was therefore used for the purpose of the present study. From Figure 2.8 it appears that the HC values for the reference standards of choice (Teebus) and standard grade (Helderberg) beans would be 1.75 and 1.84 respectively. Therefore, Teebus did not meet the USA standard value of 1.80, but in the industry, soaking times are adapted to ensure that all cultivars would take up at least 80 % water. Water uptake could therefore, rather be seen as a physical property that is manipulated by industry to enhance canning quality. If WU would be considered as a physical property, it would agree with results found in 2.3.1.1, where it was shown that WU reacted differently from other canning parameters. The lower HC values found for

Teebus is also in agreement with lower laboratory canning HC results found by Balasubramanian *et al*. (2000), which was discussed in 2.3.1.1.

2.3.2.2 Percentage washed drained weight

According to Canadian government regulations the PWDWT of dry beans should be at least 60 % (Balasubramanian *et al.*, 1999). As mentioned in 2.3.1.2, the mean PWDWT values of Teebus canned with the MCT (Figure 2.2) were slightly lower, but in agreement, with those of Canadian regulations, which could have been due to the inhibited swelling of the beans caused by the tomato sauce (Nordstrom & Sistrunk, 1977).

From Table 2.13 it is apparent that PWDWT was significantly ($P < 0.01$) influenced by cultivar and locality. This is further investigated in Chapter 4, where data from more environments (locality and season) were considered.

From Figure 2.9 it is apparent that the PWDWT values for the reference standards of choice (Teebus) and standard grade (Helderberg) beans did not differ significantly and would be 58.51 and 58.12 % respectively.

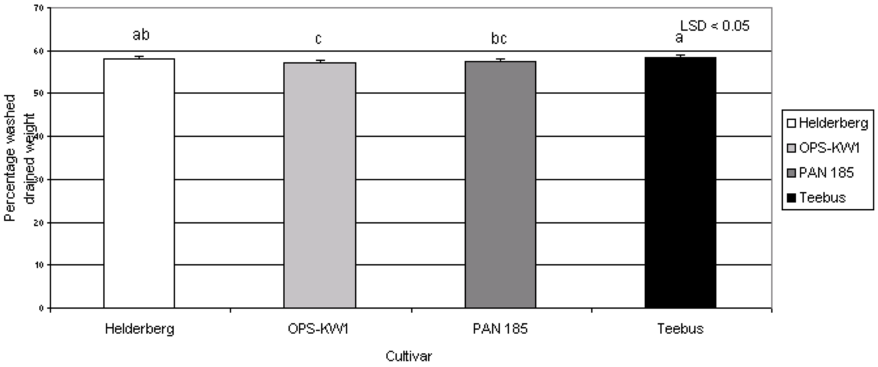


Figure 2.9 Percentage washed drained weight of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities (Different letters indicate significant differences at *P* = 0.05).

2.3.2.3 Visual appearance (scale 1 to 10) vs. visual appearance (scale 1 to 5)

Visual appearance determined with both techniques was significantly affected ($P < 0.01$) by cultivar. The VA on a 10-point scale (VA1) was more significantly influenced by locality ($P < 0.01$) than in the case of VA on a 5-point scale (VA2) ($P < 0.05$). The VA2 was not significantly influenced by cultivar x locality (Tables 2.13 & 2.14). Visual appearance (scale 1 to 10) would discriminate better between locality and cultivar x locality differences.

Visual appearance was determined more frequently in the literature on a scale from 1 to 5 (VA2) (Hosfield & Uebersax, 1980; Balasubramanian *et al.*, 1999; Balasubramanian *et al.*, 2000) than with VA1 (De Lange & Labuschagne, 2000). Highly significant correlations ($P < 0.01$) (Table 2.16) between VA1 and VA2 were observed ($r = 0.66$) indicating that both scales were able to define the appearance of canned beans and in a similar manner. R^2-values were higher and CV lower in the case of VA1 (Table 2.15). The 10-point scale (VA1) was therefore used in the present study, although VA2 is the most frequently used technique in literature. In the rest of the study VA1 is used, and referred to as VA.

Walters *et al.*, (1995) found significant negative correlations between WDWT and VA, with correlation coefficients ranging from –0.26 to –0.58. Visual appearance displayed a negative correlation with PWDWT ($r = -0.07$), but values were not significant (Table 2.16). Visual appearance was found to correlate significantly with HC ($r = -0.40$, $P < 0.01$) (Table 2.16). No significant correlations between VA and either WU or HC were mentioned in the literature, but the correlation could indicate that excessive swelling of beans caused by high WU levels could lead to splitting of beans and therefore affect VA negatively. Figure 2.10 indicates that the VA values for the reference standards of choice (Teebus) and standard grade (Helderberg) beans would be 9.74 and 9.15 respectively.

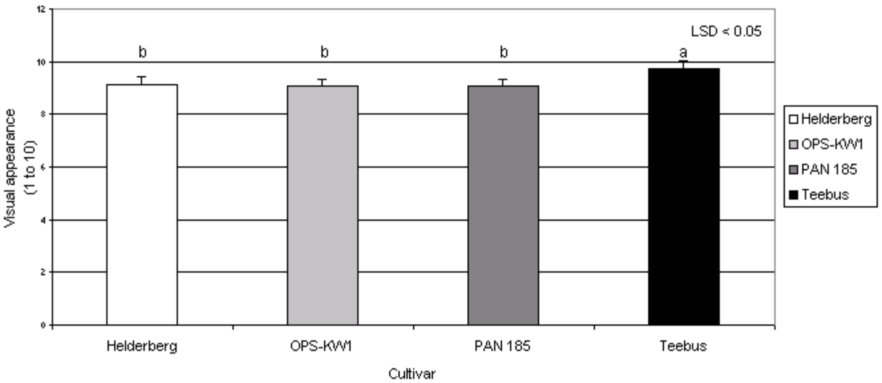


Figure 2.10 Visual appearance of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities (Different letters indicate significant differences at *P* = 0.05).

2.3.2.4 Splits (scale 1 to 10) vs. percentage splits

De Lange & Labuschagne (2000) used the 10-point scale for the evaluation of splits (SPLT1) in canned beans. All broken beans and those with cracks were considered as splits. In the literature most studies (Ghaderi *et al*., 1984; Hosfield *et al*., 1984b; Sastry *et al*., 1985; Lu & Chang, 1996) made use of a 5-point subjective scale evaluation for splits. The canning industry is interested in the actual percentage of completely broken beans in canned samples (SPLT2). Table 2.13 indicates more significant differences between cultivars, localities and cultivar x locality when SPLT1 are used, as compared to SPLT2 (Table 2.14). Splits (scale 1 to 10) would discriminate better (higher F-values) between cultivar and environmental differences in bean canning quality than SPLT2. The reason for smaller differences between cultivars with SPLT2 would be due to the fact that only totally split beans and bean parts are considered as splits, as compared to the SPLT1, where all cracked beans were also considered to be broken.

The correlation coefficient between SPLT1 and SPLT2 was significant ($r = -0.76$, $P < 0.01$) (Table 2.16), indicating that both may be used for measurements of splits in canned beans. The RMSE values were lower in the case of SPLT2, but R^2-values were lower and CV higher with SPLT2 (> 10) as compared to SPLT1 (Table 2.15). The high CV value of SPLT2 indicates that variation between replicates was unacceptably high in the case of SPLT2. Splits (scale 1 to 10) would be preferred for laboratory canning quality evaluation of canned beans, due to better accuracy. In the rest of this study, only SPLT1 was considered and was referred to as splits.

Visual appearance correlated significantly ($P < 0.01$) with splits (r = 0.67, $P < 0.01$) (Table 2.16). The lower the splits of a sample, the better should the appearance of the beans be. Figure 2.11 shows that the split values for the reference standards of choice (Teebus) and standard grade (Helderberg) beans were 9.67 and 9.56, respectively and were not significantly different.

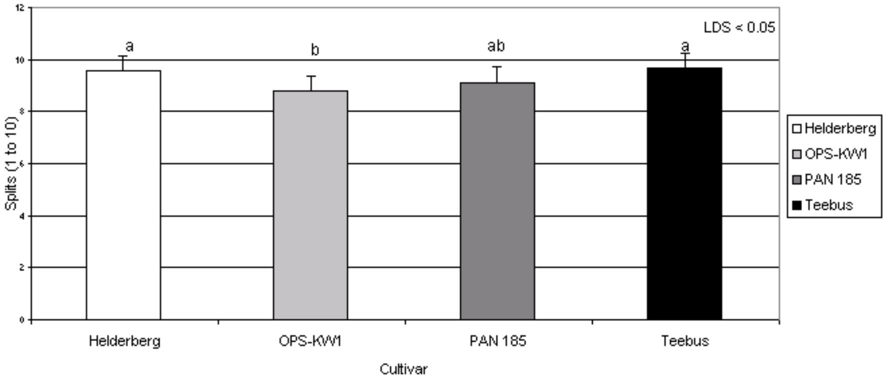


Figure 2.11 Splits of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities (Different letters indicate significant differences at *P* = 0.05).

2.3.2.5 Size

Size of canned beans had not been measured subjectively in previous studies. Deshpande *et al*. (1984) determined the length / breadth (L/B) ratio and breadth thickness (B/T) ratio of uncooked dry beans to indicate shape and size, but canned beans were not considered. Size of canned beans is important for the canning industry due to consumer preferences. Beans should be uniform in size for canning purposes, as indicated by Uebersax *et al*. (1991) and according to industry, the South African consumer is sensitive to changes in bean size in a familiar product, i.e. beans with exceptionally large or small sized seeds. Consumer preferences for size was confirmed by the significant correlations found between size and VA (r = 0.38, $P < 0.01$) (Table 2.16).

Significant correlations (Table 2.16) were found between size and HC (r = -0.54, $P < 0.01$). Size of dry beans would influence the size of canned beans. The correlation between size and HC could be a result of different dry bean seed sizes. Smaller dry bean seeds would take up more water than larger seeds (Deshpande *et al*., 1984).

Size was significantly ($P < 0.01$) affected by cultivar, locality and cultivar x locality interaction (Table 2.14). The R^2-values of size were significantly high, while RMSE and CV were low (Table 2.15), indicating that it would be of importance to use size as a canning quality parameter in the discrimination between cultivars and environments. From Figure 2.12 it is apparent that the size values for the reference standards of choice (Teebus) and standard grade (Helderberg) beans were 6.89 and 5.72 respectively.

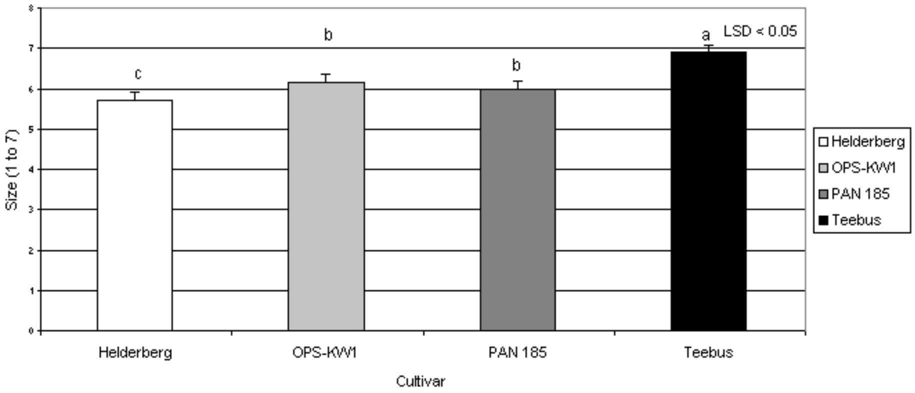


Figure 2.12 Size of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities (Different letters indicate significant differences at $P = 0.05$).

2.3.2.6 Texture

Texture values correlated significantly, but with low r-values with VA ($r = 0.28$, $P < 0.1$) (Table 2.16). Texture was also found to correlate negatively with PWDWT ($r = -0.57$, $P < 0.01$) (Table 2.16). The latter correlation was also indicated in the literature (Ghaderi *et al*., 1984; Occeña *et al*., 1992; Walters *et al*., 1997; Balasubramanian *et al*., 1999). Walters *et al*. (1995) also identified significant correlations between the HC and texture. In the present study, no significant correlations (Table 2.16) between texture and HC were found, which agrees with findings of He *et al*. (1989). From Figure 2.13 it is apparent that the texture for the reference standards of choice (Teebus) and standard grade (Helderberg) beans were 70.21 and 75.26 kg.100 g^{-1}.12 s^{-1} respectively.

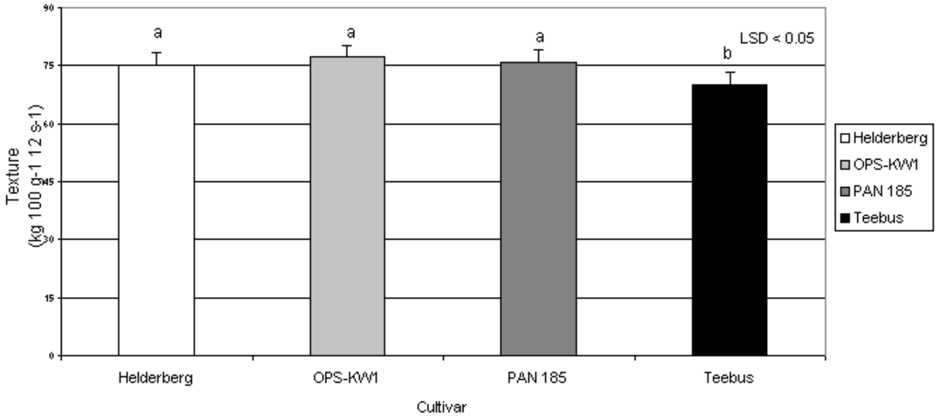


Figure 2.13 Texture of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities (Different letters indicate significant differences at *P* = 0.05).

2.3.2.7 Clumping

The degree of the packing of beans inside the can indicates the degree of clumping that would occur after processing, which might lead to cultivar rejection by the processor (Hosfield & Uebersax, 1980). Mean clumping values for cultivars (mean =

2.85) (Table 2.14) indicated that little clumping occurred during canning with MCT. Clumping of canned beans was found to be more significantly influenced by locality (F-values = 15.73) than by cultivar (F-value = 4.12) (Table 2.14), while Ghaderi *et al*. (1984) found cultivar differences for clumping not to be significant. This could have been influenced by the specific cultivars and localities included in the different trials.

The viscosity of the canned bean medium was to correlate with clumping (r = 0.68, $P < 0.05$) (Lu *et al*., 1996). Viscosity would be discussed in Chapter 4. Clumping did not correlate with any canning quality parameter (Table 2.16). Splitting of canned beans leads to clumping of individual beans (Lu & Chang, 1996). Clumping would therefore be expected to correlate with splits, but no significant correlations were found (Table 2.16). This could be due to the low level of splits recorded in the present study (mean = 2.85) (Table 2.13). Figure 2.14 indicates that clumping for the reference standards of choice (Teebus) and standard grade (Helderberg) beans were 2.89 and 2.72 respectively.

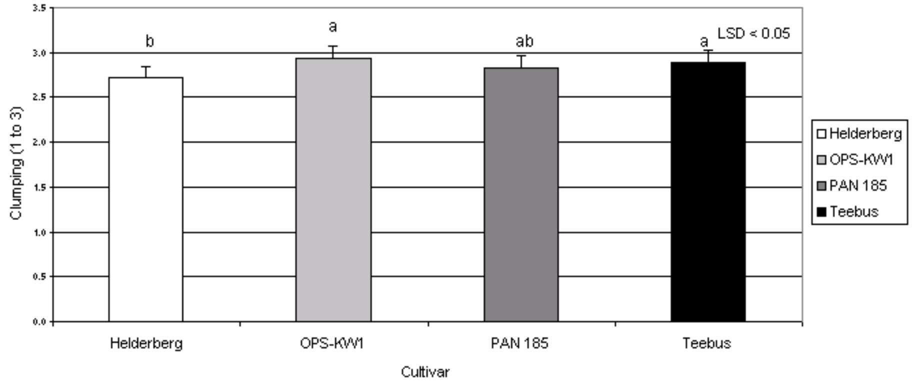


Figure 2.14 Clumping of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities (Different letters indicate significant differences at $P = 0.05$).

2.3.2.8 Colour (L-value, a_L-value and b_L-value)

Significant differences ($P < 0.01$) for cultivar and locality means for L-, a_L- and b_L-values were found, while differences in the cultivar x locality interactions were also significant for L-, and a_L-values (Table 2.14). L-, a_L- and b_L-values were found to have significantly high R^2-values, while RMSE and CV were low (Table 2.15). The R^2-values were higher, but RMSE lower for L-values as compared to those of the a_L- and b_L-values, with the range between the minimum and maximum values larger in the case of L-values (Table 2.15). This indicates that L-values could be expected to discriminate better between cultivars and localities than a_L- and b_L-values. L-values also correlated significantly with a_L- ($r = -0.57$, $P < 0.01$) and b_L- ($r = 0.81$, $P < 0.01$) (Table 2.16) values, indicating that whiter beans would be less red and more yellow in colour. The a_L-values did not correlate significantly with b_L-values. Visual appearance correlated significantly with L- ($r = 0.25$, $P < 0.01$) and b_L ($r = 0.38$, $P < 0.01$) (Table 2.16), implying that beans with lighter (whiter and more yellow) colours would have better appearances.

Lu *et al*. (1996) observed significant correlations between L-values and the degree of bean hydration (MC of soaked beans) ($r = -0.89$, $P < 0.01$). The HC did not correlate significantly with L-values in the present study (Table 2.16), but a_L-values correlated significantly with HC ($r = -0.38$, $P < 0.05$) and with PWDWT ($r = 0.30$, $P < 0.1$). The a_L-values appeared to be more sensitive to changes in the MC of beans, whether it is the water taken up during soaking or during storage in the can. The positive correlation of PWDWT with a_L-values indicates that moisture uptake in the can, led to darker (more red) appearances of beans. The latter could be expected, due to the red-coloured components in the tomato sauce that could have been absorbed by the beans together with the water. Due to the sensitive character of the a_L-values to changes in MC of canned beans, a_L-values are considered with L-values as laboratory canning evaluation parameters in the present study. The a_L-values displayed significant negative correlations with texture ($r = -0.45$, $P < 0.01$). Harder bean texture would therefore cause beans to appear lower in red intensity.

Beans with fewer splits would also be more blue in appearance, as shown by the significant correlation between b_L-values and splits ($r = 0.38$, $P < 0.01$) (Table 2.16). This correlation indicates that the b_L-value is the only colour parameter sensitive to the effect of splits in bean colour and therefore b_L-values are considered together with L- and a_L-values in the present study.

Clumping was found to correlate significantly with L- (r = -0.40, $P < 0.01$) and b_L-(r = -0.43) values (Table 2.16). Solidly clumped beans would appear whiter and more yellow than non-clumped beans. All three colour parameters were used in the present study since all could play an important role in canning quality. Since small white beans are light in colour and all beans are darker in colour after processing (Bolles *et al*., 1990), canning is mostly expected to influence the lightness character of beans, as indicated by the L-values. Colour values for the choice grade reference standard were: L-values = 40.31, a_L-values = 11.12 and b_L-values = 16.79. Values for the standard grade reference standard were: L-values = 41.46, a_L-values = 10.54 and b_L-values = 16.81 (Figures 2.15, 2.16 & 2.17). The b_L-values for choice and standard grade values did not differ significantly.

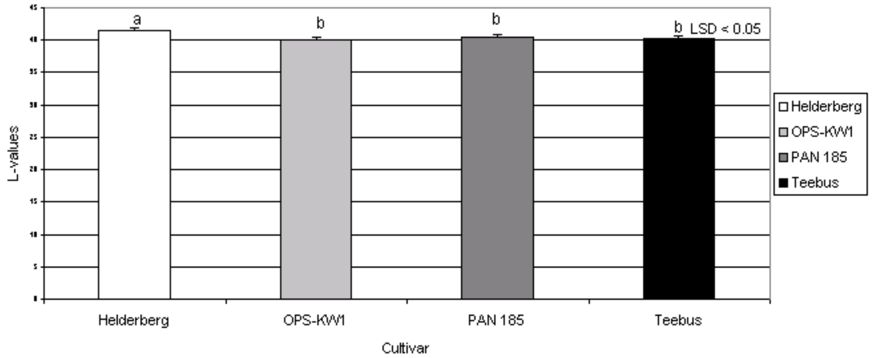


Figure 2.15 Colour (L-values) of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities (Different letters indicate significant differences at *P* = 0.05).

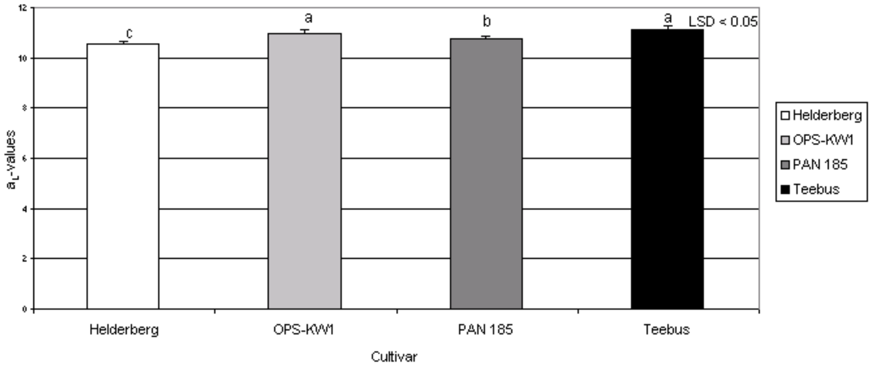


Figure 2.16 Colour (a_L-values) of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities (Different letters indicate significant differences at *P* = 0.05).

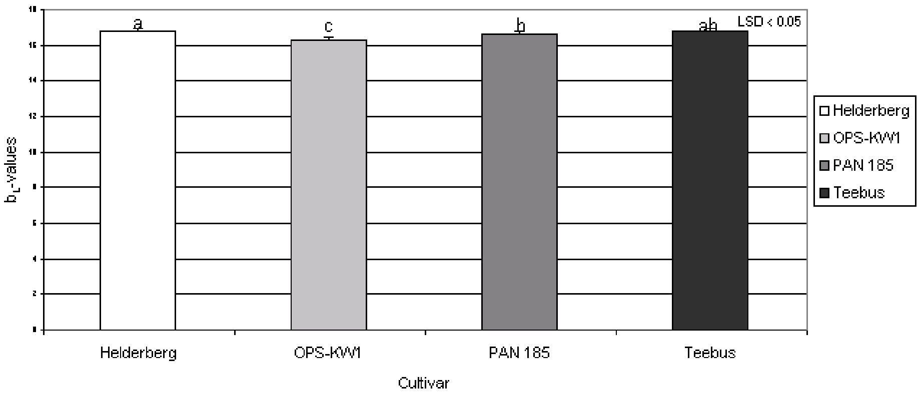


Figure 2.17 Colour (b_L-values) of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from nine localities (Different letters indicate significant differences at *P* = 0.05).

2.4 CONCLUSIONS

When Teebus (reference standard) is canned with the MCT, TXT1 values similar to that of the USA standard values were obtained, while splits and VA were significantly better with this canning technique than with the LCT and the ICT. The PWDWT for Teebus canned with the MCT was in agreement with Canadian regulations of 60 %.

Beans canned with the ICT were close to the Canadian standard in PWDWT, while WU was significantly higher than with the other two techniques. Visual appearance, splits and texture values were significantly lower for the ICT than with the MCT. The texture was also lower than the USA standard value of 72 $kg.100g^{-1}$.

Canning with the LCT resulted in significantly lower WU values than with the ICT, while the PWDWT was significantly higher. The latter caused beans to split significantly more with the LCT than with the MCT. Visual appearances of these beans were in between those of the ICT and MCT. Texture values of LCT-canned beans were softer than the MCT ones and the USA standard. The MCT was therefore, the preferred canning technique to be used in the rest of the present study.

Teebus was used as the reference standard in the current study, since this cultivar also serves as the reference standard in the industry. The PWDWT of Teebus was in agreement with that of Canadian regulations, while texture values agreed with USA standards. Teebus displayed significantly better VA than other cultivars and good split values, which confirms the use of Teebus as reference standard. The low HC is in agreement with results obtained in literature and could still give an indication of HC with industrial canning.

Hydration coefficient would be the preferred canning quality parameter over WU, since HC is most frequently used in literature for laboratory canning evaluation and RMSE and CV values were lower than for WU. The HC for laboratory canned choice grade beans should be at least 1.75, while PWDWT should meet the Canadian standard (60 %) or be at least 58.51 %. The R^2-values were higher and RMSE and CV lower for VA1 than for VA2 and VA should be at least 9.74 for choice grade beans. The CV was lower for SPLT1 than SPLT2 and splits should be at least 9.67 for choice grade beans. Due to the high CV of TXT2, TXT1 would be the preferred parameter. Texture values should meet the USA standard value of 72 $kg.100\ g^{-1}$ or should be no less than the Teebus value of 70.21 $kg.100\ g^{-1}.12\ s^{-1}$ for choice grade. Size and clumping were found to be significant in their use as canning quality parameters (R^2 = 0.91 and 0.80 respectively). Recommended values for size and clumping of choice grade beans are 6.89 and 2.89 respectively. L-values for the colour of canned beans were found to be important, as canning would mostly influence the darkness in colour of beans. The a_L-values were important, since this colour parameter was the only colour indicator identified to be sensitive for changes in bean MC, while b_L-values were identified as sensitive to the splits. Colour values for the choice grade standard should agree with the following values: L-values = 40.31, a_L-values = 11.12 and b_L-values = 16.79.

The canning quality parameter values for the reference standard “choice” and “standard” grade beans are summarised in Table 2.17.

Table 2.17 **Canning quality values for laboratory evaluation of the reference standard beans of "choice" and "standard" grade canned beans in tomato sauce for 2000/01**

Canning quality	Choice grade (Teebus)	Standard grade (Helderberg)
Hydration coefficient	1.75	1.84
Percentage washed drained weight	58.51	58.12
Visual appearance (scale 1 to 10)	9.74	9.15
Splits (scale 1 tot 10)	9.67	9.56
Size (scale 1 to 7)	6.89	5.72
Texture (kg.100 g^{-1}.12 s^{-1})	70.21	75.26
Clumping (scale 1 to 3)	2.89	2.72
Colour (L-values)	40.31	41.46
Colour (a_L-values)	11.12	10.54
Colour (b_L-values)	16.79	16.81

In Chapter 2 laboratory canning evaluation techniques were identified which delivered canned bean products with quality in agreement with those of literature standards. Evaluation parameters were identified that were statistically the most suitable to discriminate between small white bean cultivars in canning quality. In Chapter 3 results from laboratory canned beans are compared to those of bean cultivars canned industrially to identify the agreement between the laboratory canning and evaluation technique and the industrial scale canning technique.

CHAPTER 3

COMPARISON OF THE CANNING QUALITY OF LABORATORY AND INDUSTRIAL CANNED SMALL WHITE BEANS IN TOMATO SAUCE

3.1 INTRODUCTION

Laboratory canning and evaluation of dry beans are common practices for the testing of dry bean cultivars before commercial release to industry for canning purposes. The reason for laboratory testing of canning quality is due to the high cost of losses experienced, should a cultivar with poor canning properties be released and canned on industrial scale. The marketing of such beans would also increase the risk of producers not being able to sell their produce, due to the “bad name” that poor quality products might develop in the market. Chances of finding another market for small white beans with a poor canning quality are small in South Africa, since more than 80 % of these beans are used by the canning industry (De Lange & Labuschagne, 2000).

The main differences between industrial and laboratory canning of beans are related to soaking and blanching procedures (Balasubramanian *et al*., 2000). The laboratory canning protocol used by Balasubramanian *et al*. (2000) produced equivalent texture, clumping and VA values for navy and pinto beans, compared to industrial canning protocols. The HC was however found to be poor when using the laboratory protocol, but produced a good estimate of the HC under industrial canning conditions in the absence of hard-to-cook seeds (Balasubramanian *et al*., 2000).

In Chapter 2 laboratory canning and evaluation procedures were developed and identified, producing a canned product of equal quality to that of the USA (Hosfield & Uebersax, 1980) and Canadian government regulations (Balasubramanian *et al*., 1999). Teebus, which is used as the reference standard for “choice grade” in South African small white canned beans (De Lange & Labuschagne, 2000), was used as the reference standard and was identified to meet most international regulations. The problem is to identify, whether these laboratory canned beans agree in canning quality with industrial canned beans. It is necessary to ensure that the laboratory system used by the ARC–GCI for the evaluation of beans from the National Dry Bean Cultivar Trials meets the standards set by industry. Bean cultivars tested as acceptable in the laboratory should also be acceptable to the canning industry. The objectives of this chapter were to:

1. Identify whether canned "choice grade" products currently available form South African retailers meet the requirements set for good quality canned beans mentioned in Chapter 2.
2. Compare the canning quality of the same bean cultivars canned in the laboratory and industrially.

3.2 MATERIALS AND METHODS

A summary of the origin of samples and the canning and evaluation procedures used to compare the laboratory and industrial canned beans in terms of canning quality are provided in Table 3.1.

Table 3.1 Summary of the origin of samples, canning methods and evaluation procedures used to compare the laboratory and the industrial canning procedures

Canning and evaluation procedures	Samples for canning quality evaluation		
	Laboratory canned	Industrial canned (retailers)	Industrial canned
Origin of samples	Obtained from National Dry Bean Cultivar Trials. Four cultivars from four regions (nine localities) from the 2000/02 season. Samples canned in the laboratory.	Canned beans (choice grade) from four industrial canners obtained from retailers. Cultivar and season of dry beans and date of canning unknown.	Obtained from National Dry Bean Cultivar Trials. Four cultivars from four regions (nine localities) from the 2000/02 season. Samples canned by an industrial canner.
Method of canning	Modified canning technique used. 96 g samples soaked for 30 min at room temperature, blanched for 30 min at 88 °C. Fill mass equals the soaked equivalent of 96 g dry beans. Thermal processing at 121 °C for 30 min.	Industrial canning procedures were unknown.	Industrial canning procedure was unknown
Evaluation procedures			
Water uptake (WU)	WU = (Mass of soaked beans - Mass of dry beans) / Mass of dry beans x 100 WU of 80 % is considered optimum (Hosfield, 1991).		
Hydration coefficient (HC)	HC = Mass of soaked beans / Mass of dry beans HC of 1.8 is considered optimum (Hosfield, 1991).		
Percentage washed drained weight (PWDWT)	PWDWT = Washed drained weight / Mass of can contents x 100 PWDWT of 60 % is considered optimum (Balasubramanian *et al*., 1999).		PWDWT = Washed drained weight / Mass of can contents x 100 PWDWT of 60 % is considered optimum (Balasubramanian *et al*., 1999).
Visual appearance (VA)	Presence of loose seed coats, intactness, uniformity in size and colour, sauce consistence and colour. Value of 10 = intact beans, no free seed coats, uniform size and colour, bright shiny colour. Value of 1 = broken beans, loose seed coats, dull colour, dull and thick tomato sauce (De Lange & Labuschagne, 2000).	Presence of loose seed coats, intactness, uniformity in size and colour, sauce consistence and colour. Value of 10 = intact beans, no free seed coats, uniform size and colour, bright shiny colour. Value of 1 = broken beans, loose seed coats, dull colour, dull and thick tomato sauce (De Lange & Labuschagne, 2000).	
Texture	Determined on 100 g of beans with a FTC Texture Press equipped with loadcell. Measured in kg.100 g^{-1}.12 s^{-1} and kg.s $^{-1}$ (De Lange & Labuschagne, 2000).	Determined on 100 g of beans with a FTC Texture Press equipped with loadcell. Measured in kg.100 g^{-1}.12 s^{-1} and kg.s $^{-1}$ (De Lange & Labuschagne, 2000).	
Splits	Beans with cracks, splits and loose skins evaluated on a scale from 1 to 10. Value of 1 = completely broken and mushy beans. Value of 10 = beans without cracks, splits or loose skins (De Lange & Labuschagne, 2000).	Beans with cracks, splits and loose skins evaluated on a scale from 1 to 10. Value of 1 = completely broken and mushy beans. Value of 10 = beans without cracks, splits or loose skins (De Lange & Labuschagne, 2000).	% Splits = (Mass of split beans) / Mass of total bean content of can) x 100 Only completely split beans and skins considered as split
Size	Seed size within bean sample evaluated on 1 to 7 scale. Uniformity in size and exceptionally large or small beans considered. Value of 1 = exceptionally large or small seeds, unevenly sized. Value of 7 = beans of regular size, evenly sized.	Seed size within bean sample evaluated on 1 to 7 scale. Uniformity in size and exceptionally large or small beans considered. Value of 1 = exceptionally large or small seeds, unevenly sized. Value of 7 = beans of regular size, evenly sized.	Seed size within bean sample evaluated on 1 to 7 scale. Uniformity in size and exceptionally large or small beans considered. Value of 1 = exceptionally large or small seeds, unevenly sized. Value of 7 = beans of regular size, evenly sized.
Clumping	Degree of clumping of beans in can on 1 to 3 scale. Value of 1 = beans solidly clumped to bottom of can Value of 3 = no clumping, easily decanted (Balasubramanian *et al*., 1999).	Degree of clumping of beans in can on 1 to 3 scale. Value of 1 = beans solidly clumped to bottom of can Value of 3 = no clumping, easily decanted (Balasubramanian *et al*., 1999).	
Colour	Colour of washed drained beans measure on Hunter Lab Colorquest (45/0) (Balasubramanian *et al*., 1999).	Colour of washed drained beans measure on Hunter Lab Colorquest (45/0) (Balasubramanian *et al*., 1999).	

3.2.1 Canning quality evaluation of laboratory canned beans

Methods and results from the MCT evaluated beans in Chapter 2 for VA, splits, texture, size, clumping and colour (L-, a_L and b_L-values) were used. Averaged results from various localities were combined (2.2.1) to calculate values for different regions, thus enabling the comparison of laboratory and industrial canned beans (3.2.3). The decision to can beans in the laboratory according to nine localities was based upon the fact that only four cultivars were available. Using more localities would incorporate more variation when testing canning techniques for the laboratory than merely canning beans from four regions (2.2.1). Localities were chosen to represent the most important dry bean production areas.

3.2.2 Canning quality evaluation of industrial canned beans bought from retailers

Canned beans ("choice grade") from four industrial canning companies (designated A, B, C and D) were obtained from retailers. These samples were taken to provide a "baseline check" of the general quality of beans on the market and are not directly connected to the designed experiment and controlled materials. Three cans per company were used. The cultivars used by canners were not known, as were the canning technique or the date of canning, which could have influenced results. Draining and washing of beans on opening of cans were done as described in Chapter 2 (2.2.3.1.1). Due to the findings as reported in Chapter 2, beans were only evaluated for VA, splits, texture, size, clumping and colour (L-, a_L and b_L-values), according to techniques described in Chapter 2 (2.2.3.1.2, 2.2.3.1.3, 2.2.3.2.5, 2.2.3.2.6, 2.2.3.2.7 and 2.2.3.2.8 respectively).

Analysis of variance, using Costat (Cohort Version 3.02) was done for data from canning companies on each canning quality parameter to identify differences between companies for different evaluation techniques.

3.2.3 Canning quality evaluation of industrial canned beans

The same dry bean samples used for laboratory canning (2.2.1) from the four cultivars and regions evaluated were provided to a industrial canning company to be canned according to industrial canning procedures. No details about the soaking, blanching and sterilization process of this industrial canner are available. Due to large sample sizes required by industrial procedures, samples from different localities were combined over regions, i.e.: Gauteng / Mpumalanga (GP / MP) (Bapsfontein and Ermelo), Free State (FS) (Bethlehem, Clocolan, Harrismith and Reitz), KwaZulu-Natal (KZN) (Cedara and Greytown) and North West / Northern Cape area (NW /NC) (Lichtenburg).

3.2.3.1 Water uptake

The percentage WU after soaking according to the industrial procedure was received from the cannery. During industrial canning beans were soaked using different times for different cultivars until WU reached at least 80%. Water uptake was calculated as for the LCT (2.2.2.1), but draining procedures are unknown.

3.2.3.2 Percentage washed drained weight

Cans were opened after a storage period of 24 h (PWDWT1) (fresh out evaluation) and again after 7 days (PWDWT2) (equilibrated evaluation), compared to the 14 day period used in laboratory canning procedures. The shorter periods for industrial canning are due to the limited time industrial canners have to make decisions on bean canning quality. The beans were drained and washed in tap water for 2 min on a 1 000 μm screen to remove all tomato sauce before weighing in 2.2.3.1.1. The PWDWT was calculated from the data received from the canners.

3.2.3.3 Splits

Splits were determined objectively by calculating the actual percentage of split beans found in a can. Completely split beans and loose skins were considered as splits and not only the cracked beans, since the tomato sauce will cover most cracks and would therefore not easily be detected by the consumer. Splits were removed from the sample and weighed. The percentage of splits was calculated as follows:

% Splits = (Mass of split beans (g) / Mass of total bean content of can (g)) x 100

3.2.3.4 Size

Size was determined as described in Chapter 2 (2.2.3.2.6).

3.2.3.5 Statistical analysis of data

Analysis of variance, using Costat (Cohort Version 3.02), was done on data obtained from laboratory and industrial canned beans for cultivars and regions according to a randomised block design. Mean square values were obtained from the ANOVA to calculate the relative effects of region (environment) (E) and cultivar (genotype) (G) on canning quality, by using the ratio (E/G) of the two.

To compare the results of the canning quality of laboratory and industrial canned beans, canonical variate analysis (CVA) was done for the canning parameters of each technique using Genstat 5. Variables considered were HC, PWDWT, splits, CL, size, VA and colour (L-, a_L- and b_L-values). For the CVA on industrial canned beans, WU, PWDWT1, PWDWT2, size and splits were used. For environments the same parameters as for laboratory and industrial canned and evaluated cultivars were used for the four regions. 95 % Confidence circles were drawn on the plot of canonical variate 1 (CV 1) vs. 2 (CV 2) for cultivars to distinguish between choice and standard grade group beans. These circles are drawn around a group mean and the radius of the circle is given by the square root of the 95 % point of a chi-squared variable. The number of degrees of freedom is 2, since the plot is two-dimensional and value for the radius is 2.45 (Digby *et al*., 1989). These circles were also used on the plot of the CVA for regions to indicate the most important dry bean production areas in South Africa.

3.3 RESULTS AND DISCUSSION

3.3.1 Canning quality of laboratory canned beans

Tables 3.2.1 to 3.2.10 provide canning parameter values for cultivars canned in the laboratory according to regions. Table 3.2.11 provides the mean, minimum, maximum and F-values for canning parameters according to regions for laboratory canned beans. Significant differences in canning quality of regions were found for all canning parameters. Cultivars differed significantly in canning quality for all parameters, except for splits and clumping, when regions were considered (Table 3.2.11), instead of localities (Tables 2.13 & 2.14).

Table 3.2.1 Hydration coefficients of four small white bean cultivars (2000/01 season) from four regions after soaking (laboratory canning)

Cultivar (n = 4)	Replicate (n = 2)	Gauteng / Mpumalanga	Free State	North West / Northern Cape	KwaZulu-Natal	Mean (n =4)
Helderberg	1	1.86	1.84	1.83	1.83	1.84
Helderberg	2	1.85	1.83	1.84	1.84	1.84
OPS-KW1	1	1.83	1.84	1.83	1.83	1.83
OPS-KW1	2	1.82	1.85	1.83	1.84	1.84
PAN 185	1	1.85	1.85	1.83	1.84	1.85
PAN 185	2	1.84	1.83	1.83	1.83	1.83
Teebus	1	1.75	1.77	1.74	1.73	1.75
Teebus	2	1.76	1.77	1.74	1.73	1.75
Mean		1.82	1.82	1.81	1.81	
Min		1.75	1.77	1.73	1.74	
Max		1.86	1.85	1.84	1.84	
Range		0.10	0.08	0.11	0.11	

%CV = 0.31

Table 3.2.2 Percentage washed drained weight of four small white bean cultivars (2000/01 season) from four regions (laboratory canning)

Cultivar (n = 4)	Replicate (n = 2)	Gauteng / Mpumalanga	Free State	North West / Northern Cape	KwaZulu-Natal	Mean (n =4)
Helderberg	1	58.36	56.69	58.64	58.73	57.93
Helderberg	2	58.28	57.11	58.00	58.97	58.12
OPS-KW1	1	57.56	56.16	58.59	58.95	57.56
OPS-KW1	2	56.93	56.37	57.61	55.97	56.42
PAN 185	1	58.32	56.40	56.95	58.34	57.68
PAN 185	2	57.57	56.18	57.45	58.55	57.44
Teebus	1	58.22	59.70	58.30	58.39	58.77
Teebus	2	58.13	59.39	58.72	57.86	58.46
Mean		57.92	57.25	58.22	58.03	
Min		56.93	56.16	55.97	56.95	
Max		58.36	59.70	58.97	58.64	
Range		1.44	3.55	3.00	1.69	

%CV = 1.03

Table 3.2.3 Visual appearance (scale 1 to 10) of four small white bean cultivars (2000/01 season) from four regions (laboratory canning)

Cultivar (n = 4)	Replicate (n = 2)	Gauteng / Mpumalanga	Free State	North West / Northern Cape	KwaZulu-Natal	Mean (n =4)
Helderberg	1	9.25	9.00	10.00	9.00	9.08
Helderberg	2	8.75	9.00	9.00	8.50	8.75
OPS-KW1	1	8.75	10.00	9.00	9.00	9.25
OPS-KW1	2	8.50	9.50	9.00	9.00	9.00
PAN 185	1	8.50	9.50	9.00	9.00	9.00
PAN 185	2	8.75	10.00	9.00	9.50	9.42
Teebus	1	9.25	10.00	10.00	9.50	9.58
Teebus	2	9.75	10.00	10.00	9.00	9.58
Mean		8.94	9.63	9.06	9.38	
Min		8.50	9.00	8.50	9.00	
Max		9.25	10.00	9.50	10.00	
Range		0.75	1.00	1.00	1.00	

%CV = 3.26

Table 3.2.4 Splits (scale 1 to 10) of four small white bean cultivars (2000/01 season) from four regions (laboratory canning)

Cultivar (n = 4)	Replicate (n = 2)	Gauteng / Mpumalanga	Free State	North West / Northern Cape	KwaZulu-Natal	Mean (n =4)
Helderberg	1	10.00	10.00	10.00	10.00	10.00
Helderberg	2	8.50	10.00	10.00	9.00	9.17
OPS-KW1	1	8.00	10.00	10.00	9.00	9.00
OPS-KW1	2	7.50	10.00	10.00	9.00	8.83
PAN 185	1	8.00	10.00	10.00	10.00	9.33
PAN 185	2	8.50	10.00	10.00	9.00	9.17
Teebus	1	9.50	10.00	10.00	9.00	9.50
Teebus	2	9.50	10.00	10.00	10.00	9.83
Mean		8.69	10.00	9.38	10.00	
Min		7.50	10.00	9.00	10.00	
Max		10.00	10.00	10.00	10.00	
Range		2.50	0.00	1.00	0.00	

%CV = 4.44

Table 3.2.5 Size (scale 1 to 7) of four small white bean cultivars (2000/01 season) from four regions (laboratory canning)

Cultivar (n = 4)	Replicate (n = 2)	Gauteng / Mpumalanga	Free State	North West / Northern Cape	KwaZulu-Natal	Mean (n =4)
Helderberg	1	6.00	5.50	6.00	5.50	5.75
Helderberg	2	5.75	5.50	6.00	5.50	5.69
OPS-KW1	1	6.50	6.50	5.00	6.00	6.00
OPS-KW1	2	6.25	6.50	5.00	6.00	5.94
PAN 185	1	5.75	6.00	6.00	6.00	5.94
PAN 185	2	5.75	6.50	6.00	6.50	6.19
Teebus	1	7.00	7.00	7.00	6.50	6.88
Teebus	2	7.00	7.00	7.00	6.50	6.88
Mean		6.25	6.31	6.06	6.00	
Min		5.75	5.50	5.50	5.00	
Max		7.00	7.00	6.50	7.00	
Range		1.25	1.50	1.00	2.00	

%CV = 2.32

Table 3.2.6 Texture (kg.100 g^{-1}.12 s^{-1}) of four small white bean cultivars (2000/01 season) from four regions (laboratory canning)

Cultivar (n = 4)	Replicate (n = 2)	Gauteng / Mpumalanga	Free State	North West / Northern Cape	KwaZulu-Natal	Mean (n =4)
Helderberg	1	74.45	93.95	65.30	67.80	75.38
Helderberg	2	72.85	94.20	65.70	61.30	73.51
OPS-KW1	1	75.58	94.35	63.80	72.85	76.64
OPS-KW1	2	77.73	88.85	62.80	69.60	74.74
PAN 185	1	70.60	95.80	71.20	69.60	76.80
PAN 185	2	69.63	97.50	64.70	72.50	76.08
Teebus	1	66.15	63.80	72.70	78.05	70.18
Teebus	2	70.90	65.40	65.70	81.30	70.83
Mean		72.23	86.73	71.63	66.49	
Min		66.15	63.80	61.30	62.80	
Max		77.73	97.50	78.05	72.70	
Range		11.58	33.70	16.75	9.90	

%CV = 3.61

Table 3.2.7 Clumping (scale 1 to 3) of four small white bean cultivars (2000/01 season) from four regions (laboratory canning)

Cultivar (n = 4)	Replicate (n = 2)	Gauteng / Mpumalanga	Free State	North West / Northern Cape	KwaZulu-Natal	Mean (n =4)
Helderberg	1	2.75	3.00	2.00	2.50	2.56
Helderberg	2	3.00	3.00	2.00	2.50	2.63
OPS-KW1	1	3.00	3.00	2.00	3.00	2.75
OPS-KW1	2	3.00	3.00	3.00	3.00	3.00
PAN 185	1	3.00	3.00	2.00	2.50	2.63
PAN 185	2	3.00	3.00	3.00	2.50	2.88
Teebus	1	3.00	3.00	3.00	2.50	2.88
Teebus	2	3.00	3.00	3.00	2.50	2.88
Mean		2.97	3.00	2.63	2.50	
Min		2.75	3.00	2.50	2.00	
Max		3.00	3.00	3.00	3.00	
Range		0.25	0.00	0.50	1.00	

%CV = 8.70

Table 3.2.8 L-values of four small white bean cultivars (2000/01 season) from four regions (laboratory canning)

Cultivar (n = 4)	Replicate (n = 2)	Gauteng / Mpumalanga	Free State	North West / Northern Cape	KwaZulu-Natal	Mean (n =4)
Helderberg	1	41.38	41.79	44.10	39.99	41.82
Helderberg	2	41.35	41.98	43.20	40.26	41.69
OPS-KW1	1	39.36	40.34	42.77	39.75	40.56
OPS-KW1	2	39.68	39.81	42.41	40.48	40.59
PAN 185	1	40.15	41.70	43.30	40.04	41.30
PAN 185	2	39.53	41.45	41.25	39.76	40.50
Teebus	1	39.55	40.45	41.52	40.16	40.42
Teebus	2	39.98	40.51	42.39	40.72	40.90
Mean		40.12	41.00	40.14	42.62	
Min		39.36	39.81	39.75	41.25	
Max		41.38	41.98	40.48	44.10	
Range		2.02	2.17	0.73	2.85	

%CV = 1.24

Table 3.2.9 The a_L-values of four small white bean cultivars (2000/01 season) from four regions (laboratory canning)

Cultivar (n = 4)	Replicate (n = 2)	Gauteng / Mpumalanga	Free State	North West / Northern Cape	KwaZulu-Natal	Mean (n =4)
Helderberg	1	10.31	10.30	10.19	10.30	10.27
Helderberg	2	10.52	10.35	10.20	10.35	10.35
OPS-KW1	1	11.18	10.71	11.02	10.71	10.91
OPS-KW1	2	10.97	10.66	10.63	10.66	10.73
PAN 185	1	10.93	10.12	10.09	10.12	10.31
PAN 185	2	10.91	10.11	11.08	10.11	10.55
Teebus	1	11.13	11.14	10.88	11.14	11.07
Teebus	2	11.08	10.88	10.82	10.88	10.92
Mean		10.88	10.53	10.53	10.61	
Min		10.31	10.11	10.11	10.09	
Max		11.18	11.14	11.14	11.08	
Range		0.88	1.03	1.03	0.99	

%CV = 2.01

Table 3.2.10 The b_L-values of four small white bean cultivars (2000/01 season) from four regions (laboratory canning)

Cultivar (n = 4)	Replicate (n = 2)	Gauteng / Mpumalanga	Free State	North West / Northern Cape	KwaZulu-Natal	Mean (n =4)
Helderberg	1	16.54	17.09	17.55	16.57	16.94
Helderberg	2	16.65	17.24	17.37	16.59	16.96
OPS-KW1	1	15.89	16.43	17.37	16.53	16.55
OPS-KW1	2	15.88	16.19	17.28	16.79	16.53
PAN 185	1	16.42	16.97	17.40	16.73	16.88
PAN 185	2	16.29	16.89	17.23	16.60	16.75
Teebus	1	16.38	17.04	17.26	16.87	16.88
Teebus	2	16.53	16.86	17.56	17.15	17.02
Mean		16.32	16.84	16.73	17.38	
Min		15.88	16.19	16.53	17.23	
Max		16.65	17.24	16.87	17.55	
Range		0.77	1.05	0.33	0.32	

%CV = 0.77

Table 3.2.11 Minimum, mean, maximum and the F-values of the canning quality parameters of four small white bean cultivars experimentally canned from four dry bean production regions from the 2000/01 season

Canning quality	Mean	Minimum	Maximum	F-values	
				Cultivar (df = 3)	**Region (df = 3)**
Hydration coefficient	1.81	1.73	1.86	499.39 ***	15.16 ***
Percentage washed drained weight	57.86	55.97	59.70	8.16 **	4.00 *
Visual appearance (1 to 10)	9.25	8.50	10.00	7.60 **	8.46 **
Splits (1 to 10)	9.52	7.50	10.00	2.96 ns	17.54 ***
Size (1 to 7)	6.16	5.00	7.00	98.72 ***	8.72 **
Clumping (1 to 3)	2.77	2.00	3.00	2.45 ns	8.53 **
Texture (kg 100 g-1 12 s-1)	74.27	61.30	97.50	7.77 **	84.08 ***
L-values	40.97	39.36	44.10	8.99 **	42.37 ***
a_L-values	10.64	10.09	11.18	17.87 ***	4.70 *
b_L-values	16.81	15.88	17.56	17.89 ***	91.62 ***

*** $P < 0.01$; ** $P < 0.05$; * $P < 0.1$; ns P0.05

3.3.2 Canning quality of industrial canned beans obtained from retailers

Canned beans from retailers were evaluated to establish the quality of canned bean products that are available from retailers and to determine whether there is a need for improvement of product quality. Table 3.3 provides the canning quality of the canned beans from four industrial canners. Table 3.4 shows the minimum, maximum, mean and F-values of the canning quality parameters of the products.

Significant differences were observed between canning companies for all canning parameters, except for splits and clumping (Table 3.4). This indicates that standard evaluation values for South African canning companies were not set as for Canadian (Balasubramanian *et al.*, 1999) and USA (Hosfield & Uebersax, 1980) companies. Mean values for all canning parameters did not agree with choice grade values, as identified in Chapter 2 (Table 2.17). Mean texture values did not agree with the USA guidelines of 72 kg.100 g^{-1}. Ranges for texture and L-values were large, indicating no consistency of the canning quality of choice grade beans from South African canning companies. Therefore the need exists for a set of standard values for the canning of South African choice grade small white beans, as was attempted to be done in the previous chapter (Table 2.17).

Table 3.3 Canning quality parameters of "choice grade" canned beans in tomato sauce from four industrial canners, obtained from retailers

Company (n = 4)	Replicate (n = 3)	Visual appearance (scale 1 to 10)	Splits (scale 1 to 10)	Texture (kg.100 g^{-1}.12 s^{-1})	Size (scale 1 to 7)	Clumping (scale 1 to 3)	Colour		
							L-value	a_L-value	b_L-value
A	1	8.00	10.00	65.70	6.00	3.00	34.44	11.34	14.37
A	2	8.00	10.00	65.80	7.00	3.00	34.30	11.24	14.34
A	3	10.00	10.00	65.70	7.00	2.00	34.75	11.40	14.46
B	1	6.00	10.00	43.60	7.00	3.00	43.16	10.43	16.21
B	2	6.00	8.00	43.80	7.00	3.00	41.05	10.33	15.84
B	3	6.00	8.00	42.20	7.00	3.00	42.59	10.35	16.17
C	1	6.00	8.00	52.50	5.00	2.00	45.74	9.86	16.58
C	2	6.00	10.00	51.20	5.00	2.00	45.53	9.92	16.71
C	3	6.00	10.00	52.10	5.00	3.00	46.20	9.81	16.63
D	1	6.00	8.00	78.20	6.00	2.00	47.23	9.15	16.25
D	2	8.00	10.00	74.40	7.00	2.00	43.40	10.53	16.61
D	3	8.00	8.00	77.70	6.00	2.00	44.46	9.40	16.80
Mean		7.00	9.17	59.41	6.25	2.50	41.90	10.31	15.91
Minimum		6.00	8.00	42.20	5.00	2.00	34.30	9.15	14.34
Maximum		10.00	10.00	78.20	7.00	3.00	47.23	11.40	16.80
Range		4.00	2.00	36.00	2.00	1.00	12.93	2.25	2.46

Table 3.4 Mean, minimum and maximum values, coefficients of variation and F-values pertaining to canning quality parameters of the canned small white beans of four industrial canning companies

Canning quality parameters	Mean	Minimum	Maximum	Coefficient of variation	F-values	
					Company (df = 3)	Replicates (df = 2)
Visual appearance (scale 1 to 10)	7.00	6.00	10.00	10.65	8.80*	1.80^{ns}
Splits (1 tot 10)	9.17	8.00	10.00	12.06	1.00^{ns}	0.27^{ns}
Texture (kg.100 g^{-1}.12 s^{-1})	59.41	42.20	78.20	1.95	491.34***	1.80^{ns}
Size (scale 1 to 7)	6.25	5.00	7.00	5.96	16.60**	0.25^{ns}
Clumping (scale 1 to 3)	2.50	2.00	3.00	16.33	3.33^{ns}	0.00^{ns}
L-value	41.90	34.30	47.23	2.29	86.71***	0.76^{ns}
a_L-value	10.31	9.15	11.40	3.72	11.01**	0.76^{ns}
b_L-value	15.91	14.34	16.80	1.13	102.13***	0.96^{ns}

*** = $P < 0.01$; ** = $P < 0.05$; * = $P < 0.1$; ; ns > P 0.05

n = 12

3.3.3 Canning quality evaluation of industrial canned beans

The WU, PWDWT1, PWDWT2 and size of small white beans that were canned by an industrial canner, are provided in Tables 3.5 to 3.9. In Table 3.10 mean, minimum, maximum and F-values for cultivars from four different regions that were canned and evaluated industrially are indicated. As for laboratory canned beans (Table 3.2.11), significant differences were found for WU, PWDWT1, PWDWT2, splits and size for different cultivars (Table 3.10). Differences for regions were only significant in the case of WU and size, while all parameters were significantly different at different regions in the case of laboratory canned beans (Table 3.2.11). Table 3.11 indicates the relative effects of environment and cultivar on canning quality of small white beans canned industrial and in the laboratory. The ratio (E/G) indicates whether a parameter is mostly affected by G or E. A value of > 1, indicates that the parameters are mostly affected by E, while a value of < 1 indicate that G would mostly affect the parameter.

The different canning quality parameters as determined by an industrial canner are discussed in 3.3.3.1 to 3.3.3.4. Mean values for dry bean cultivar parameters as determined by an industrial canner are illustrated in Figures 3.1 to 3.5.

Table 3.5 Percentage water uptake of four small white cultivars (2000/01 season) from four regions, as determined by an industrial canner

Cultivar (n = 4)	Gauteng / Mpumalanga	Free State	KwaZulu-Natal	North West / Northern Cape	Mean (n = 4)
Helderberg	96.00	97.20	96.00	97.50	96.68
OPS-KW1	97.00	98.00	99.00	100.20	98.55
PAN 185	96.50	97.50	99.00	102.00	98.75
Teebus	89.20	90.00	90.80	91.00	90.25
Mean	94.68	95.68	96.20	97.68	
Min	89.20	90.00	90.80	91.00	
Max	97.00	98.00	99.00	102.00	
Range	7.80	8.00	8.20	11.00	

%CV = 0.98

Table 3.6 Percentage washed drained weight of four canned small white bean cultivars (2000/01 season) from four regions as determined by an industrial canner, after 24 h' storage (fresh out evaluation)

Cultivar (n = 4)	Gauteng / Mpumalanga	Free State	KwaZulu-Natal	North West / Northern Cape	Mean (n = 4)
Helderberg	57.07	59.02	60.73	58.78	58.90
OPS-KW1	56.59	56.59	57.37	55.10	56.41
PAN 185	60.98	57.07	59.02	57.07	58.54
Teebus	61.46	57.56	63.90	60.98	60.98
Mean	59.02	57.56	60.26	57.98	
Min	56.59	56.59	57.37	55.10	
Max	61.46	59.02	63.90	60.98	
Range	4.88	2.44	6.54	5.88	

%CV = 3.12

Table 3.7 Percentage washed drained weight of four small white bean cultivars (2000/01 season) from four regions as determined by an industrial canner, after 7 days' storage (equilibrated evaluation)

Cultivar (n = 4)	Gauteng / Mpumalanga	Free State	KwaZulu-Natal	North West / Northern Cape	Mean (n = 4)
Helderberg	60.00	60.24	62.20	58.78	60.30
OPS-KW1	57.80	57.07	57.00	56.90	57.19
PAN 185	61.46	59.02	60.24	57.56	59.57
Teebus	66.22	57.56	64.51	64.02	63.08
Mean	61.37	58.47	60.99	59.32	
Min	57.80	57.07	57.00	56.90	
Max	66.22	60.24	64.51	64.02	
Range	8.42	3.17	7.51	7.12	

%CV = 3.56

Table 3.8 **Percentage splits of four canned small white bean cultivars (2000/01 season) from four regions as determined by an industrial canner**

Cultivar (n = 4)	Gauteng / Mpumalanga	Free State	KwaZulu-Natal	North West / Northern Cape	Mean (n = 4)
Helderberg	35.00	16.00	39.00	54.00	36.00
OPS-KW1	22.00	44.00	6.00	23.00	23.75
PAN 185	20.00	38.00	31.00	65.00	38.50
Teebus	1.00	6.00	13.00	3.00	5.75
Mean	19.50	26.00	22.25	36.25	
Min	1.00	6.00	6.00	3.00	
Max	35.00	44.00	39.00	65.00	
Range	34.00	38.00	33.00	62.00	

%CV = 57.35

Table 3.9 **Bean size of four canned small white bean cultivars (2000/01 season) from four regions as determined by an industrial canner**

Cultivar (n = 4)	Gauteng / Mpumalanga	Free State	KwaZulu-Natal	North West / Northern Cape	Mean (n = 4)
Helderberg	4.00	4.00	5.00	5.00	4.50
OPS-KW1	5.00	5.00	6.00	5.00	5.25
PAN 185	5.00	4.00	6.00	4.00	4.75
Teebus	7.00	6.00	7.00	6.00	6.50
Mean	5.25	4.75	6.00	5.00	
Min	4.00	4.00	5.00	4.00	
Max	7.00	6.00	7.00	6.00	
Range	3.00	2.00	2.00	2.00	

%CV = 8.98

Table 3.10 **Mean, minimum and maximum and F-values values pertaining to canning quality parameters of small white beans from four different industrial canning companies**

Canning quality parameters	Mean	Minimum	Maximum	F-value	
				Cultivar (df = 3)	Region (df = 3)
Water uptake (%)	96.06	89.20	102.00	71.35 ***	7.04 **
Percentage washed drained weight (24 h)	58.48	55.10	63.90	5.64 *	1.29 ^{ns}
Percentage washed drained weight (7 days)	59.76	56.90	66.22	5.95 **	1.90 ^{ns}
Splits (%)	26.00	1.00	65.00	4.03 *	0.97 ^{ns}
Size (scale 1 to 7)	5.25	4.00	7.00	14.25 ***	5.25 *

*** $P < 0.01$; ** $P < 0.05$; * $P < 0.1$; ns > P 0.05

Table 3.11 The relative effects of growth environment and cultivar on canning quality characteristics of small white beans from different regions as determined with laboratory and industrial canning

Canning quality	Mean square		
	Cultivar (G)[#] (df = 3)	Region (E)[##] (df = 3)	Ratio (E/G)
Laboratory canning			
Hydration coefficient	0.02	4.84	322.67
Washed drained weight (%)	2.91	1.43	0.49
Visual appearance (scale 1 to 10)	0.69	0.77	1.12
Splits (scale 1 tot 10)	0.53	3.13	5.91
Size (scale 1 to 7)	2.01	0.18	0.09
Clumping (scale 1 to 3)	0.14	0.50	3.57
Texture (kg.100 g^{-1}.12 s^{-1})	55.95	605.31	10.82
L-value	2.33	10.99	4.72
a_L-value	0.82	0.22	0.27
b_L-value	0.30	1.52	5.07
Industrial canning			
Water uptake (%)	63.43	6.26	0.10
Washed drained weight (%)(24 h)	17.30	3.97	0.23
Washed drained weight (%)(7 days)	23.50	7.52	0.32
Splits (%)	895.17	215.17	0.24
Size (scale 1 to 7)	3.17	1.17	0.37

#G = Genotype; ##E = Environment

Values > 1 attributed to E; Values < 1 attributed to G

3.3.3.1 Water uptake

It is apparent from Figure 3.1 that Teebus had significantly lower WU values than the other cultivars, while OPS-KW1 and PAN 185 had the highest values. Teebus also displayed significantly lower HC values when laboratory canned (Chapter 2, Figure 2.8), while PAN 185 and Helderberg had the highest values. Water uptake values with industrial canned beans are influenced by soaking time, due to adjustments made in the soaking time of different cultivars to ensure the optimum WU of all beans. It is therefore confirmed that Teebus was unable to take up water to the same extent as the other cultivars, even with adjustments in soaking time. All cultivars displayed WU values higher than the requirement of 80 % set for USA canned beans (Hosfield *et al.*, 1984a). According to Figure 2.8 Teebus was unable to reach the HC value of 1.8 set by USA standards when canned on laboratory scale (Hosfield *et al.*, 1984a), however, it did meet the standard of 80 % when canned under industrial conditions. Similar results were obtained by Balasubramanian *et al.* (2000) in a laboratory canning protocol for black, navy and pinto beans in brine, showed poor HC values, whereas the estimate of HC was good for the industrial HC in the absence of hard-to-cook seeds. Although Teebus could not reach standard HC values with the MCT, the standard WU value was reached under industrial canning conditions.

As explained, WU in industrial canning is determined differently for industrial canned beans, than for those canned in the laboratory. In industry a certain cultivar is soaked, until WU reaches 80 %, compared to the soaking of all beans for a specific time with laboratory canning. This could explain the differences in the E/G ratios of laboratory (HC) and industrial canned beans (WU). This ratio was > 1 in the first case and < 1 in the latter case (Table 3.11). An E/G ratio of > 1 indicates that differences in HC were mostly due to regions. The E/G ratio of > 1 of laboratory canned beans could have been caused by averaging the results of nine localities to obtain regional values, while the industry canned a combined sample of different localities in a specific region. The first case could have resulted in more environmental variation. The reason for the high ratio in the case of laboratory canned beans is uncertain. Only four regions and four cultivars were used in the present chapter and further investigation would be done into the effect of E and G on HC where more localities and cultivars / entries are used in Chapters 4 & 5.

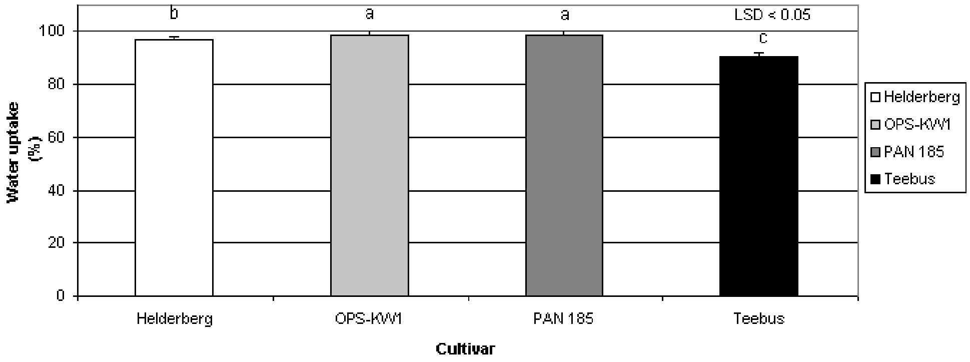


Figure 3.1 Percentage water uptake of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from four regions, canned and evaluated by an industrial canning company (Different letters indicate significant differences at *P* = 0.05).

3.3.3.2 Percentage washed drained weight

Figures 3.2 and 3.3 indicate that OPS-KW1 had lower PWDWT values than Teebus, for both 24 h (PWDWT1) and 7 days (PWDWT2) storage after canning. Figure 3.3 and Table 3.10 (F-values) indicate that differences between cultivars were more significant with PWDWT2. According to Bolles *et al.* (1982) this could be due to the WU that takes place inside the can during the first seven days after canning. Results for PWDWT2 are in agreement with those of Chapter 2 (Figure 2.9) for laboratory canned beans, since both represents the equilibrated values. For both laboratory and industrial canning, Teebus were close to the 60 % standard set by Canadian government regulations (Balasubramanian *et al.*, 1999). Both Helderberg and PAN 185 did not differ significantly from Teebus in PWDWT2 values.

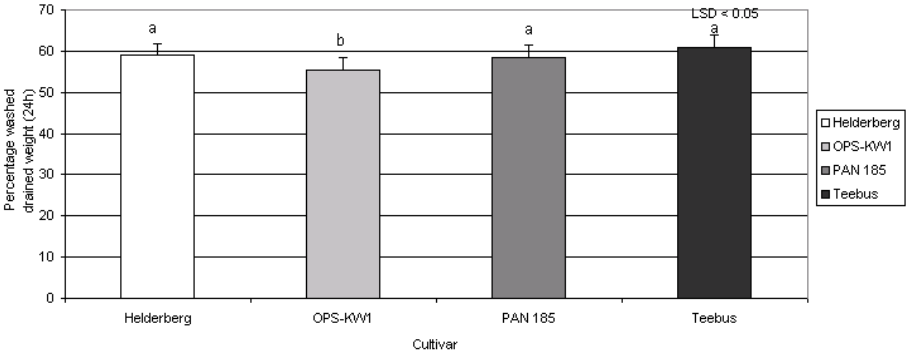


Figure 3.2 Percentage washed drained weight of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from four regions, canned and evaluated by an industrial canning company, 24 h after canning (fresh out evaluation) (Different letters indicate significant differences at *P* = 0.05).

These results indicated that PWDWT was the almost the same for cultivars when beans were canned either in the laboratory or industrially. In both the laboratory (PWDWT) and industrial canned beans (PWDWT 1 and PWDWT2) the E/G ration was < 1 (Table 3.11), indicating that PWDWT is also more affected by cultivar than by region in cases where the same small number of cultivars (n = 4) and regions (n = 4) are used.

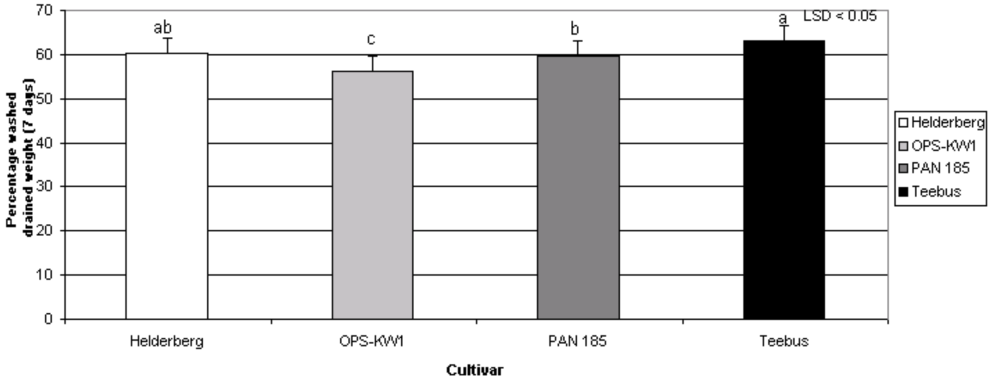


Figure 3.3 Percentage washed drained weight of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from four regions, canned and evaluated by an industrial canning company, 7 days after canning (equilibrated evaluation) (Different letters indicate significant differences at P = 0.05).

3.3.3.3 Splits

Teebus had significantly less splits than Helderberg and PAN 185 (Figure 3.4), while Teebus had the fewest splits when canned in the laboratory (Figure 2.11). The E/G ratio for splits of industrially canned beans was < 1, indicating that split values were mostly affected by cultivar (Table 3.11). Contrary to this the E/G ratio was > 1 for splits of laboratory canned beans. Splits of these beans were mostly affected by environment. This could have been caused by the different ways used to calculate regional values for canning parameters. In the case of laboratory canned beans, averaged results of localities were used, while industrial samples were canned according to regions, as explained in 3.2.1. Differences between industrial and laboratory results could also have been caused by the different techniques used to determine splits (2.2.3.1.3 & 3.2.3.3).

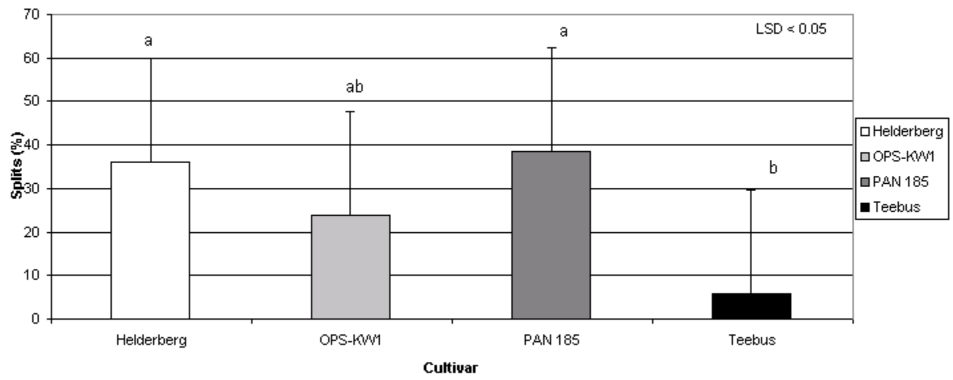


Figure 3.4 Percentage splits of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from four regions canned and evaluated by an industrial canning company (Different letters indicate significant differences at *P* = 0.05).

3.3.3.4 Size

According to Figure 3.5 size values of canned beans were significantly higher in the case of Teebus, which is in agreement with results for laboratory canned beans in Chapter 2 (Figure 2.12). No significant differences were observed between size values of Helderberg, PAN 185 and OPS-KW1 in the case of industrially canned beans, while that of Helderberg was significantly lower when laboratory canned (Figure 2.12). The E/G ratios of both industrial and laboratory canned beans were > 1 (Table 3.11), indicating that variation in size values was predominantly caused by cultivar effects.

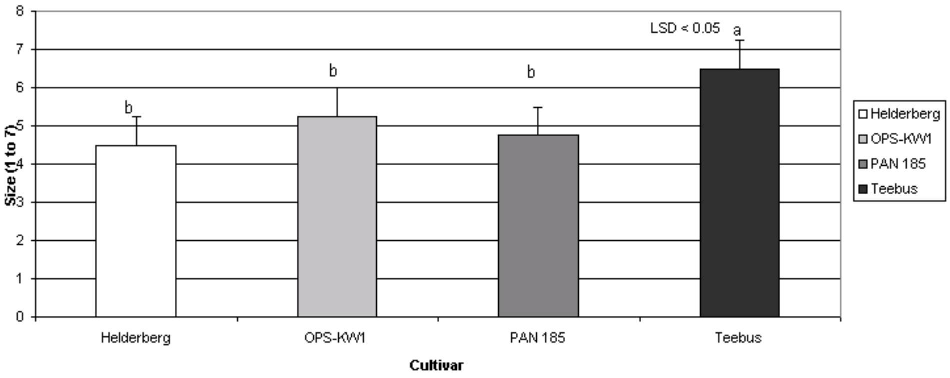


Figure 3.5 Size values of Helderberg, OPS-KW1, PAN 185 and Teebus (reference standard) from four regions, canned and evaluated by an industrial canning company (Different letters indicate significant differences at *P* = 0.05).

Visual appearance, clumping, texture, L-, a_L- and b_L-values were only applicable to laboratory canned beans, since industrial canners do not use these parameters in their evaluation systems. All these parameters, except for a_L-values had E/G ratios > 1, indicating that regions affected these values more than cultivar. The a_L-values were mostly affected by cultivar. The E/G ratios determined were specifically for the situation where four cultivars and four regions were used and mostly (except for splits) indicated the same factors to be important in canning quality determination for industrial and laboratory canned beans. Scenarios to investigate the effect of an increase in the number of genotypes or environments on E/G ratios of canning parameters would be considered in Chapters 4 & 5.

3.3.4 Comparison of the evaluation of canning quality of laboratory and industrially canned beans

Due to different quality parameters used for the evaluation of laboratory and industrially canned beans, only a comparison of similar parameters was only possible with ANOVA. Canonical variate analysis is used when it is of more interest to show differences between groups than individuals (Digby *et al*., 1989). Canonical variate analysis was used to group cultivars canned by industry and the laboratory as choice of standard grade beans. Regions were grouped according to those with the highest production of dry beans in South Africa. These grouping were done to identify whether industrial canning quality of beans are represented by laboratory canning and evaluation procedures, since different canning parameters used by the two prevent the direct comparison of these two techniques.

3.3.4.1 Cultivars

The CVA for laboratory canned beans, considering all canning parameters, indicated that canonical variates 1 (CV 1) (94.96 %) and 2 (CV 2) (4.91 %) were able to account for 99.87 % of the variation in canning quality of cultivars. The latent vectors for CV 1 (4.74) and CV 2 (0.25) were only > 1 in the case of CV 1. Latent roots of < 1 indicate the presence of more within group variation than between group variation (Digby *et al*., 1989). Therefore CV 1 would be more important to discriminate between groups. From the latent vectors followed the following discriminating equations for CV 1 and CV 2:

$$\text{CV 1} = 0.116\ (b_L\text{-value}) - 47.507\ (\text{HC}) + 0.711\ (\text{Size}) + 0.039\ (a_L\text{-value}) + 79.51 \qquad (1)$$

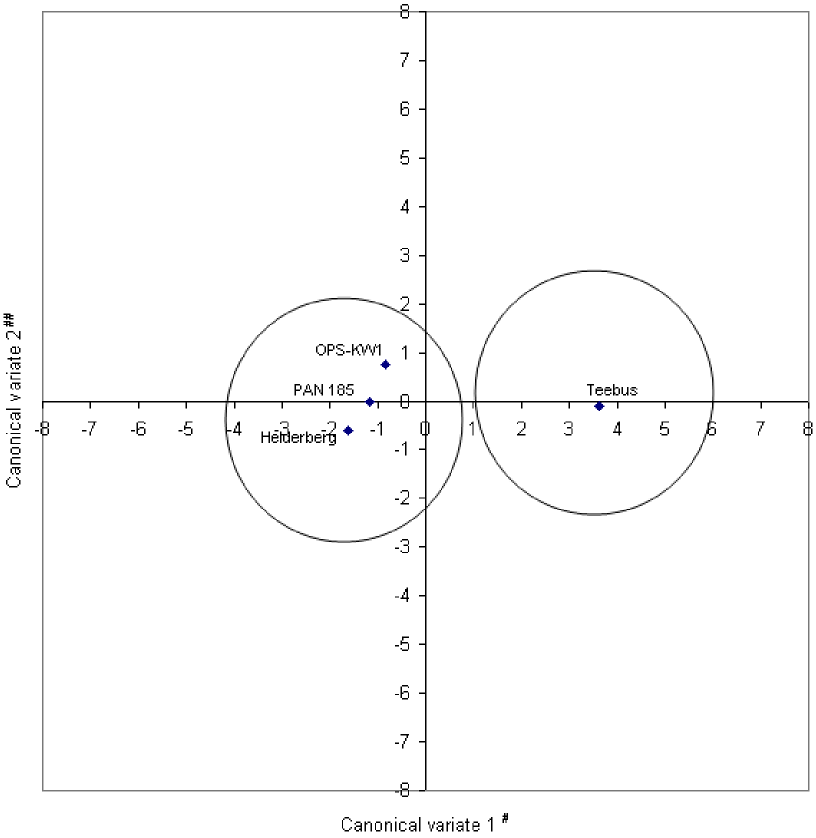
$$\text{CV 2} = -1.166\ (b_L\text{-value}) + 13.033\ (\text{HC}) + 0.842\ (\text{Size}) + 1.216\ (a_L\text{-value}) - 22.67 \qquad (2)$$

Table 3.12 provides the correlation coefficients between canning quality parameters and CV 1 and CV2. Only positive correlations with $r > 0.60$ and negative correlations with $r < -0.60$ were considered. It is apparent that HC correlated negatively and size positively with CV 1. From the correlations it was shown that HC and size would contribute mostly to the variation for CV 1. The b_L-values correlated negatively with CV 2. These correlations indicate that b_L-values contribute mostly to CV 2, but latent roots were < 1. Figure 3.6 displays the plot of the scores for cultivars for CV 1 and CV 2. Cultivars to the right side of the plot would be those with low HC and high size values. Cultivars to the bottom half of the plot would be those with high b_L-values (more yellow and less blue). The 95 % confidence circles on the plot indicate choice and standard grade group cultivars. Teebus served as the reference standard for choice grade and Helderberg for standard grade cultivars. Teebus differed significantly from all other cultivars (outside 95 % confidence circle). Therefore no other cultivar belonged to the choice grade group. OPS-KW1 and PAN 185 were not significantly different from Helderberg (within the 95 % confidence circle) and were standard grade cultivars.

Table 3.12 Correlation matrix of canonical variates 1 and 2 with canning quality parameters of laboratory canned small white bean cultivars

	b_L-value	Hydration Coefficient	Size	a_L-value
Canonical variate 1	0.12	-0.99	0.68	0.37
Canonical variate 2	-0.77	0.06	0.33	0.57

Teebus had a high score for CV 1 (Figure 3.6), which indicated good size, but low HC values according to equation 1. This was also found in Figures 2.8 & 2.12. Helderberg, PAN 185 and OPS-KW1 had lower CV 1 scores (Figure 3.6), indicating higher HC (Figure 2.8) and lower size values (Figure 2.12) than Teebus (equation 1). Teebus and the standard grade cultivars had similar scores for CV 2 (close to the X-gridline) (Figure 3.6) due to b_L-values close to the average (equation 2).



#Canonical variate 1 = (-) Hydration coefficient; Size
##Canonical variate 2 = (-) b_L = values

Figure 3.6 Plot of canonical variate 1 vs. 2 for laboratory canned small white bean cultivars to indicate groupings between cultivars (groups within the same circle indicate no significant differences at *P* = 0.05).

Canonical variate 1 (81.26 %) and 2 (17.77 %) from the CVA for industrial canned beans, considering all canning parameters, accounted for 99.03 % of the variation in cultivar canning quality. The latent roots for CV 1 (8.61) and CV 2 (1.88) were > 1, indicating that variation in canning quality was mostly within groups (Digby *et al.*, 1989). From the latent vectors followed the following discriminating equations for CV 1 and CV 2:

$$CV\ 1 = 0.731\ (WU) + 0.116\ (PWDWT2) - 0.714\ (Size) - 0.014\ (Splits) + 0.056\ (PWDWT1) - 76.26 \quad (3)$$

$$CV2 = -0.098\ (WU) + 0.107\ (PWDWT2) - 1.181\ (Size) + 0.022\ (Splits) + 0.409\ (PWDWT1) - 15.34 \quad (4)$$

Figure 3.7 provides a plot of the scores of CV 1 vs. CV 2, as well as the 95 % confidence circles for Teebus and Helderberg. Table 3.13 indicates that WU and splits correlated positively, and size negatively, with CV 1. According to these correlations CV 1 would mostly be influenced by WU, splits and size. It was found that PWDWT1 and PWDWT2 correlated with CV 2 (Table 3.13). Cultivars with good size, few splits and low WU values would be situated to the left of the plot. Those with good PWDWT1 and PWDWT2 values would be found at the top-half of the plot. As in the case of laboratory canned beans, Teebus differed significantly from all the other cultivars. PAN 185 and OPS-KW1 did not differ significantly from Helderberg and belonged to the standard grade group.

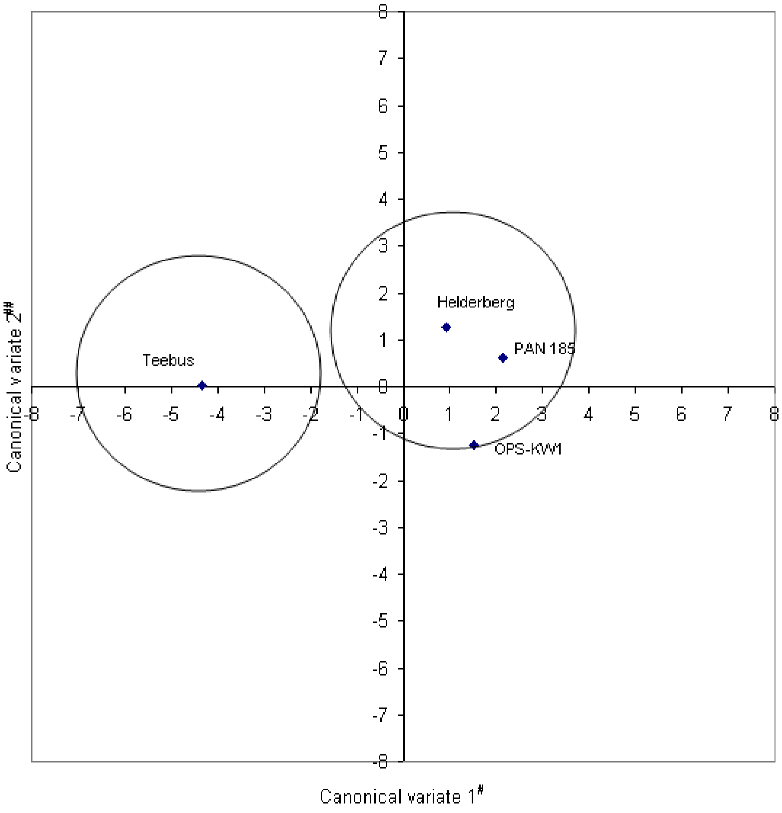
Table 3.13 Correlation matrix of canonical variates 1 and 2 for canning quality parameters of industrial canned small white bean cultivars

	Water uptake	**PWDWT2**##	**Size**	**Splits**	**PWDWT1**#
Canonical variate 1	0.98	-0.61	-0.77	0.69	-0.57
Canonical variate 2	-0.17	0.62	-0.33	0.35	0.64

\# PWDWT1 = Percentage washed drained weight after 24 h

\## PWDWT2 = Percentage washed drained weight after 7 days

The low CV 1 scores (Figure 3.7) for Teebus indicated good size (Figure 3.5), lower WU values (Figure 3.1) and few splits (Figure 3.4) (equation 3). The CV 2 scores of Teebus and standard grade cultivars slightly positive, due to mostly high PWDWT1 and PWDWT2 values, except for the lower values of OPS-KW1 with a negative CV 2 score (Figures 3.2 & 3.3) (equation 4). The high CV 1 scores of the standard grade cultivars (Helderberg, PAN 185 and OPS-KW1) (Figure 3.7) were due to high WU (Figure 3.1), low size values (Figure 3.5) and more split beans (Figure 3.4) (equation 3).



#Canonical variate 1 = (-) Size; Water uptake; Splits

##Canonical variate 2 = Percentage washed drained weight after 7 days; Percentage washed drained weight after 48 h

Figure 3.7 Plot of canonical variate 1 vs. 2 for industrial canned small white bean cultivars to indicate groupings between cultivars (groups within the same circle indicate no significant differences at *P* = 0.05).

These results indicated that the grouping of cultivars with respect to the standard and choice grade groups did not differ for the laboratory and industrial canned beans. The laboratory canning and evaluation system therefore was able to group the canning quality of small white bean cultivars into choice and standard grade groups with the same accuracy as industrial canned beans. Recently industrial canners accepted PAN 185 and OPS-KW1 as acceptable for choice grade canning, despite the poor canning results, as compared to Teebus. This decision was not only based on canning quality results, but also on agronomical performance of these cultivars. PAN 185 and OPS-KW1 have higher yields than Teebus (Liebenberg *et al.*, 2001; Liebenberg *et al.*, 2002). Production of a cultivar with exceptional good canning quality, but lower yield will increase the risk of low production especially in poor cropping seasons. PAN 185 and

OPS-KW1 were acceptable for standard grade canning and by optimizing the industrial canning process and canning conditions specifically for these cultivars, they could be canned to deliver products with acceptable canning quality. The industry requested that despite their decision, Teebus should still be the only cultivar used as a reference standard for choice grade beans.

3.3.4.2 Regions

The CVA for laboratory canned beans, considering all canning parameters, indicated that CV 1 (58.65 %) and CV 2 (32.85 %) accounted for 91.50 % of the variation in the canning quality of beans from different regions. The latent roots for CV 1 (2.97) and CV 2 (1.66) were > 1, indicating that for both variations in canning quality was mostly within groups (Digby *et al.*, 1989). From the latent vectors followed the following discriminating equations for CV 1 and CV 2:

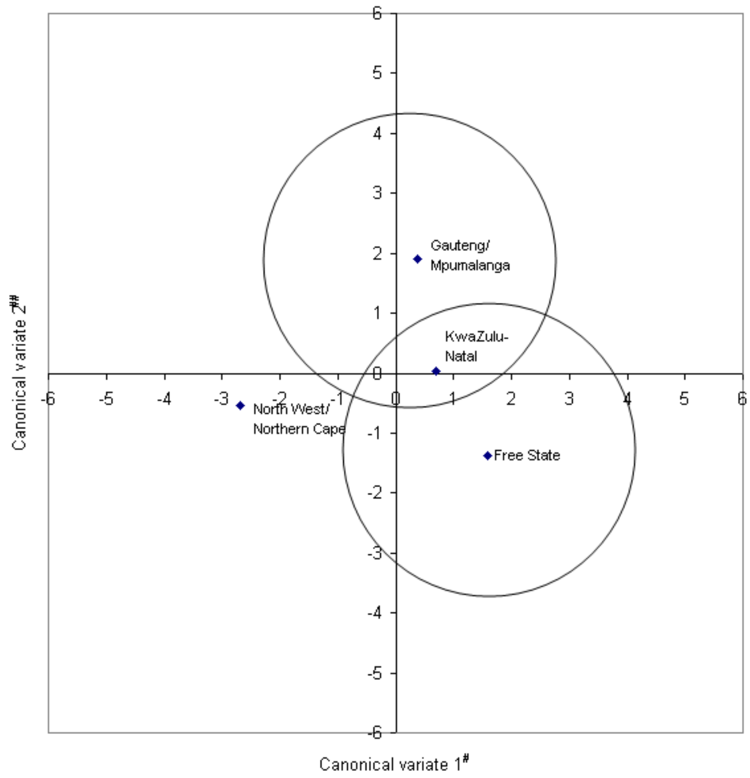
$$\text{CV 1} = -1.507\,(b_L\text{-value}) - 0.788\,(L\text{-value}) - 0.341\,(\text{Splits}) + 0.048\,(\text{Texture}) + 57.28 \quad (5)$$

$$\text{CV 2} = 1.727\,(b_L\text{-value}) - 0.765\,(L\text{-value}) + 1.166\,(\text{Splits}) + 0.106\,(\text{Texture}) - 16.67 \quad (6)$$

From Table 3.14 it is apparent that the b_L- and L-values correlated negatively with CV 1. Texture and splits correlated positively with CV 2. The plot of CV 1 vs. CV 2 scores for regions together with 95 % confidence circle indicating the most important dry bean production areas in South Africa is illustrated in Figure 3.8. The GP / MP region is the most important production area of dry beans and had a crop of 36 550 tons in 2002/03 and the estimated crop for 2003/04 was 42 500 tons. The second most important production area is FS with a crop of 15 700 tons for 2002/03 and estimated crop of 18 750 tons for 2003/04. Beans from regions to the right side of the plot would be those with low L- and b_L-values and more splits. Beans from regions to the top of the plot would be those with harder textures and fewer splits (Figure 3.8).

Table 3.14 Correlation matrix of canonical variates 1 and 2 for canning quality parameters of regions (laboratory canned small white beans)

	b_L-values	L-values	Splits	Texture
Canonical variate 1	-0.94	-0.92	-0.63	0.35
Canonical variate 2	0.24	0.06	0.65	0.76



#Canonical variate 1 = (-) b_L - values; (-) L-values
##Canonical variate 2 =Texture; Splits

Figure 3.8 Plot of canonical variate 1 vs. 2 for laboratory canned small white bean cultivars to indicate groupings between regions (groups within the same circle indicate no significant differences at *P* = 0.05).

Beans from KZN did not differ in canning quality from those of the most important bean production areas. Although the canning quality of beans from KZN was not different, beans from this region are not often canned, due to low production and distance from canning plants. The total crop for KZN was only 1 520 tons of dry beans for 2002/03 and the estimated crop for 2003/04 was even lower (1 450 tons). One of the reasons for this could be the high incidence of dry bean diseases in this region (Liebenberg *et al.*, 2001; Liebenberg *et al.*, 2002; Liebenberg *et al.*, 2003). The canning quality of beans from the NW / NC was significantly different from those of the most important production regions (Figure 3.8). The lower CV 1 scores of beans from this region were due to the higher b_L- and L-values (more white and yellow) (equation 5). The high CV 1 scores of beans from GP / MP, KZN and FS were due to lower higher b_L- and L-values (darker) (equation 5). Equation 6 indicates that the high CV 2 score for GP / MP were due to harder beans with few splits, while the opposite was true of FS, with a lower CV 2 score. Although FS was the second highest production area, beans from this area do not necessarily have good canning qualities. Beans from NW / NC also had low CV 2 scores (softer with more splits) (equation 6).

The CVA for regions for industrial canned beans was able to explain 98.53 % of the variation between regional canning qualities. The contribution of CV 1 to the variation in regional canning quality was 83.61 %, while that of CV 2 was 14.92 %. The latent roots for CV 1 (1.52) and CV 2 (0.27) were only > 1 in the case of CV 1. Latent roots of < 1 indicate the presence of more within group variation than between group variation (Digby *et al.*, 1989). From the latent vectors followed the following discriminating equations for CV 1 and CV 2:

$$\text{CV 1} = 0.496\,(\text{WU}) + 0.286\,(\text{PWDWT2}) + 1.673\,(\text{Size}) + 0.003\,(\text{Splits}) - 73.55 \qquad (7)$$

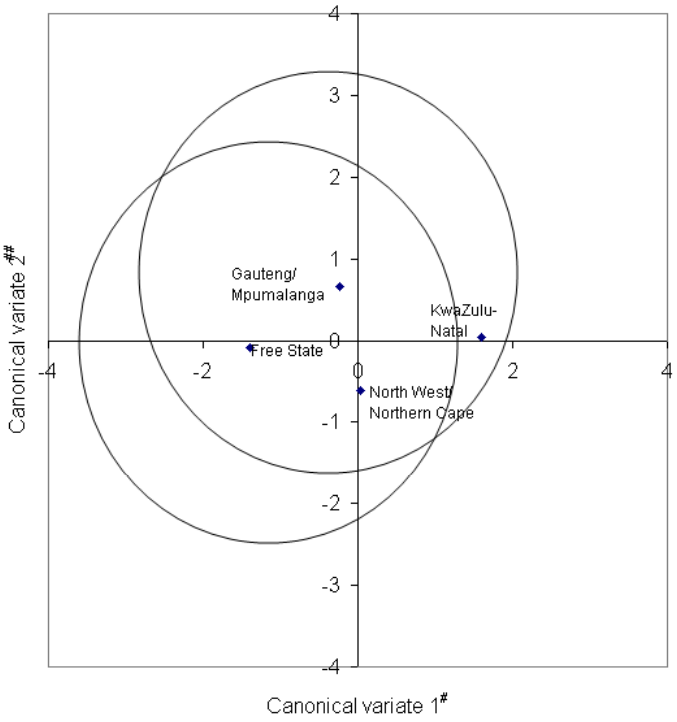
$$\text{CV 2} = 0.077\,(\text{WU}) + 0.266\,(\text{PWDWT2}) - 0.576\,(\text{Size}) - 0.052\,(\text{Splits}) - 18.91 \qquad (8)$$

Table 3.15 indicates that size correlated with CV 1, while WU and splits correlated negatively and PWDWT2 positively with CV 2. The plot of CV 1 vs. CV 2 scores for regions together with the 95 % confidence circle to indicate the most important dry bean production areas (GP / MP and FS) in South Africa is illustrated in Figure 3.9. Beans with better size values would be found to the right side of the plot, while those with few splits, high PWDWT 2 and low WU values, would be found in the lower half of the plot.

Table 3.15 Correlation matrix of canonical variates 1 and 2 for canning quality parameters of regions of industrial canned small white beans

	Water uptake	PWDWT2#	Size	Splits
Canonical variate 1	0.09	0.28	0.60	-0.07
Canonical variate 2	-0.61	0.75	0.28	-0.70

\# PWDWT2 = Percentage washed drained weight after 24 h



#Canonical variate 1 = Size

##Canonical variate 2 = (-) Water uptake; Percentage washed drained weight after 7 days; (-) Splits

Figure 3.9 Plot of canonical variate 1 vs. 2 for small white bean cultivars canned by industry to indicate groupings between regions (groups within the same circle indicate no significant differences at *P* = 0.05).

No significant differences were found between the canning quality of beans from different regions that were canned industrially (Figure 3.9), but beans from KZN fell outside the 95 % confidence circle of Free State. The higher CV 1 values of beans from KZN were due to higher size values than those of Free State (equation 7).

For industrial canning all E/G ratios were indicated to be < 1 (Table 3.11), which indicates that canning quality was mostly affected by cultivar. Environment affected most factors (VA, splits, clumping, texture, L- and b_L-value) when laboratory canning was applied, since different canning parameters and evaluation procedures were used than by the industry (Table 3.11). A second reason for the better discrimination between regions with laboratory canning could be the different techniques used by industry for canning quality evaluation. Industrial canners are more interested in the canning quality of different cultivars, since obtaining beans from specific regions are constraint by availability. The laboratory canning and evaluation system was shown to offer a successful indication of industrial canning where differences in the grouping of cultivars according to canning grades need to be identified.

3.4 CONCLUSIONS

Evaluation of the canning quality of industrial canned beans obtained from retailers indicated significant differences between canning companies for all canning parameters, except for splits and clumping. Mean texture values did not agree with the USA guidelines of 72 kg.100 g^{-1}. Mean values for all canning parameters, did not even agree with choice grade bean values. These results confirmed that standard evaluation values for South African canning companies were not set as is the case for the canning industries in Canada and the USA. Different cultivars are grown in SA and canning is mainly in tomato sauce, which means that SA needs an own set of standards.

Beans that were industrially canned met the required 80 % WU set by the USA for canned beans. This is due to the altered soaking times that the industry uses to provide for differences in bean cultivars. Laboratory canned beans had poor HC values but the estimation of HC was a good alternative for the industrial WU. The PWDWT2 of industrially canned beans was in agreement with the PWDWT of laboratory canned beans. For both industrially and laboratory canned beans, Teebus had PWDWT values close to the 60 % standard set by Canadian government.

Splits were determined as a percentage for industrial canned beans, while those of laboratory canned beans were indicated on a 1 to 10 scale. With both techniques Teebus displayed few splits. The identification of cultivars in terms of splits with laboratory and industrial techniques was therefore the same. Both industrial and laboratory techniques identified Teebus to have better size values. The G/E ratio for splits indicated splits to be mostly affected by cultivar, in the case of industrially canned beans, while the opposite was true for laboratory canned beans, due to different evaluation techniques used. All other G/E ratios gave similar results for laboratory and industrial canning.

Comparison of laboratory and industrially canned bean cultivars by the use of CVA identified the HC, size, b_L- and a_L-values to be the most important parameters to discriminate between cultivars for CV 1 and CV 2 when laboratory techniques were used. Percentage washed drained weight after 7 days (PWDWT1), size, WU, splits and PWDWT2 were identified to distinguish to a higher degree between cultivars for CV 1 and CV 2 when industrial techniques were used. Both the CVA for laboratory and industrial canned beans indicated Teebus to be the only cultivar to belong to the choice grade group and have significantly better canning quality than the other cultivars. Both indicated Helderberg, OPS-KW1 and PAN 185 to belong to the standard grade class for canning quality. Discrimination between cultivar canning quality groups was therefore the same for laboratory and industrial canned beans.

Comparison of laboratory and industrially canned beans in terms of regions by the use of CVA, identified the b_L- and L-values, splits and texture to be the most important parameters to discriminate between regions for CV 1 and CV 2, when laboratory techniques were used. Size, WU, splits and PWDWT1 were identified to distinguish to a higher degree between regions for CV 1 and CV 2, when industrial techniques were used. The CVA for laboratory canned beans indicated beans from NW / NC to be significantly different in canning quality than the groups of the most important production regions for dry beans in South Africa. However, the CVA for regions of industrial canned beans indicated no significant differences between regions in terms of canning quality. Laboratory techniques for canning and evaluation could therefore be used successfully to identify bean cultivars intended for industrial canning.

CHAPTER 4

CANNING QUALITY OF SMALL WHITE BEAN CULTIVARS DETERMINED OVER TWO SEASONS, USING MODIFIED CANNING AND EVALUATION TECHNIQUES

4.1 INTRODUCTION

New small white bean cultivars released by seed companies should possess a good canning ability to make it financially viable for the company to proceed with its production, since this type of bean is mostly used for canning. Differences in canning quality within the same type of bean, resulting from different cultivars, localities and seasons, necessitates regular evaluation of the canning quality of new and existing small white bean cultivars from different environments.

The rate of WU of beans is related to bean size, since small beans take up water more rapidly than medium- or large-sized beans (Del Valle *et al*., 1992). Beans considered for canning purposes should be fully mature and uniform in size to be acceptable (Uebersax *et al*., 1991). Bean sizes are usually “screened” to ensure that all canners receive defined size ranges. However, the inherent size is important to breeders and growers who want to limit the amount of “overs” and “unders” during these screenings, to increase the “yield” of acceptable sized beans. A too low MC at time of processing could lead to water imbibition problems during processing (Nordstrom & Sistrunk, 1979), thereby slowing the rate of WU (Hosfield & Uebersax, 1979). Physical properties such as seed size MC should therefore be considered with canning properties when evaluating canning quality of beans.

It is known that cultivar differences affect canning quality, as cultivar differences also influences other seed quality aspects, such as seed size, which could influence canning quality (De Lange & Labuschagne, 2000). The influence of locality and season on canning quality of beans can be seen where differences in canning quality traits could not be explained by genotype differences (Varner & Uebersax, 1995).

Cultivars, environments and cultivar x environment interactions would not only affect canning quality, but also physical and chemical properties of beans. Environment and the cultivar x environment interaction significantly affect physical properties, such as seed count values (Balasubramanian *et al.*, 1999). Different cultivars and environments were indicated to influence the chemical analysis values (% N, % Ca and % K) of small white beans significantly (De Lange & Labuschagne, 2000). Both physical and chemical properties could affect canning quality.

Canning quality data of cultivars, localities and seasons should be considered in relation to the physical properties of the beans. The statistical analysis of canning quality data is complicated by the use of a combination of canning quality parameters that should be interpreted simultaneously. Because data from the same cultivars and localities are not in all cases obtainable over more than one season, the use of ANOVA for statistical interpretation of data is difficult. A multivariate analysis offers a possible solution by grouping all cultivars and environments according to canning quality. The problem is to identify differences in the canning quality of dry bean cultivars, localities and seasons by using modified canning and evaluation procedures. The objectives of this chapter were to:

1. Employ the modified laboratory canning method as a parameter together with other physical properties in the determination of the canning quality of seven small white dry bean cultivars from 33 localities and two seasons.
2. Interpret canning quality data using multivariate analysis and identify a possible model to identify the canning quality of small white beans in Chapter 5.

4.2 MATERIALS AND METHODS

4.2.1 Dry bean cultivars

Four small white bean cultivars from the National Dry Bean Cultivar Trials of the ARC-GCI were used from the 2001/02 season and six from the 2002/03 season. Names of cultivars and localities used for each season are summarized in Table 4.1. Localities represented four areas in South Africa, namely NW / NC, GP / MP, FS and

KZN, as well as one locality from Lesotho (Table 4.1). In most cases the rainfall, average maximum temperature, soil type, soil analysis (pH, P and K) and fertilisation (N, P and K) of localities were known at the time of canning (Appendix A). The cultivars were planted in a randomised block design with three replicates. Four row plots (5 m long and 750 mm apart) were planted with a self-driven planter and beans were planted at 75 mm spacing within rows. Fertilisation was applied at recommended rates for each locality. Samples were harvested manually from the middle two rows of individual plots. All three replicates of cultivars were used for canning purposes. All samples were kept refrigerated at 4 °C for no longer than two months before canning.

Table 4.1 Small white bean cultivars and localities from 2001/02 and 2002/03 used for canning

Factor	**Season**	
	2001/02	**2002/03**
Cultivar	Teebus	Teebus
	Teebus RR1	Teebus RR1
	PAN 185	PAN 185
	-	PAN 120
	-	PAN 121
	OPS-KW1	PAN 123
Locality	Bergville (KZN)	Bergville (KZN)
	Clocolan (FS)	Clocolan (FS)
	Delmas (GP / MP)	Delmas (GP / MP)
	Ermelo (GP / MP)	Ermelo (GP / MP)
	Harrismith (FS)	Harrismith (FS)
	Lichtenburg (NW / NC)	Lichtenburg (NW / NC)
	Reitz (FS)	Reitz (FS)
	Arnot (GP / MP)	-
	Koedoeskop (NW / NC)	-
	Kroonstad (FS)	-
	Maseru (Lesotho)	-
	Potchefstroom (NW / NC)	-
	Syferbult (NW / NC)	-
	Ukulinga (KZN)	-
	Wildebeesfontein (GP / MP)	-
	-	Bethal (GP / MP)
	-	Bethlehem (FS)
	-	Cedara (KZN)
	-	Chrissiesmeer (GP / MP)
	-	Coligny (NW / NC)
	-	Cradock (KZN)
	-	Ficksburg (FS)
	-	Greytown (KZN)
	-	Kokstad (KZN)
	-	Vryheid (KZN)

KZN = KwaZulu Natal

GP / MP = Gauteng / Mpumalanga

NW / NC = North West / Northern Cape

FS = Free State

#Regions are indicated in brackets

4.2.2 Determination of physical properties

4.2.2.1 Moisture content

The MC of dry bean seed was determined using a Bullwark P9 seed analyser (Sinar Africa, P.O. Box 1633, Honeydew 2040).

4.2.2.2 Hundred seed mass

The 100SM of the samples was determined by recording the mass of 100 randomly selected dry bean seeds (Balasubramanian *et al*., 1999). A Numigral Seed Counter (Num 1, Chopin) was used for the automatic counting of 100 kernels.

4.2.3 Determination of canning quality

Canning of samples was done according to the MCT described in Chapter 2 (2.2.2.3). Canning quality was determined as was done in Chapter 2. The HC (2.2.3.2.1), PWDWT (2.2.3.1.1), VA (2.2.3.1.2), splits (2.2.3.1.3), size (2.2.3.2.6), texture (2.2.3.2.5), clumping (2.2.3.2.7) and colour (2.2.3.2.8) were determined. Viscosity was determined as described by Balasubramanian *et al*. (1999) using a Brookfield Programmable DVII+ Viscometer, equipped with a no. 3 spindle at 100 rpm. Tomato sauce was drained from the cans and 80 mL placed into a 100 mL glass beaker. Samples were covered with watch glasses to prevent evaporation and kept in a water bath (25 °C) until the temperature at the centre reached 25 °C, since viscosity is affected by temperature. Readings were recorded every 15 sec until 20 readings were collected. Viscosity values were averaged and expressed in cP.

4.2.4 Statistical analysis of data

Analysis of variance was performed on data from different seasons to indicate differences between cultivars and localities (Costat, Cohort Version 6). The G/E ratios were determined from mean square values as explained in Chapter 3 (3.2.3.5). All data were subjected to CVA to identify cultivar groupings according to choice and standard grade beans and to identify a possible model for the prediction of canning quality (Genstat 5). Canonical variate analysis for different environments (locality x season) was also done. Canonical variate analysis for dry bean production environments for region x season was also done, by averaging the results of localities within different regions according to Table 4.1. Variables considered for CVA on cultivars and environments were HC, PWDWT, VA, splits, size, texture, clumping and colour (L-, a_L- and b_L-values). Viscosity was not considered due to the results obtained in 4.3.2. 95 % Confidence circles were used as described in 3.2.3.5.

4.3 RESULTS AND DISCUSSION

4.3.1 Physical properties of dry bean cultivars

The MC and 100SM values of dry bean cultivars from 2001/02 and 2002/03 are provided in Tables 4.2.1 to 4.3.2. Table 4.4 indicates the mean, minimum, maximum and F-values for 2001/02 and 2002/03. The effect of cultivar, locality and cultivar x locality interaction was significant on 100SM, while only locality had a significant influence on MC. Differences between replicates were significant, except for 100SM during 2001/02. Although differences between replicates were mostly significant, CV values were lower than 10.0 in all cases and RMSE values were lower than 5.0 (Table 4.5). R^2-values were significant for MC and 100SM in both seasons. The data obtained for physical properties were therefore significant. Table 4.6 provides the relative effects of cultivar and locality on MC and 100SM of dry beans.

Table 4.2.1 Moisture content (%) before canning of four small white bean cultivars (2001/02 season) from 16 localities

Cultivar	Replicate	Arnot	Bergville	Clocolan	Coligny	Delmas	Ermelo	Harrismith	Koedoes-kop	Kroonstad	Lichten-burg	Maseru	Potchef-stroom	Reitz	Syferbult	Ukulinga	Wildebees-fontein	Mean
OPS-KW1	1	12.30	10.10	10.30	10.30	10.00	10.20	10.10	11.00	10.10	10.20	13.20	10.20	10.10	11.40	10.20	10.30	10.63
OPS-KW1	2	10.20	10.10	10.10	10.70	10.00	10.10	10.00	10.70	10.00	10.10	12.00	10.10	10.10	10.80	10.70	10.30	10.38
OPS-KW1	3	10.10	10.00	10.10	10.30	10.00	10.10	10.10	10.60	10.10	10.20	12.30	10.10	10.10	10.70	10.80	10.30	10.37
PAN 185	1	12.40	10.10	10.30	10.80	10.00	10.10	10.10	11.00	10.10	10.10	13.70	10.20	10.20	12.00	10.30	10.60	10.75
PAN 185	2	10.20	10.00	10.20	10.60	10.00	10.20	10.10	11.40	10.10	10.30	13.70	10.20	10.20	11.30	10.50	10.40	10.59
PAN 185	3	10.20	10.10	10.20	10.60	10.00	10.20	10.00	10.80	10.20	10.20	11.80	10.10	10.10	10.90	10.50	10.30	10.39
Teebus	1	11.50	10.20	10.10	10.90	10.10	10.30	10.20	11.00	10.20	10.30	12.40	10.30	10.30	11.50	11.10	10.40	10.68
Teebus	2	10.30	10.20	10.20	11.10	10.10	10.40	10.20	11.10	10.10	10.30	12.20	10.30	10.30	11.00	11.10	10.40	10.58
Teebus	3	10.30	10.10	10.20	10.60	10.20	10.30	10.10	10.30	10.20	10.40	13.30	10.30	10.30	11.00	11.10	10.50	10.58
Teebus RR1	1	11.80	10.20	10.20	10.90	10.10	10.30	10.10	10.60	10.20	10.20	12.70	10.30	10.30	11.70	11.10	10.40	10.69
Teebus RR1	2	10.30	10.20	10.20	10.30	10.20	10.40	10.10	10.60	10.30	10.30	12.30	10.20	10.30	11.20	11.60	10.30	10.55
Teebus RR1	3	10.30	10.30	10.10	10.50	10.10	10.40	10.20	10.70	10.20	10.30	13.80	10.20	10.30	11.10	11.60	10.30	10.65
Mean		10.83	10.13	10.18	10.63	10.07	10.25	10.11	10.82	10.15	10.24	12.78	10.21	10.22	11.22	10.88	10.38	
Min		10.10	10.00	10.10	10.30	10.00	10.10	10.00	10.30	10.00	10.10	11.80	10.10	10.10	10.70	10.20	10.30	
Max		12.40	10.30	10.30	11.10	10.20	10.40	10.20	11.40	10.30	10.40	13.80	10.30	10.30	12.00	11.60	10.60	
Range		2.30	0.30	0.20	0.80	0.20	0.30	0.20	1.10	0.30	0.30	2.00	0.20	0.20	1.30	1.40	0.30	

cultivar (n = 4); replicate (n = 3); localities (n = 16), % CV = 8.75

Table 4.2.2 Moisture content (%) before canning of six small white bean cultivars (2002/03 season) from 17 localities

Cultivar	Replicate	Bergville	Bethlehem	Bethal	Cedara	Chrissies-meer	Clocolan	Coligny	Cradock	Delmas	Ermelo	Ficksburg	Greytown	Harrismith	Kokstad	Lichten-burg	Reitz	Vryheid	Mean
PAN 120	1	10.40	10.10	9.90	10.30	10.40	10.30	10.10	11.10	10.10	10.00	10.10	9.90	10.10	10.30	9.90	11.00	10.40	10.26
PAN 120	2	10.50	10.10	10.00	10.10	10.30	10.30	10.10	11.60	10.10	9.90	10.00	9.80	10.30	10.30	9.80	10.00	10.20	10.20
PAN 120	3	10.40	10.10	10.00	10.10	10.60	10.10	10.00	12.30	10.10	10.10	10.30	9.90	11.30	10.30	9.90	10.10	10.30	10.35
PAN 121	1	10.70	10.10	10.00	10.40	11.20	10.20	10.10	12.80	10.10	10.30	10.50	9.80	10.20	10.60	10.00	11.80	10.40	10.54
PAN 121	2	12.20	10.20	9.90	10.50	10.60	10.20	10.00	11.60	10.20	10.10	10.30	10.20	10.30	11.10	9.90	10.00	10.20	10.44
PAN 121	3	11.15	10.10	9.90	10.30	10.40	10.20	10.10	13.10	10.10	10.30	10.20	9.80	10.20	10.50	9.90	10.00	10.30	10.39
PAN 123	1	10.70	10.10	10.00	10.70	12.00	10.10	10.10	11.80	10.20	10.30	10.20	9.80	10.10	10.20	9.90	13.20	10.20	10.56
PAN 123	2	10.80	10.10	10.00	10.30	10.80	10.10	10.00	10.60	10.10	10.20	10.30	9.80	10.20	10.40	9.80	10.00	10.20	10.22
PAN 123	3	11.50	10.10	10.00	10.20	10.70	10.20	10.10	10.50	10.10	10.80	10.10	9.80	10.30	10.30	9.90	10.00	10.10	10.28
PAN 185	1	12.00	10.00	10.00	10.20	10.40	10.00	9.90	14.90	9.90	10.10	10.20	9.90	10.00	10.10	9.90	10.90	10.30	10.51
PAN 185	2	10.90	10.00	9.90	10.10	10.30	10.10	10.00	11.80	10.00	10.20	11.00	9.70	10.20	10.30	9.90	10.00	10.20	10.27
PAN 185	3	11.10	10.10	10.00	10.10	10.30	10.10	10.10	11.70	10.00	10.50	10.10	9.90	10.00	10.30	9.90	9.90	10.30	10.26
Teebus	1	12.90	10.10	10.00	10.50	10.90	10.20	10.10	9.90	10.10	10.20	10.30	9.90	10.20	10.20	9.90	11.50	10.40	10.43
Teebus	2	10.90	10.20	10.00	10.10	10.50	10.20	10.10	10.80	10.20	10.20	10.30	9.80	10.20	10.40	9.80	11.00	10.20	10.29
Teebus	3	10.70	10.00	10.10	10.70	10.70	10.20	10.10	10.90	10.20	10.10	10.20	9.80	10.20	10.30	9.90	10.00	10.30	10.26
Teebus RR1	1	12.70	10.10	10.00	10.40	10.70	10.20	10.00	11.50	10.20	10.10	10.20	9.90	10.20	10.30	9.90	11.70	10.30	10.49
Teebus RR1	2	10.90	10.10	10.00	10.70	10.60	10.20	10.10	11.70	10.20	10.50	10.50	9.80	10.40	10.90	10.10	11.00	10.30	10.47
Teebus RR1	3	10.60	10.01	10.00	10.30	11.00	10.10	10.10	10.80	10.20	10.30	10.50	9.80	10.30	10.60	9.90	10.10	10.10	10.28
Mean		11.17	10.09	9.99	10.33	10.69	10.17	10.06	11.63	10.12	10.23	10.29	9.85	10.26	10.41	9.90	10.68	10.26	
Min		10.40	10.00	9.90	10.10	10.30	10.00	9.90	9.90	9.90	9.90	10.00	9.70	10.00	10.10	9.80	9.90	10.10	
Max		12.90	10.20	10.10	10.70	12.00	10.30	10.10	14.90	10.20	10.80	11.00	10.20	11.30	11.10	10.10	13.20	10.40	
Range		2.50	0.20	0.20	0.60	1.70	0.30	0.20	5.00	0.30	0.90	1.00	0.50	1.30	1.00	0.30	3.30	0.30	

cultivar (n = 6); replicate (n = 3); localities (n = 17), % CV = 3.33

Table 4.3.1 Hundred seed mass (g.100^{-1} beans) before canning of four small white bean cultivars (2001/02 season) from 16 localities

Cultivar	Replicate	Arnot	Bergville	Clocolan	Coligny	Delmas	Ermelo	Harrismith	Koedoes-kop	Kroonstad	Lichten-burg	Maseru	Potchef-stroom	Reitz	Syferbult	Ukulinga	Wildebees-fontein	Mean
OPS-KW1	1	17.60	19.14	17.43	18.70	18.76	18.20	18.29	24.20	16.10	17.60	22.75	17.78	16.70	14.73	22.33	19.70	18.75
OPS-KW1	2	18.91	19.86	19.33	19.30	18.45	18.40	17.54	25.29	15.90	17.75	17.90	18.34	16.50	15.29	21.79	19.20	18.73
OPS-KW1	3	19.17	19.14	18.25	18.20	21.28	18.60	18.35	24.51	17.20	20.71	20.46	17.43	19.00	16.31	21.01	19.60	19.33
PAN 185	1	16.60	16.96	16.61	17.20	17.09	17.10	16.95	16.05	14.20	16.03	18.84	16.56	15.70	11.64	18.61	17.50	16.48
PAN 185	2	16.47	17.27	15.67	17.40	16.79	17.00	16.19	22.10	15.40	17.22	18.84	14.79	15.70	11.60	18.30	17.00	16.73
PAN 185	3	16.30	17.41	14.76	15.40	16.03	16.20	16.44	21.72	16.20	15.95	17.55	16.59	15.20	11.64	19.15	16.60	16.45
Teebus	1	21.80	21.74	26.40	25.40	24.92	26.20	25.12	12.03	23.70	22.32	24.63	21.49	23.50	20.39	21.30	26.20	22.95
Teebus	2	20.84	22.37	27.11	23.80	22.00	26.40	24.76	13.15	25.60	21.60	23.76	22.68	22.40	19.34	21.56	24.70	22.63
Teebus	3	20.24	22.12	25.28	23.00	26.46	21.80	25.95	13.86	27.10	22.64	22.02	21.83	22.60	18.41	22.23	24.60	22.51
Teebus RR1	1	27.40	23.51	27.61	25.40	27.17	26.20	26.17	15.93	25.10	21.85	28.05	24.55	26.10	21.44	27.83	25.90	25.01
Teebus RR1	2	26.25	24.02	28.87	23.20	23.30	26.40	26.07	17.28	24.70	20.96	26.80	22.58	24.80	20.81	28.80	26.70	24.47
Teebus RR1	3	30.60	22.50	26.57	24.50	25.88	23.80	26.42	20.16	27.90	23.37	30.45	23.90	24.90	21.47	30.42	25.80	25.54
Mean		21.02	20.50	21.99	20.96	21.51	21.36	21.52	18.86	20.76	19.83	22.67	19.88	20.26	16.92	22.78	21.96	
Min		16.30	16.96	14.76	15.40	16.03	16.20	16.19	12.03	14.20	15.95	17.55	14.79	15.20	11.60	18.30	16.60	
Max		30.60	24.02	28.87	25.40	27.17	26.40	26.42	25.29	27.90	23.37	30.45	24.55	26.10	21.47	30.42	26.70	
Range		14.30	7.06	14.11	10.00	11.14	10.20	10.23	13.26	13.70	7.42	12.90	9.76	10.90	9.87	12.12	10.10	

cultivar (n = 4); replicate (n = 3); localities (n = 16), % CV = 9.11

Table 4.3.2 Hundred seed mass (g.100^{-1} beans) before canning of six small white bean cultivars (2002/03 season) from 17 localities

Cultivar	Replicate	Bergville	Bethlehem	Bethal	Cedara	Chrissies-meer	Clocolan	Coligny	Cradock	Delmas	Ermelo	Ficksburg	Greytown	Harrismith	Kokstad	Lichten-burg	Reitz	Vryheid	Mean
PAN 120	1	21.28	20.81	15.87	17.77	21.40	18.26	17.76	30.26	19.53	19.80	16.39	22.00	17.71	16.28	17.50	16.67	22.23	19.50
PAN 120	2	21.13	19.35	17.16	17.41	20.76	17.09	17.33	22.10	19.81	17.52	18.24	18.01	16.58	16.16	11.91	18.65	18.59	18.11
PAN 120	3	21.20	21.16	17.19	18.57	24.14	17.50	16.55	21.71	20.44	18.39	17.58	21.55	21.77	17.17	19.57	18.39	17.76	19.45
PAN 121	1	25.71	25.81	23.71	22.97	24.18	22.94	20.28	28.07	22.74	23.67	21.01	22.91	22.81	22.19	18.47	24.77	23.78	23.30
PAN 121	2	24.65	21.49	23.59	22.37	23.67	22.29	22.17	31.35	21.50	22.69	22.70	20.52	22.13	21.43	11.69	22.47	24.27	22.41
PAN 121	3	24.22	26.35	24.82	23.22	24.27	23.54	14.24	27.65	23.84	25.11	21.83	21.16	22.56	20.16	18.87	24.74	25.07	23.04
PAN 123	1	20.25	21.27	19.50	19.27	21.68	19.38	19.54	26.83	19.75	21.07	18.11	23.30	18.74	22.51	18.25	18.87	22.98	20.66
PAN 123	2	20.75	18.45	18.40	18.19	22.20	17.68	19.50	27.62	18.20	19.57	17.55	18.13	17.84	19.83	10.87	17.03	23.46	19.13
PAN 123	3	20.22	18.20	18.68	17.54	20.64	18.16	19.44	25.91	20.77	20.41	18.76	22.26	19.74	20.69	18.63	18.13	23.31	20.09
PAN 185	1	18.64	16.73	12.97	15.52	17.66	14.58	15.13	17.40	15.38	14.26	14.52	18.88	13.49	16.17	14.54	14.55	18.05	15.79
PAN 185	2	18.33	15.57	15.56	15.93	17.28	14.23	13.87	18.97	15.87	14.98	17.18	16.94	14.47	16.29	15.92	13.16	16.37	15.94
PAN 185	3	17.62	16.52	14.93	16.10	16.15	13.19	22.89	17.63	16.27	15.23	14.55	21.09	13.56	16.20	18.24	14.74	15.41	16.49
Teebus	1	21.03	23.70	23.60	22.75	26.76	24.08	20.01	29.64	25.51	25.09	21.59	20.42	21.29	21.04	14.04	22.22	22.09	22.64
Teebus	2	20.65	21.84	24.00	19.10	23.30	22.34	20.62	29.16	23.82	25.44	21.82	16.79	21.41	22.53	17.21	21.67	21.11	21.93
Teebus	3	19.21	23.86	24.63	21.31	22.28	23.28	21.98	28.49	24.15	24.72	21.12	20.92	21.36	20.99	17.89	22.75	23.93	22.52
Teebus RR1	1	26.33	22.47	18.51	23.49	25.59	24.66	21.29	21.98	26.18	25.18	22.90	20.55	23.15	20.61	14.53	24.61	26.28	22.84
Teebus RR1	2	26.30	21.20	26.17	21.01	27.66	24.97	13.87	31.32	25.64	26.66	21.24	16.26	24.62	22.06	16.63	24.38	27.15	23.36
Teebus RR1	3	26.22	26.61	27.02	22.32	26.88	22.86	26.40	31.40	25.34	26.60	23.11	21.32	24.43	21.99	18.19	23.48	27.21	24.79
Mean		21.87	21.19	20.35	19.71	22.58	20.06	19.05	25.97	21.37	21.47	19.46	20.17	19.87	19.68	16.28	20.07	22.17	
Min		17.62	15.57	12.97	15.52	16.15	13.19	13.87	17.40	15.38	14.26	14.52	16.26	13.49	16.16	10.87	13.16	15.41	
Max		26.33	26.61	27.02	23.49	27.66	24.97	26.40	31.40	26.18	26.66	23.11	23.30	24.62	22.53	19.57	24.77	27.21	
Range		8.71	11.04	14.05	7.97	11.51	11.78	12.53	14.00	10.80	12.40	8.59	7.04	11.13	6.37	8.70	11.61	11.80	

cultivar (n = 6); replicate (n = 3); localities (n = 17), % CV = 8.67

Table 4.4 Mean, minimum and maximum value and F-values pertaining to main and interaction effects of the moisture content and hundred seed mass of four small white bean cultivars (2001/02 season) from 16 localities

Canning quality	Mean	Minimum	Maximum	F-value			
				Cultivar	Locality	Replicates	Cultivar x locality
2001/02				**(df = 3)**	**(df = 15)**	**(df = 2)**	**(df = 2)**
Moisture content (%)	10.57	10.00	13.80	2.37 ns	45.50 ***	5.48 **	0.59 ns
Hundred seed mass (g)	20.80	12.03	30.60	487.40 ***	18.54 ***	1.12 ns	12.66 ***
2002/03				**(df = 5)**	**(df = 16)**	**(df = 2)**	**(df = 80)**
Moisture content (%)	10.29	9.70	14.90	0.49 ns	7.28 ***	4.20 *	0.96 ns
Hundred seed mass (g)	20.67	10.87	31.40	109.99 ***	125.60 ***	6.56 **	2.77 **

Table 4.5 R^2-values, root mean square errors and coefficients of variation pertaining to moisture content and hundred seed mass of small white bean cultivars from 33 localities for the 2001/02 and 2002/03 seasons

Physical property	$^{\#}R^2$	Root mean square error	Coefficient of variation (%)
2001/02			
Moisture content (%)	0.50 ***	0.90	8.75
Hundred seed mass ($g.100^{-1}$ beans))	0.93 ***	1.78	9.11
2002/03			
Moisture content (%)	0.85 ***	0.35	3.33
Hundred seed mass ($g.100^{-1}$ beans)	0.86 ***	1.79	8.67

R^2 = Sum square model / Sum square total

*** $P < 0.01$

Table 4.6 The relative effects of growth environment and cultivar on physical characteristics of small white dry beans from different localities

Physical property	Mean square		Ratio
	Cultivar (G$^{\#}$)	(E$^{\#\#}$)	(E/G)
2001/02	**(df = 3)**	**(df = 15)**	
Moisture content (%)	0.29	5.63	19.41
Hundred seed mass (g)	684.96	26.05	0.04
2002/03	**(df = 5)**	**(df = 16)**	
Moisture content (%)	0.40	5.90	14.75
Hundred seed mass (g)	350.02	399.69	1.14

#G = Genotype; ##E = Environment

Values > 1 attributed to E; Values < 1 attributed to G

4.3.1.1 Effect of cultivar on physical properties

4.3.1.1.1 Effect of cultivar on moisture content

Figures 4.1a & b show that no significant cultivar differences were observed for MC in either of the seasons. This could be explained by the fact that most of the variation in MC was caused by environmental effects (E/G ratio > 1) (Table 4.6).

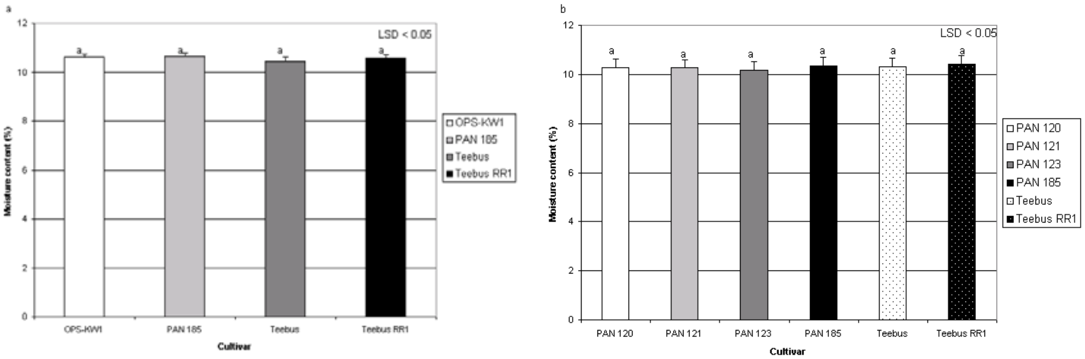


Figure 4.1 Mean moisture content values before canning of small white bean cultivars from 33 localities for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

4.3.1.1.2 Effect of cultivar on hundred seed mass

The mean 100SM values of cultivars for 2001/02 and 2002/03 are provided in Figures 4.2a & b.

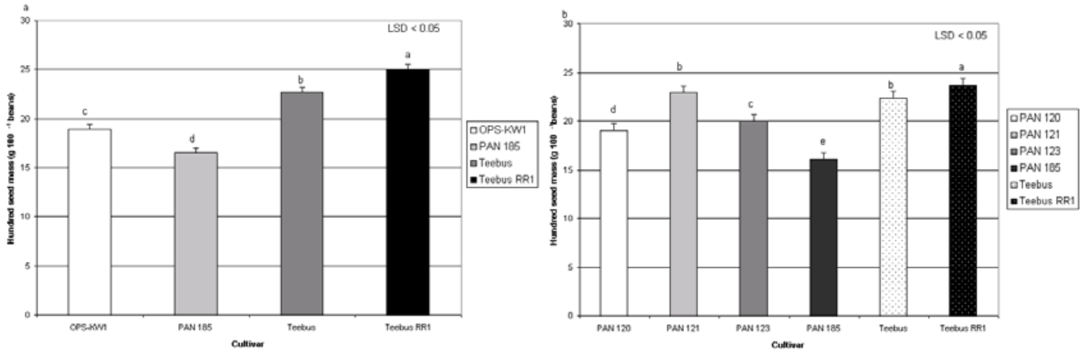


Figure 4.2 Mean hundred seed mass before canning of small white bean cultivars from 33 localities for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

Teebus RR1, followed by Teebus, had significantly larger seeds than other cultivars, except for PAN 121 (Figures 4.2a & b). Water uptake of these beans during soaking is expected to be poor due to a larger size (Del Valle *et al*., 1992). PAN 185 had significantly smaller seeds than other cultivars for both seasons (Figure 4.2a & b). This could be a negative aspect of PAN 185, since the consumer gets accustomed to a particular size of bean and beans that are too large or too small would be rejected. On the other hand, hydration of these beans during soaking is expected to be higher, due to the larger surface area (Deshpande & Cheryan, 1986). PAN 121 was similar to Teebus in seed size. This could be an advantage for PAN 121, as Teebus is seen as the industry standard and is considered as an acceptable sized bean. The significant influence of cultivar on seed size was also observed by Ghaderi *et al*., (1984) and De Lange & Labuschagne (2000) and is illustrated by the E/G ratio of 100SM of > 1 for the 2002/03 season (Table 4.6).

4.3.1.2 Effect of locality on physical properties

4.3.1.2.1 Effect of locality on moisture content

The mean MC values of localities for 2001/02 and 2002/03 are provided in Figures 4.3a & b. Beans from Maseru had significantly higher MC values than those from other localities (Figure 4.3a). Moisture content of dry beans is influenced by rainfall (Forney *et al*., 1990). Maseru is situated in Lesotho, which are situated to the eastern parts of South Africa where higher rainfall occurs, which could explain the higher MC values of these beans. The same could be the case with Syferbult, which also had high MC values (Figure 4.3a), as this locality is also situated to the eastern part of the country. The high MC of such beans could affect the canning quality negatively, by causing brown discoloration or off-flavours when stored at high temperatures (Uebersax *et al*., 1991). The strong effect that environment has on MC of beans are illustrated by the E/G ratio of > 1 for both seasons (Table 4.6).

Significantly lower MC values were recorded for 2002/03 with beans from Coligny than from other sites (Figure 4.3b). A too low MC at time of processing could lead to water imbibition problems during processing (Nordstrom & Sistrunk, 1979), while more splitting could also occur during canning (Nordstrom & Sistrunk, 1979; Gonzalez *et al*., 1982).

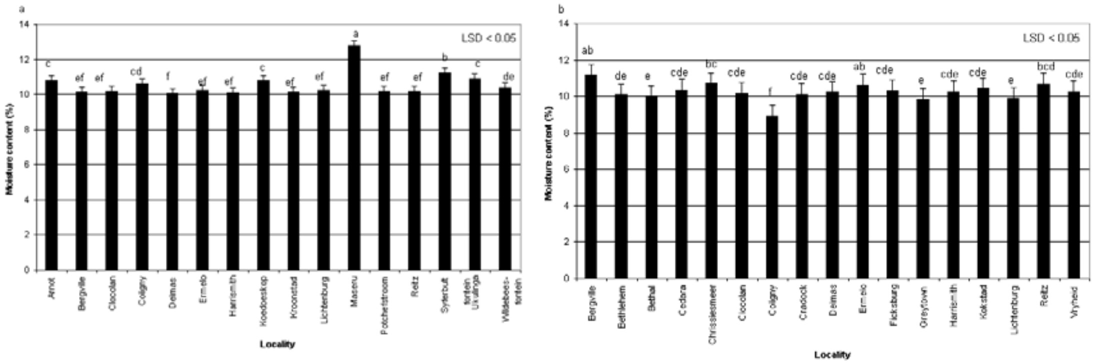


Figure 4.3 Mean moisture content pertaining to various localities of canned small white bean cultivars for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

4.3.1.2.2 Effect of locality on hundred seed mass

The mean 100SM values pertaining to localities for 2001/02 and 2002/03 are provided in Figures 4.4a & b. Beans from Syferbult was significantly smaller than those of other localities during 2001/02, followed by Koedoeskop (Figure 4.4a). The 100SM (indication of seed size) is negatively correlated with MC of dry beans (Faris & Smith, 1964). This would explain the low 100 SM values for Syferbult, which was indicated to be the second highest of MC values during 2001/02 (Figure 4.3a). Koedoeskop was also among the highest ranking localities for MC (Figure 4.3a). Beans from Lichtenburg on the other hand had significantly lower 100SM values than those from other localities during 2002/03 (Figure 4.4b) and had low MC values (Figure 4.3b).

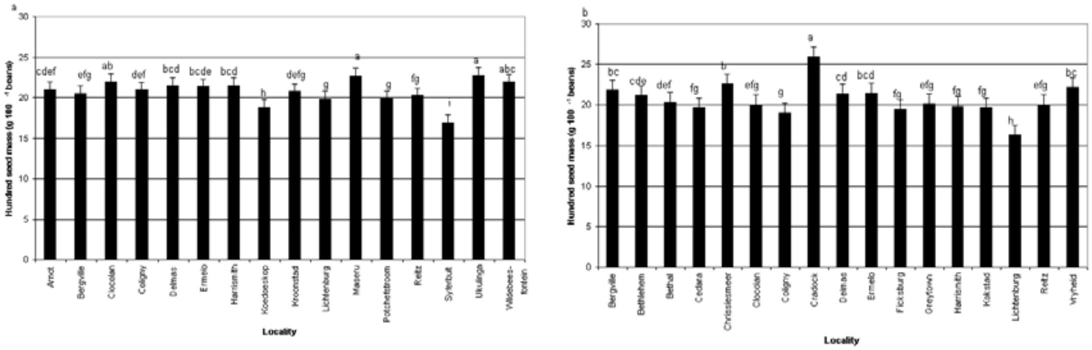


Figure 4.4 Mean hundred seed mass pertaining to localities of canned small white bean cultivars for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

Beans from Cradock displayed significantly higher 100SM values during 2002/03 (Figure 4.4b), while being among the localities with low MC values during the same season (Figure 4.3b). As mentioned (4.3.1.1.2), small sized beans would hydrate better on soaking (Del Valle *et al*., 1992), but could be rejected by the consumer if the size deviates too much from regular sized beans.

4.3.2 Canning quality of dry bean cultivars

Tables 4.7.1 to 4.17.2 indicate the canning quality values of small white bean cultivars for the 2001/02 and 2002/03 seasons. Mean, minimum, maximum and F-values values of cultivar, locality, replicates and cultivar x locality interactions are provided in Tables 4.18 and 4.19 for 2001/02 and 2002/03 respectively. As the same cultivars and localities were not included in trials during both seasons, a separate ANOVA was performed for each season. No variation in clumping data was found for 2001/02 (Table 4.18). No significant differences between replicates were found for canning parameters (Tables 4.18 & 4.19), while significant differences were found between cultivars and localities for both seasons. All cultivar x locality interactions, except for clumping were significant during 2001/02 (Table 4.18). Differences in cultivar x locality interactions were not significant during 2002/03 for size and colour values (L-, a_L- and b_L-values) (Table 4.19).

Table 4.7.1 Hydration coefficients after soaking of four small white bean cultivars from 16 localities (2001/02 season)

Cultivar	Replicate	Arnot	Bergville	Clocolan	Coligny	Delmas	Ermelo	Harrismith	Koedoeskop	Kroonstad	Lichtenburg	Maseru	Potchefstroom	Reitz	Syferbult	Ukulinga	Wildebeesfontein	Mean
OPS-KW1	1	1.82	1.86	1.89	1.89	1.87	1.84	1.89	1.99	1.92	1.86	1.85	1.48	1.88	1.89	1.85	1.85	1.85
OPS-KW1	2	1.87	1.88	1.87	1.89	1.86	1.85	1.90	2.05	1.91	1.91	1.83	1.42	1.86	1.85	1.83	1.84	1.85
OPS-KW1	3	1.84	1.88	1.88	1.91	1.87	1.86	1.88	2.04	1.90	1.84	1.81	1.41	1.86	1.91	1.82	1.86	1.85
PAN 185	1	1.83	1.89	1.89	1.89	1.88	1.90	1.91	2.10	1.92	1.84	1.82	1.46	1.89	1.89	1.86	1.84	1.86
PAN 185	2	1.87	1.88	1.91	1.89	1.88	1.83	1.93	2.06	1.90	1.89	1.89	1.43	1.89	1.89	1.87	1.86	1.87
PAN 185	3	1.87	1.88	1.91	1.87	1.88	1.86	1.92	2.08	1.93	1.86	1.89	1.55	1.89	1.78	1.87	1.84	1.87
Teebus	1	1.38	1.53	1.56	1.78	1.44	1.74	1.72	1.84	1.43	1.72	1.73	1.39	1.68	1.69	1.81	1.74	1.64
Teebus	2	1.38	1.54	1.59	1.78	1.49	1.75	1.65	1.77	1.51	1.62	1.78	1.37	1.68	1.67	1.80	1.74	1.63
Teebus	3	1.37	1.58	1.56	1.74	1.56	1.68	1.64	1.78	1.51	1.71	1.77	1.32	1.67	1.70	1.80	1.74	1.63
Teebus RR1	1	1.76	1.54	1.65	1.80	1.60	1.74	1.73	1.82	1.63	1.63	1.75	1.42	1.71	1.63	1.77	1.75	1.68
Teebus RR1	2	1.66	1.68	1.68	1.73	1.56	1.70	1.71	1.76	1.63	1.63	1.70	1.44	1.73	1.61	1.76	1.69	1.67
Teebus RR1	3	1.66	1.65	1.70	1.73	1.58	1.73	1.69	1.82	1.48	1.70	1.73	1.39	1.74	1.88	1.76	1.76	1.69
Mean		1.69	1.73	1.76	1.82	1.71	1.79	1.80	1.92	1.72	1.77	1.80	1.42	1.79	1.78	1.82	1.79	
Min		1.37	1.53	1.56	1.73	1.44	1.68	1.64	1.76	1.43	1.62	1.70	1.32	1.67	1.61	1.76	1.69	
Max		1.87	1.89	1.91	1.91	1.88	1.90	1.93	2.10	1.93	1.91	1.89	1.55	1.89	1.91	1.87	1.86	
Range		0.50	0.36	0.36	0.18	0.44	0.22	0.29	0.34	0.50	0.29	0.19	0.23	0.23	0.30	0.11	0.18	

cultivar (n = 4); replicate (n = 3); localities (n = 16), % CV = 2.08

Table 4.7.2 Hydration coefficients after soaking of six small white bean cultivars from 17 localities determined (2002/03) season)

Cultivar	Replicate	Bergville	Bethlehem	Bethal	Cedara	Chrissiesmeer	Clocolan	Coligny	Cradock	Delmas	Ermelo	Ficksburg	Greytown	Harrismith	Kokstad	Lichtenburg	Reitz	Vryheid	Mean
PAN 120	1	1.69	1.75	1.74	1.75	1.84	1.79	1.85	1.81	1.79	1.81	1.81	1.89	1.86	1.83	1.89	1.62	1.79	1.79
PAN 120	2	1.71	1.78	1.61	1.86	1.85	1.80	1.89	1.89	1.79	1.78	1.80	1.77	1.87	1.79	1.79	1.75	1.81	1.80
PAN 120	3	1.71	1.74	1.61	1.77	1.83	1.77	1.90	1.90	1.78	1.83	1.83	1.88	1.87	1.84	1.82	1.71	1.85	1.80
PAN 121	1	1.42	1.27	1.38	1.66	1.66	1.41	1.48	1.81	1.48	1.40	1.59	1.73	1.61	1.75	1.78	1.46	1.39	1.55
PAN 121	2	1.45	1.30	1.46	1.71	1.62	1.54	1.63	1.76	1.42	1.55	1.45	1.74	1.62	1.79	1.86	1.37	1.55	1.58
PAN 121	3	1.68	1.25	1.36	1.58	1.64	1.42	1.55	1.81	1.44	1.50	1.62	1.75	1.61	1.78	1.75	1.35	1.46	1.56
PAN 123	1	1.68	1.68	1.66	1.75	1.74	1.80	1.81	1.84	1.67	1.75	1.80	1.85	1.78	1.69	1.82	1.60	1.76	1.75
PAN 123	2	1.71	1.59	1.48	1.77	1.79	1.77	1.86	1.82	1.68	1.77	1.78	1.83	1.74	1.74	1.80	1.59	1.80	1.74
PAN 123	3	1.75	1.67	1.60	1.76	1.76	1.74	1.85	1.83	1.64	1.70	1.80	1.72	1.73	1.80	1.83	1.70	1.76	1.74
PAN 185	1	1.74	1.94	1.91	1.83	1.82	1.91	1.97	1.87	1.91	1.97	1.91	1.97	1.87	1.88	1.99	1.92	1.81	1.90
PAN 185	2	1.79	1.90	1.86	1.86	1.82	1.90	1.96	1.91	1.89	1.89	1.87	1.96	1.90	1.86	1.99	1.92	1.84	1.89
PAN 185	3	1.73	1.91	1.88	1.84	1.88	1.90	1.83	1.92	1.60	1.90	1.90	1.97	1.94	1.87	2.01	1.92	1.88	1.88
Teebus	1	1.65	1.77	1.50	1.67	1.77	1.64	1.80	1.79	1.70	1.90	1.60	1.81	1.71	1.74	1.69	1.51	1.56	1.69
Teebus	2	1.61	1.90	1.36	1.76	1.76	1.55	1.78	1.78	1.60	1.82	1.70	1.79	1.71	1.76	1.73	1.43	1.50	1.68
Teebus	3	1.68	1.83	1.42	1.71	1.79	1.57	1.84	1.77	1.67	1.73	1.70	1.84	1.69	1.77	1.75	1.50	1.50	1.69
Teebus RR1	1	1.62	1.60	1.51	1.70	1.75	1.59	1.79	1.88	1.73	1.78	1.66	1.87	1.74	1.77	1.78	1.55	1.70	1.71
Teebus RR1	2	1.66	1.55	1.46	1.72	1.76	1.61	1.80	1.80	1.69	1.68	1.69	1.77	1.68	1.86	1.76	1.50	1.67	1.69
Teebus RR1	3	1.66	1.50	1.51	1.72	1.75	1.59	1.74	1.80	1.69	1.72	1.71	1.81	1.68	1.76	1.74	1.48	1.64	1.68
Mean		1.66	1.66	1.57	1.75	1.77	1.68	1.80	1.83	1.68	1.75	1.73	1.83	1.76	1.79	1.82	1.60	1.68	
Min		1.42	1.25	1.36	1.58	1.62	1.41	1.48	1.76	1.42	1.40	1.45	1.72	1.61	1.69	1.69	1.35	1.39	
Max		1.79	1.94	1.91	1.86	1.88	1.91	1.97	1.92	1.91	1.97	1.91	1.97	1.94	1.88	2.01	1.92	1.88	
Range		0.37	0.69	0.55	0.28	0.25	0.50	0.49	0.17	0.48	0.57	0.46	0.25	0.33	0.19	0.32	0.57	0.49	

cultivar (n = 6); replicate (n = 3); localities (n = 17), % CV = 2.74

Table 4.8.1 Percentage washed drained weight 14 days after canning of four small white bean cultivars from 16 localities (2001/02 season)

Cultivar	Replicate	Arnot	Bergville	Clocolan	Coligny	Delmas	Ermelo	Harrismith	Koedoes-kop	Kroonstad	Lichten-burg	Maseru	Potchef-stroom	Reitz	Syferbult	Ukulinga	Wildebees-fontein	Mean
OPS-KW1	1	52.18	54.05	55.28	56.49	55.44	56.45	56.97	59.90	54.90	58.32	52.69	57.59	55.62	51.65	57.87	54.85	55.64
OPS-KW1	2	54.00	58.15	55.42	56.86	55.95	54.71	57.21	60.95	54.79	59.50	53.07	56.49	54.89	53.06	55.42	53.84	55.89
OPS-KW1	3	54.01	56.36	54.44	56.77	57.14	56.23	57.43	60.82	53.80	59.84	54.79	56.15	56.35	51.60	55.69	54.18	55.98
PAN 185	1	52.90	56.50	55.97	55.64	55.75	55.80	57.18	59.88	56.45	56.99	51.06	57.27	56.01	52.43	58.10	54.54	55.78
PAN 185	2	54.87	56.41	55.43	56.26	55.28	55.71	58.81	58.92	54.72	58.31	58.56	56.48	56.01	53.05	57.23	55.69	56.36
PAN 185	3	55.00	56.68	54.56	55.19	57.25	56.89	57.34	59.36	56.03	58.50	59.47	57.53	56.37	52.11	58.57	54.99	56.61
Teebus	1	51.17	51.14	53.31	53.85	53.08	57.43	56.46	58.25	51.12	56.32	51.84	55.59	54.58	56.27	56.29	53.90	54.41
Teebus	2	51.08	56.31	54.13	55.91	52.61	58.10	56.25	60.18	51.24	54.07	51.59	55.00	54.58	52.73	56.62	54.13	54.66
Teebus	3	50.84	54.43	52.15	54.50	52.37	51.77	56.31	59.74	51.46	57.25	52.57	54.11	54.16	54.09	56.06	53.67	54.09
Teebus RR1	1	52.30	52.28	54.80	54.36	54.10	53.99	57.37	59.10	55.08	55.20	53.42	56.33	54.68	54.02	57.37	53.66	54.88
Teebus RR1	2	53.83	55.44	54.62	56.39	52.31	55.29	56.22	59.42	52.74	55.91	52.86	57.00	56.29	51.84	58.22	53.40	55.11
Teebus RR1	3	55.20	54.87	56.00	55.72	52.48	58.68	56.90	59.08	51.59	56.89	54.26	55.72	55.02	52.11	57.15	55.34	55.44
Mean		53.11	55.22	54.68	55.66	54.48	55.92	57.04	59.63	53.66	57.26	53.85	56.27	55.38	52.91	57.05	54.35	
Min		50.84	51.14	52.15	53.85	52.31	51.77	56.22	58.25	51.12	54.07	51.06	54.11	54.16	51.60	55.42	53.40	
Max		55.20	58.15	56.00	56.86	57.25	58.68	58.81	60.95	56.45	59.84	59.47	57.59	56.37	56.27	58.57	55.69	
Range		4.36	7.01	3.85	3.01	4.94	6.91	2.59	2.70	5.33	5.78	8.40	3.48	2.20	4.67	3.14	2.29	

cultivar (n = 4); replicate (n = 3); localities (n = 16), % CV = 2.17

Table 4.8.2 Percentage washed drained weight 14 days after canning of six small white bean cultivars from 17 localities (2002/03 season)

Cultivar	Replicate	Bergville	Bethlehem	Bethal	Cedara	Chrissies-meer	Clocolan	Coligny	Cradock	Delmas	Ermelo	Ficksburg	Greytown	Harrismith	Kokstad	Lichten-burg	Reitz	Vryheid	Mean
PAN 120	1	52.91	56.28	56.59	55.04	56.70	59.71	60.09	57.26	59.79	60.07	58.99	62.82	56.46	57.85	63.45	57.40	59.96	58.32
PAN 120	2	52.47	55.24	55.29	59.65	54.63	59.22	60.69	60.12	59.35	57.77	56.08	59.24	56.70	58.14	62.51	58.77	57.68	57.85
PAN 120	3	55.27	57.44	54.65	57.93	54.72	59.17	59.53	60.14	58.51	58.81	58.69	63.06	54.92	58.57	64.30	59.89	55.68	58.31
PAN 121	1	52.05	51.77	54.33	55.68	54.19	55.60	53.27	61.76	55.48	54.14	55.95	59.60	54.46	56.40	64.38	56.90	56.27	56.01
PAN 121	2	52.45	52.35	52.16	57.97	54.32	58.06	56.13	61.20	55.29	55.85	54.00	62.06	53.55	57.13	64.60	54.73	59.48	56.55
PAN 121	3	53.13	52.97	52.42	55.58	55.03	56.26	54.44	58.44	56.31	54.17	56.17	60.64	55.97	56.47	62.81	54.77	56.36	56.00
PAN 123	1	53.23	55.29	56.82	58.01	52.95	58.24	59.21	59.59	57.64	56.99	58.83	62.12	57.00	56.38	62.29	57.00	57.36	57.59
PAN 123	2	53.56	54.39	52.34	54.90	54.40	59.51	58.84	60.52	53.53	56.53	56.30	59.37	54.88	56.66	61.54	56.98	57.44	56.57
PAN 123	3	54.15	54.94	54.57	58.00	54.99	58.97	56.09	59.50	56.65	57.68	59.11	61.93	58.35	56.92	61.71	57.09	57.62	57.54
PAN 185	1	51.57	57.31	53.09	54.96	54.85	56.53	59.30	56.12	57.88	57.32	56.73	59.19	54.25	56.29	59.47	55.95	56.84	56.33
PAN 185	2	53.44	55.88	59.24	54.29	56.73	57.00	58.33	57.49	57.36	55.31	54.79	59.48	54.98	55.69	59.39	55.09	56.01	56.50
PAN 185	3	52.10	55.50	52.45	54.49	54.72	56.48	56.99	60.22	52.84	54.95	56.98	59.50	57.55	56.22	60.89	57.07	55.86	56.17
Teebus	1	52.86	56.74	54.84	53.36	52.42	56.20	58.18	59.56	56.42	55.32	56.35	59.90	53.37	55.84	60.03	55.94	56.80	56.12
Teebus	2	52.38	54.50	54.03	58.38	53.61	56.04	57.15	59.38	56.41	53.96	56.95	58.02	54.56	55.48	61.17	53.40	54.27	55.86
Teebus	3	52.15	51.55	51.43	56.24	53.11	56.57	55.94	57.28	56.77	53.99	54.81	60.72	55.99	55.47	61.52	54.93	53.22	55.39
Teebus RR1	1	50.32	55.41	54.05	55.93	53.02	56.01	59.05	62.71	57.07	54.93	57.83	61.29	52.98	57.35	63.49	55.78	56.95	56.72
Teebus RR1	2	53.47	50.51	53.06	54.86	54.27	55.95	59.31	59.05	57.88	54.78	56.91	61.43	53.38	57.43	62.90	54.40	55.25	56.17
Teebus RR1	3	54.49	52.80	54.60	56.28	52.67	57.07	50.64	59.67	58.04	54.84	56.40	62.40	53.40	56.24	61.19	55.43	56.50	56.04
Mean		52.89	54.49	54.22	56.20	54.30	57.37	57.40	59.45	56.85	55.97	56.77	60.71	55.15	56.70	62.09	56.20	56.64	
Min		50.32	50.51	51.43	53.36	52.42	55.60	50.64	56.12	52.84	53.96	54.00	58.02	52.98	55.47	59.39	53.40	53.22	
Max		55.27	57.44	59.24	59.65	56.73	59.71	60.69	62.71	59.79	60.07	59.11	63.06	58.35	58.57	64.60	59.89	59.96	
Range		4.94	6.92	7.80	6.29	4.31	4.11	10.05	6.59	6.95	6.11	5.10	5.04	5.37	3.10	5.21	6.49	6.74	

cultivar (n = 6); replicate (n = 3); localities (n = 17), % CV = 2.44

Table 4.9.1 Visual appearance (scale 1 to 10) 14 days after canning of four small white bean cultivars from 16 localities (2001/02 season)

Cultivar	Replicate	Arnot	Bergville	Clocolan	Coligny	Delmas	Ermelo	Harrismith	Koedoes-kop	Kroonstad	Lichten-burg	Maseru	Potchef-stroom	Reitz	Syferbult	Ukulinga	Wildebees-fontein	Mean
OPS-KW1	1	10.00	10.00	10.00	10.00	8.00	10.00	10.00	8.00	8.00	10.00	10.00	10.00	10.00	8.00	10.00	10.00	9.50
OPS-KW1	2	10.00	8.00	10.00	10.00	10.00	10.00	10.00	8.00	10.00	10.00	10.00	8.00	10.00	10.00	8.00	10.00	9.50
OPS-KW1	3	10.00	10.00	10.00	10.00	10.00	10.00	10.00	8.00	10.00	10.00	10.00	10.00	10.00	8.00	8.00	10.00	9.63
PAN 185	1	8.00	8.00	8.00	10.00	10.00	10.00	8.00	8.00	8.00	10.00	8.00	10.00	8.00	6.00	10.00	10.00	8.73
PAN 185	2	8.00	8.00	8.00	8.00	8.00	10.00	8.00	8.00	10.00	10.00	8.00	8.00	8.00	6.00	10.00	10.00	8.50
PAN 185	3	8.00	8.00	8.00	10.00	10.00	10.00	8.00	8.00	10.00	10.00	8.00	8.00	8.00	10.00	10.00	10.00	9.00
Teebus	1	10.00	8.00	10.00	10.00	10.00	10.00	10.00	8.00	10.00	10.00	10.00	10.00	8.00	8.00	10.00	10.00	9.63
Teebus	2	10.00	8.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	8.00	10.00	9.75
Teebus	3	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Teebus RR1	1	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	8.00	10.00	10.00	9.88
Teebus RR1	2	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Teebus RR1	3	10.00	8.00	10.00	10.00	10.00	10.00	10.00	8.00	10.00	10.00	10.00	10.00	10.00	6.00	10.00	10.00	9.60
Mean		9.50	8.83	9.50	9.83	9.67	10.00	9.50	8.67	9.67	10.00	9.50	9.50	9.50	8.33	9.50	10.00	
Min		8.00	8.00	8.00	8.00	8.00	10.00	8.00	8.00	8.00	10.00	8.00	9.50	8.00	6.00	9.50	10.00	
Max		10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	
Range		2.00	2.00	2.00	2.00	2.00	0.00	2.00	2.00	2.00	0.00	2.00	2.00	2.00	4.00	2.00	0.00	

cultivar (n = 4); replicate (n = 3); localities (n = 16), % CV = 7.35

Table 4.9.2 Visual appearance (scale 1 to 10) determined 14 days after canning of six small white bean cultivars from 17 localities (2002/03 season)

Cultivar	Replicate	Bergville	Bethlehem	Bethal	Cedara	Chrissies-meer	Clocolan	Coligny	Cradock	Delmas	Ermelo	Ficksburg	Greytown	Harrismith	Kokstad	Lichten-burg	Reitz	Vryheid	Mean
PAN 120	1	10.00	10.00	7.00	8.00	8.00	8.00	6.00	8.00	10.00	7.00	6.00	8.00	8.00	8.00	4.00	6.00	8.00	7.65
PAN 120	2	8.00	9.00	8.00	6.00	6.00	8.00	8.00	8.00	10.00	7.00	6.00	6.00	8.00	6.00	5.00	6.00	8.00	7.24
PAN 120	3	8.00	10.00	7.00	8.00	8.00	8.00	8.00	8.00	10.00	6.00	8.00	6.00	9.00	8.00	6.00	6.00	8.00	7.76
PAN 121	1	8.00	8.00	8.00	6.00	6.00	6.00	8.00	6.00	10.00	7.00	6.00	6.00	8.00	8.00	6.00	6.00	6.00	7.00
PAN 121	2	8.00	9.00	9.00	6.00	8.00	8.00	8.00	6.00	9.00	7.00	6.00	6.00	8.00	6.00	6.00	8.00	4.00	7.18
PAN 121	3	8.00	8.00	7.00	8.00	8.00	8.00	8.00	7.00	9.00	8.00	6.00	6.00	8.00	8.00	4.00	6.00	4.00	7.12
PAN 123	1	8.00	7.00	7.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	6.00	4.00	8.00	4.00	6.00	6.00	8.00	7.06
PAN 123	2	8.00	8.00	9.00	8.00	8.00	8.00	8.00	8.00	9.00	8.00	8.00	4.00	8.00	6.00	4.00	6.00	8.00	7.41
PAN 123	3	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	7.00	6.00	8.00	6.00	8.00	6.00	4.00	8.00	8.00	7.35
PAN 185	1	8.00	8.00	9.00	6.00	6.00	6.00	8.00	6.00	6.00	8.00	6.00	10.00	6.00	8.00	6.00	6.00	10.00	7.24
PAN 185	2	8.00	8.00	8.00	6.00	8.00	6.00	6.00	6.00	8.00	9.00	6.00	10.00	6.00	6.00	6.00	6.00	6.00	7.00
PAN 185	3	8.00	7.00	8.00	6.00	6.00	6.00	10.00	7.00	8.00	9.00	6.00	6.00	6.00	8.00	6.00	6.00	8.00	7.12
Teebus	1	8.00	8.00	9.00	8.00	10.00	10.00	8.00	10.00	10.00	9.00	8.00	4.00	8.00	8.00	6.00	10.00	10.00	8.47
Teebus	2	8.00	7.00	8.00	6.00	10.00	10.00	8.00	9.00	10.00	9.00	9.00	4.00	9.00	8.00	4.00	8.00	8.00	7.94
Teebus	3	10.00	8.00	7.00	8.00	9.00	10.00	8.00	10.00	10.00	9.00	8.00	5.00	8.00	8.00	6.00	10.00	8.00	8.35
Teebus RR1	1	10.00	9.00	9.00	8.00	10.00	10.00	9.00	8.00	10.00	9.00	10.00	5.00	10.00	8.00	6.00	10.00	10.00	8.88
Teebus RR1	2	10.00	8.00	9.00	8.00	10.00	10.00	10.00	8.00	10.00	10.00	10.00	6.00	10.00	8.00	4.00	8.00	10.00	8.76
Teebus RR1	3	10.00	8.00	9.00	8.00	10.00	10.00	10.00	8.00	10.00	10.00	10.00	6.00	10.00	8.00	6.00	10.00	10.00	9.00
Mean		8.56	8.22	8.11	7.22	8.17	8.22	8.17	7.72	9.11	8.11	7.39	6.00	8.11	7.22	5.28	7.33	7.89	
Min		8.00	7.00	7.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	4.00	6.00	4.00	4.00	6.00	4.00	
Max		10.00	10.00	9.00	8.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	8.00	6.00	10.00	10.00	
Range		2.00	3.00	2.00	2.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	6.00	4.00	4.00	2.00	4.00	6.00	

cultivar (n = 6); replicate (n = 3); localities (n = 17), % CV = 10.42

Table 4.10.1 Splits (scale 1 to 10) 14 days after canning of four small white bean cultivars from 16 localities (2001/02 season)

Cultivar	Replicate	Arnot	Bergville	Clocolan	Coligny	Delmas	Ermelo	Harrismith	Koedoeskop	Kroonstad	Lichtenburg	Maseru	Potchefstroom	Reitz	Syferbult	Ukulinga	Wildebeesfontein	Mean
OPS-KW1	1	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	6.00	10.00	10.00	10.00	10.00	6.00	10.00	9.50
OPS-KW1	2	10.00	5.00	10.00	10.00	10.00	10.00	8.00	8.00	10.00	8.00	10.00	10.00	10.00	10.00	10.00	10.00	9.13
OPS-KW1	3	10.00	6.00	10.00	10.00	10.00	10.00	8.00	8.00	10.00	8.00	8.00	10.00	10.00	10.00	6.00	10.00	9.00
PAN 185	1	10.00	10.00	10.00	10.00	10.00	10.00	10.00	5.00	10.00	10.00	10.00	8.00	10.00	10.00	10.00	10.00	9.56
PAN 185	2	10.00	10.00	10.00	8.00	10.00	10.00	10.00	6.00	10.00	8.00	6.00	8.00	10.00	10.00	10.00	10.00	9.13
PAN 185	3	10.00	10.00	10.00	10.00	10.00	10.00	8.00	8.00	8.00	10.00	10.00	10.00	10.00	10.00	8.00	10.00	9.50
Teebus	1	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	8.00	10.00	10.00	9.88
Teebus	2	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Teebus	3	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	8.00	10.00	10.00	9.88
Teebus RR1	1	10.00	10.00	10.00	10.00	10.00	10.00	10.00	6.00	8.00	10.00	10.00	10.00	10.00	10.00	8.00	10.00	9.50
Teebus RR1	2	10.00	10.00	8.00	8.00	10.00	10.00	10.00	8.00	10.00	10.00	10.00	8.00	10.00	10.00	10.00	10.00	9.50
Teebus RR1	3	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Mean		10.00	9.25	9.83	9.67	10.00	10.00	9.50	8.25	9.67	9.17	9.50	9.50	10.00	9.67	9.00	10.00	
Min		10.00	5.00	8.00	8.00	10.00	10.00	8.00	5.00	8.00	6.00	6.00	8.00	10.00	8.00	6.00	10.00	
Max		10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	
Range		0.00	5.00	2.00	2.00	0.00	0.00	2.00	5.00	2.00	4.00	4.00	2.00	0.00	2.00	4.00	0.00	

cultivar (n = 4); replicate (n = 3); localities (n = 16), % CV = 8.84

Table 4.10.2 Splits (scale 1 to 10) 14 days after canning of six small white bean cultivars from 17 localities (2002/03 season)

Cultivar	Replicate	Bergville	Bethlehem	Bethal	Cedara	Chrissiesmeer	Clocolan	Coligny	Cradock	Delmas	Ermelo	Ficksburg	Greytown	Harrismith	Kokstad	Lichtenburg	Reitz	Vryheid	Mean
PAN 120	2	9.00	8.00	8.00	8.00	9.00	9.00	8.00	8.00	9.00	8.00	7.00	7.00	9.00	8.00	6.50	9.00	8.00	8.15
PAN 120	3	9.00	9.00	8.00	8.00	9.00	9.00	9.00	8.00	9.00	6.00	7.00	8.00	9.00	8.00	7.00	8.00	9.00	8.24
PAN 121	1	7.00	9.00	7.00	7.00	8.00	7.00	8.00	7.00	8.00	7.00	5.00	6.00	7.00	8.00	7.00	7.00	7.00	7.18
PAN 121	2	7.00	8.00	8.00	7.00	8.00	7.00	8.00	6.00	8.00	7.00	6.00	8.00	8.00	8.00	8.00	9.00	6.00	7.47
PAN 121	3	9.00	9.00	7.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	5.00	6.00	8.00	8.00	6.00	8.00	6.00	7.53
PAN 123	1	7.00	8.00	7.00	9.00	9.00	8.00	8.00	8.00	8.00	7.00	6.00	6.00	7.00	6.00	7.00	8.00	8.00	7.47
PAN 123	2	8.00	9.00	8.00	9.00	9.00	8.00	8.00	7.00	9.00	7.00	6.00	7.00	8.00	6.00	6.00	8.00	8.00	7.71
PAN 123	3	8.00	9.00	7.00	8.00	8.00	8.00	8.00	8.00	8.00	6.00	5.00	8.00	8.00	7.00	6.00	8.00	9.00	7.59
PAN 185	1	9.00	7.00	9.00	9.00	9.00	9.00	9.00	9.00	8.00	8.00	6.00	8.00	9.00	9.00	8.00	9.00	8.00	8.41
PAN 185	2	9.00	9.00	9.00	9.00	9.00	9.00	8.00	7.00	9.00	9.00	7.00	9.00	9.00	9.00	8.00	9.00	9.00	8.65
PAN 185	3	9.00	9.00	9.00	9.00	9.00	9.00	9.00	8.00	9.00	9.00	7.00	9.00	9.00	8.00	9.00	9.00	8.00	8.71
Teebus	1	9.00	9.00	8.00	9.00	9.00	9.00	7.00	8.00	8.00	8.00	6.00	4.00	9.00	8.00	7.00	9.00	9.00	8.00
Teebus	2	9.00	8.00	7.00	7.00	9.00	9.00	9.00	8.00	8.00	8.00	8.00	4.00	8.00	8.00	5.00	9.00	9.00	7.82
Teebus	3	9.00	9.00	9.00	9.00	9.00	8.00	7.00	9.00	8.00	8.00	9.00	7.00	8.00	7.00	7.00	9.00	9.00	8.29
Teebus RR1	1	9.00	8.00	8.00	8.00	9.00	9.00	7.00	8.00	9.00	9.00	8.00	4.00	9.00	8.00	7.00	9.00	9.00	8.12
Teebus RR1	2	9.00	9.00	8.00	9.00	9.00	9.00	9.00	8.00	9.00	9.00	8.00	5.00	8.00	8.00	7.00	9.00	9.00	8.35
Teebus RR1	3	9.00	9.00	9.00	8.00	9.00	9.00	9.00	8.00	9.00	8.00	9.00	7.00	9.00	8.00	8.00	9.00	8.00	8.53
Mean		8.53	8.59	8.00	8.29	8.76	8.47	8.18	7.82	8.47	7.76	6.76	6.65	8.35	7.76	7.03	8.59	8.18	
Min		7.00	7.00	7.00	7.00	8.00	7.00	7.00	6.00	8.00	6.00	5.00	4.00	7.00	6.00	5.00	7.00	6.00	
Max		9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	
Range		2.00	2.00	2.00	2.00	1.00	2.00	2.00	3.00	1.00	3.00	4.00	5.00	2.00	3.00	4.00	2.00	3.00	

cultivar (n = 6); replicate (n = 3); localities (n = 17), % CV = 7.88

Table 4.11.1 Size (scale 1 to 7) 14 days after canning of four small white bean cultivars from 16 localities (2001/02 season)

Cultivar	Replicate	Arnot	Bergville	Clocolan	Coligny	Delmas	Ermelo	Harrismith	Koedoeskop	Kroonstad	Lichtenburg	Maseru	Potchefstroom	Reitz	Syferbult	Ukulinga	Wildebeesfontein	Mean
OPS-KW1	1	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	5.00	6.00	6.00	6.00	6.00	5.00	6.00	6.00	5.88
OPS-KW1	2	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	5.00	6.00	6.00	5.00	6.00	5.88
OPS-KW1	3	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	5.00	6.00	5.94
PAN 185	1	5.00	5.00	5.00	6.00	6.00	6.00	5.00	5.00	5.00	6.00	5.00	5.00	5.00	5.00	6.00	6.00	5.38
PAN 185	2	5.00	5.00	5.00	5.00	5.00	6.00	5.00	5.00	6.00	6.00	6.00	5.00	5.00	4.00	6.00	6.00	5.31
PAN 185	3	5.00	6.00	5.00	5.00	6.00	6.00	5.00	5.00	6.00	6.00	6.00	5.00	5.00	5.00	6.00	6.00	5.50
Teebus	1	6.00	6.00	7.00	7.00	6.00	7.00	7.00	6.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	7.00	6.50
Teebus	2	6.00	6.00	7.00	7.00	6.00	7.00	7.00	7.00	7.00	6.00	7.00	6.00	7.00	6.00	6.00	7.00	6.56
Teebus	3	6.00	7.00	6.00	7.00	6.00	6.00	7.00	7.00	7.00	6.00	6.00	6.00	6.00	7.00	6.00	7.00	6.44
Teebus RR1	1	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	6.00	7.00	7.00	7.00	5.00	7.00	7.00	6.81
Teebus RR1	2	7.00	7.00	7.00	6.00	7.00	7.00	7.00	7.00	7.00	6.00	7.00	7.00	7.00	7.00	7.00	7.00	6.88
Teebus RR1	3	6.00	6.00	7.00	7.00	7.00	7.00	7.00	6.00	7.00	7.00	7.00	7.00	6.00	7.00	7.00	7.00	6.75
Mean		5.92	6.08	6.17	6.25	6.17	6.42	6.25	6.08	6.33	6.08	6.33	5.92	6.08	5.75	6.08	6.50	
Min		5.00	5.00	5.00	5.00	5.00	6.00	5.00	5.00	5.00	6.00	5.00	5.00	5.00	4.00	5.00	6.00	
Max		7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	
Range		2.00	2.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00	3.00	2.00	1.00	

cultivar (n = 4); replicate (n = 3); localities (n = 16), % CV = 3.14

Table 4.11.2 Size (scale 1 to 7) determined 14 days after canning of six small white bean cultivars from 17 localities (2002/03 season)

Cultivar	Replicate	Bergville	Bethlehem	Bethal	Cedara	Chrissiesmeer	Clocolan	Coligny	Cradock	Delmas	Ermelo	Ficksburg	Greytown	Harrismith	Kokstad	Lichtenburg	Reitz	Vryheid	Mean
PAN 120	1	7.00	7.00	5.00	6.00	6.00	6.00	6.00	6.00	7.00	7.00	6.00	6.00	6.00	6.00	5.00	5.00	6.00	6.06
PAN 120	2	6.00	6.00	6.00	5.00	5.00	6.00	6.00	6.00	7.00	5.00	6.00	6.00	6.00	5.00	6.00	5.00	6.00	5.76
PAN 120	3	6.00	6.00	5.00	6.00	6.00	6.00	6.00	6.00	7.00	7.00	6.00	7.00	7.00	6.00	6.00	5.00	6.00	6.12
PAN 121	1	6.00	6.00	7.00	6.00	6.00	6.00	6.00	6.00	7.00	7.00	6.00	7.00	6.00	6.00	6.00	6.00	6.00	6.24
PAN 121	2	7.00	7.00	7.00	6.00	7.00	6.00	6.00	7.00	6.00	7.00	7.00	7.00	7.00	6.00	5.00	6.00	7.00	6.53
PAN 121	3	6.00	6.00	7.00	6.00	6.00	7.00	6.00	7.00	5.00	7.00	7.00	7.00	6.00	6.00	6.00	5.00	6.00	6.24
PAN 123	1	7.00	5.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	7.00	5.00	7.00	6.00	6.00	6.00	5.00	6.00	6.00
PAN 123	2	6.00	6.00	5.00	6.00	6.00	6.00	6.00	7.00	7.00	6.00	7.00	7.00	6.00	6.00	6.00	5.00	6.00	6.12
PAN 123	3	6.00	6.00	6.00	6.00	6.00	6.00	6.00	7.00	5.00	6.00	7.00	5.00	6.00	6.00	6.00	6.00	7.00	6.06
PAN 185	1	6.00	6.00	5.00	5.00	5.00	5.00	6.00	5.00	5.00	6.00	5.00	6.00	5.00	6.00	5.00	5.00	6.00	5.41
PAN 185	2	6.00	6.00	5.00	5.00	6.00	5.00	5.00	5.00	6.00	6.00	5.00	6.00	5.00	5.00	5.00	5.00	5.00	5.35
PAN 185	3	6.00	5.00	7.00	5.00	5.00	5.00	7.00	6.00	6.00	5.00	5.00	6.00	5.00	6.00	5.00	5.00	6.00	5.59
Teebus	1	6.00	6.00	7.00	6.00	7.00	7.00	7.00	7.00	7.00	7.00	6.00	7.00	6.00	6.00	6.00	7.00	7.00	6.59
Teebus	2	6.00	5.00	7.00	6.00	7.00	7.00	6.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	6.00	6.00	6.00	6.53
Teebus	3	7.00	6.00	6.00	6.00	6.00	7.00	6.00	7.00	7.00	6.00	6.00	7.00	6.00	6.00	6.00	7.00	6.00	6.35
Teebus RR1	1	7.00	7.00	7.00	7.00	7.00	7.00	7.00	6.00	7.00	7.00	7.00	7.00	7.00	6.00	6.00	7.00	7.00	6.82
Teebus RR1	2	7.00	6.00	7.00	6.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	6.00	6.00	6.00	7.00	6.71
Teebus RR1	3	7.00	6.00	6.00	6.00	7.00	7.00	7.00	7.00	7.00	6.00	7.00	7.00	7.00	6.00	6.00	7.00	7.00	6.65
Mean		6.39	6.00	6.17	5.83	6.17	6.22	6.22	6.39	6.44	6.44	6.22	6.61	6.17	5.94	5.72	5.72	6.28	
Min		6.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	
Max		7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	6.00	7.00	7.00	
Range		1.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00	2.00	2.00	

cultivar (n = 6); replicate (n = 3); localities (n = 17), % CV = 8.06

Table 4.12.1 Texture (kg.100 g^{-1}.12 s^{-1}) 14 days after canning of four small white bean cultivars from 16 localities (2001/02 season)

Cultivar	Replicate	Arnot	Bergville	Clocolan	Coligny	Delmas	Ermelo	Harrismith	Koedoes-kop	Kroonstad	Lichten-burg	Maseru	Potchef-stroom	Reitz	Syferbult	Ukulinga	Wildebees-fontein	Mean
OPS-KW1	1	87.25	80.70	71.75	71.50	77.55	58.95	68.65	62.20	82.65	63.40	96.70	66.60	63.55	116.65	52.95	71.90	74.56
OPS-KW1	2	82.6	61.25	68.85	65.90	74.45	69.95	55.45	58.15	83.45	60.80	82.95	63.30	69.25	106.50	70.70	78.75	72.02
OPS-KW1	3	79.85	67.75	80.35	71.25	63.45	60.45	58.05	64.15	97.25	57.00	63.30	79.20	62.20	111.35	63.10	78.70	72.34
PAN 185	1	83.3	68.05	64.65	75.90	76.10	72.00	60.50	61.35	69.65	63.55	47.93	68.40	62.25	111.85	53.35	76.70	69.72
PAN 185	2	75.6	64.45	68.15	65.45	70.30	71.20	48.40	62.25	82.60	66.25	44.80	67.75	62.25	103.25	54.05	69.15	67.24
PAN 185	3	73.45	63.50	80.45	76.10	68.05	63.20	52.00	60.15	67.40	69.55	51.05	65.55	68.40	118.00	54.35	72.70	68.99
Teebus	1	101.20	64.25	86.35	74.80	99.5	92.00	66.65	49.60	112.10	60.00	109.45	71.80	70.35	59.30	63.70	75.10	78.51
Teebus	2	101.60	63.70	79.05	64.05	97.35	91.00	59.60	55.00	106.70	76.50	102.55	66.20	70.35	80.15	53.70	75.75	77.70
Teebus	3	106.45	70.85	89.85	78.55	104.40	93.30	59.60	50.60	115.55	61.15	81.75	84.15	89.90	75.65	63.95	83.25	81.81
Teebus RR1	1	78.25	99.20	74.35	71.90	85.55	79.35	54.40	50.60	78.60	72.95	91.60	70.85	76.75	72.05	58.35	74.70	74.34
Teebus RR1	2	76.55	71.15	76.75	65.25	94.95	74.00	56.40	54.80	96.35	69.65	94.40	63.30	62.75	87.3	54.55	87.00	74.07
Teebus RR1	3	72.85	67.50	65.10	62.15	94.25	53.60	54.60	59.50	106.15	65.20	61.55	63.00	72.35	96.00	57.15	72.40	70.21
Mean		84.91	70.20	75.47	70.23	83.825	73.25	57.86	57.36	91.54	65.50	77.34	69.18	69.20	94.84	58.33	76.34	
Min		72.85	61.25	64.65	62.15	63.45	53.60	48.40	49.60	67.40	57.00	44.80	63.00	62.20	59.30	52.95	69.15	
Max		106.45	99.20	89.85	78.55	104.40	93.30	68.65	64.15	115.55	76.50	109.45	84.15	89.90	118.00	70.70	87.00	
Range		33.60	37.95	25.20	16.40	40.95	39.70	20.25	14.55	48.15	19.50	64.65	21.15	27.70	58.70	17.75	17.85	

cultivar (n = 4); replicate (n = 3); localities (n = 16), % CV = 10.15

Table 4.12.2 Texture (kg.100 g^{-1}.12 s^{-1}) 14 days after canning of six small white bean cultivars from 17 localities (2002/03 season)

Cultivar	Replicate	Bergville	Bethlehem	Bethal	Cedara	Chrissies-meer	Clocolan	Coligny	Cradock	Delmas	Ermelo	Ficksburg	Greytown	Harrismith	Kokstad	Lichten-burg	Reitz	Vryheid	Mean
PAN 120	1	86.20	81.00	86.65	81.45	62.35	50.10	56.25	43.00	48.70	62.70	57.60	49.50	87.05	65.65	51.25	70.00	75.73	65.60
PAN 120	2	75.73	81.05	96.70	62.45	69.10	53.55	41.70	40.35	57.30	66.95	63.10	59.30	76.90	61.50	45.50	62.15	70.35	63.75
PAN 120	3	89.15	71.65	97.75	54.40	73.05	54.65	58.65	41.15	59.45	68.85	56.85	63.00	74.55	59.55	50.50	60.05	81.10	65.55
PAN 121	1	81.10	126.75	126.70	66.75	84.80	81.90	130.55	39.05	75.30	89.45	65.70	51.95	85.55	67.30	42.45	115.48	91.05	83.64
PAN 121	2	96.80	156.85	117.10	62.50	92.35	62.40	123.45	39.35	78.60	86.40	82.60	56.45	84.40	64.75	43.95	130.35	96.50	86.75
PAN 121	3	87.85	149.95	123.40	71.80	74.65	77.55	116.35	39.20	69.15	99.70	67.40	62.40	89.15	71.15	41.75	100.60	101.95	84.94
PAN 123	1	87.70	84.40	83.50	61.70	75.15	58.90	56.60	46.15	54.70	75.35	49.30	45.90	64.10	70.35	49.75	71.55	63.45	64.62
PAN 123	2	63.45	87.85	84.98	90.80	84.40	48.65	50.95	46.15	58.33	69.50	75.55	63.75	68.20	57.45	44.40	80.65	64.55	67.04
PAN 123	3	86.25	86.13	86.45	61.05	70.45	53.55	53.78	46.15	61.95	58.10	60.40	64.15	56.80	88.35	52.20	63.70	68.60	65.77
PAN 185	1	80.60	74.00	113.90	79.30	70.65	68.35	64.40	56.85	63.35	50.55	68.80	68.00	94.25	64.35	59.90	78.80	67.65	71.98
PAN 185	2	77.90	83.85	107.45	89.55	57.30	71.80	61.40	48.85	68.15	80.90	55.85	64.75	81.55	68.00	52.25	84.70	79.15	72.55
PAN 185	3	79.15	85.15	113.00	74.80	63.98	71.45	66.70	46.50	65.75	78.50	62.33	59.50	69.55	72.50	51.45	71.70	81.00	71.35
Teebus	1	81.00	70.10	132.73	75.95	80.50	70.20	68.08	45.35	57.65	70.30	64.30	61.45	86.05	67.35	82.65	72.60	64.45	73.57
Teebus	2	64.45	91.70	143.55	76.40	73.40	63.70	68.90	44.80	63.50	78.10	62.20	70.30	78.25	68.00	67.80	93.90	76.50	75.61
Teebus	3	90.55	80.90	121.90	64.55	77.75	65.10	73.50	53.30	60.05	74.45	71.45	62.95	73.30	65.40	74.20	86.00	82.40	75.16
Teebus RR1	1	82.40	125.65	90.45	67.90	78.35	70.00	62.80	42.58	62.85	70.60	53.15	61.25	90.50	65.45	63.65	72.15	60.20	71.76
Teebus RR1	2	73.30	149.60	91.28	88.10	66.55	68.90	55.85	43.10	55.45	70.15	75.50	49.85	80.85	54.30	62.90	84.20	69.25	72.89
Teebus RR1	3	73.75	137.63	92.10	59.40	86.80	61.35	59.33	42.05	59.00	66.75	66.45	51.45	76.60	63.90	64.40	71.60	67.95	70.62
Mean		84.80	101.34	106.09	71.60	74.53	64.01	70.55	44.66	62.18	73.18	64.36	59.22	78.76	66.41	55.61	81.68	75.66	
Min		75.66	70.10	83.50	54.40	57.30	48.65	41.70	39.05	48.70	50.55	49.30	45.90	56.80	54.30	41.75	60.05	60.20	
Max		60.20	156.85	143.55	90.80	92.35	81.90	130.55	56.85	78.60	99.70	82.60	70.30	94.25	88.35	82.65	130.35	101.95	
Range		23.50	86.75	60.05	36.40	35.05	33.25	88.85	17.80	29.90	49.15	33.30	24.40	37.45	34.05	40.90	70.30	41.75	

cultivar (n = 6); replicate (n = 3); localities (n = 17), % CV = 9.71

Table 4.13.1 Clumping (scale 1 to 3) 14 days after canning of four small white bean cultivars from 16 localities (2001/02 season)

Cultivar	Replicate	Arnot	Bergville	Clocolan	Coligny	Delmas	Ermelo	Harrismith	Koedoes-kop	Kroonstad	Lichten-burg	Maseru	Potchef-stroom	Reitz	Syferbult	Ukulinga	Wildebees-fontein	Mean
OPS-KW1	1	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
OPS-KW1	2	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
OPS-KW1	3	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
PAN 185	1	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
PAN 185	2	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
PAN 185	3	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Teebus	1	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Teebus	2	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Teebus	3	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Teebus RR1	1	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Teebus RR1	2	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Teebus RR1	3	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Mean		3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	
Min		3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	
Max		3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	
Range		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	

cultivar (n = 4); replicate (n = 3); localities (n = 16), % CV = no variation in data

Table 4.13.2 Clumping (scale 1 to 3) 14 days after canning of six small white bean cultivars from 17 localities (2002/03 season)

Cultivar	Replicate	Bergville	Bethlehem	Bethal	Cedara	Chrissies-meer	Clocolan	Coligny	Cradock	Delmas	Ermelo	Ficksburg	Greytown	Harrismith	Kokstad	Lichten-burg	Reitz	Vryheid	Mean
PAN 120	1	3.00	3.00	3.00	3.00	3.00	2.00	3.00	2.00	2.00	3.00	3.00	2.00	2.00	3.00	3.00	3.00	2.00	2.65
PAN 120	2	3.00	3.00	3.00	3.00	2.00	3.00	2.00	1.00	3.00	3.00	3.00	3.00	2.00	2.00	3.00	2.00	3.00	2.59
PAN 120	3	3.00	3.00	3.00	3.00	2.00	3.00	2.00	1.00	3.00	3.00	3.00	3.00	2.00	2.00	3.00	3.00	3.00	2.65
PAN 121	1	3.00	3.00	3.00	3.00	3.00	2.00	3.00	3.00	2.00	3.00	3.00	3.00	2.00	3.00	2.00	3.00	2.00	2.71
PAN 121	2	3.00	3.00	3.00	2.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	3.00	2.00	3.00	2.71
PAN 121	3	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.00	2.00	3.00	3.00	2.88
PAN 123	1	3.00	3.00	2.00	3.00	3.00	3.00	2.00	2.00	2.00	3.00	3.00	2.00	2.00	2.00	2.00	2.00	2.00	2.41
PAN 123	2	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.00	3.00	2.00	3.00	2.88
PAN 123	3	2.00	3.00	3.00	2.00	3.00	3.00	2.00	2.00	2.00	3.00	3.00	3.00	2.00	3.00	2.00	2.00	3.00	2.53
PAN 185	1	3.00	3.00	3.00	3.00	3.00	2.00	2.00	2.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.82
PAN 185	2	3.00	3.00	3.00	3.00	3.00	2.00	2.00	3.00	2.00	3.00	3.00	3.00	2.00	3.00	3.00	3.00	3.00	2.76
PAN 185	3	2.00	3.00	3.00	2.00	3.00	3.00	3.00	1.00	3.00	3.00	3.00	3.00	2.00	3.00	2.00	3.00	3.00	2.65
Teebus	1	2.00	2.00	3.00	3.00	3.00	2.00	2.00	3.00	3.00	3.00	3.00	2.00	3.00	3.00	2.00	3.00	3.00	2.65
Teebus	2	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.00	3.00	3.00	2.00	3.00	3.00	2.88
Teebus	3	2.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.94
Teebus RR1	1	3.00	3.00	3.00	2.00	3.00	3.00	2.00	2.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.82
Teebus RR1	2	3.00	3.00	3.00	3.00	3.00	3.00	2.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	2.00	3.00	3.00	2.88
Teebus RR1	3	3.00	3.00	3.00	2.00	3.00	2.00	3.00	2.00	3.00	3.00	3.00	2.00	3.00	3.00	2.00	3.00	3.00	2.71
Mean		2.78	2.94	2.94	2.72	2.89	2.67	2.50	2.33	2.72	3.00	3.00	2.67	2.50	2.67	2.50	2.72	2.83	
Min		2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.00	2.00	3.00	3.00	2.00	2.00	2.00	2.00	2.00	2.00	
Max		3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	
Range		1.00	1.00	1.00	1.00	1.00	1.00	1.00	2.00	1.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	

cultivar (n = 6); replicate (n = 3); localities (n = 17), % CV = 14.9

Table 4.14.1 L-values 14 days after canning of four small white bean cultivars from 16 localities (2001/02 season)

Cultivar	Replicate	Arnot	Bergville	Clocolan	Coligny	Delmas	Ermelo	Harrismith	Koedoes-kop	Kroonstad	Lichten-burg	Maseru	Potchef-stroom	Reitz	Syferbult	Ukulinga	Wildebees-fontein	Mean
OPS-KW1	1	41.99	40.84	41.89	43.48	42.72	42.55	43.51	47.06	46.74	44.43	39.80	43.89	43.82	42.55	41.35	42.19	43.05
OPS-KW1	2	41.89	39.77	44.12	44.02	42.70	43.46	42.97	50.22	44.55	45.62	39.70	44.80	43.45	43.34	41.79	41.95	43.40
OPS-KW1	3	41.06	40.13	44.80	44.30	43.06	45.39	44.01	46.09	45.13	44.59	41.00	44.56	42.77	42.16	40.76	43.24	43.32
PAN 185	1	42.41	41.34	44.95	44.29	43.53	46.66	44.54	43.15	47.04	46.71	40.82	43.31	44.81	43.59	44.70	43.64	44.09
PAN 185	2	42.67	40.57	41.53	46.01	44.35	44.86	44.46	43.79	46.18	43.43	40.92	45.61	44.99	43.63	45.01	43.26	43.83
PAN 185	3	42.80	40.19	45.70	47.72	44.52	45.05	44.10	47.96	46.79	45.07	40.58	45.27	45.15	43.41	45.48	43.59	44.59
Teebus	1	39.15	39.81	41.71	41.81	40.57	43.65	42.04	46.81	43.53	44.54	39.23	43.29	40.02	41.04	41.90	42.46	41.97
Teebus	2	39.31	40.15	41.29	43.46	41.06	44.45	41.65	50.70	44.57	43.05	41.08	44.36	40.89	42.93	42.17	42.53	42.73
Teebus	3	40.02	39.16	44.34	43.99	41.94	41.08	41.72	50.10	40.84	42.06	41.91	44.24	40.54	42.98	42.13	41.94	42.44
Teebus RR1	1	40.37	40.79	42.92	43.55	41.04	44.36	42.97	47.51	44.33	44.20	40.56	45.84	38.92	41.87	40.47	41.95	42.60
Teebus RR1	2	40.05	40.78	41.04	41.88	41.58	41.96	42.38	47.79	42.23	42.07	39.98	43.41	39.84	41.83	40.43	41.66	41.81
Teebus RR1	3	37.84	40.24	43.71	46.90	41.48	41.40	41.48	47.17	43.13	44.68	37.22	43.78	41.96	42.51	41.15	41.59	42.27
Mean		40.80	40.31	43.17	44.28	42.38	43.74	42.99	47.36	44.59	44.20	40.23	44.36	42.26	42.65	42.28	42.50	
Min		37.84	39.16	41.04	41.81	40.57	41.08	41.48	43.15	40.84	42.06	37.22	43.29	38.92	41.04	40.43	41.59	
Max		42.80	41.34	45.70	47.72	44.52	46.66	44.54	50.70	47.04	46.71	41.91	45.84	45.15	43.63	45.48	43.64	
Range		4.96	2.18	4.66	5.91	3.95	5.58	3.06	7.55	6.20	4.65	4.69	2.55	6.23	2.59	5.05	2.05	

cultivar (n = 4); replicate (n = 3); localities (n = 16), % CV = 2.62

Table 4.14.2 L- values 14 days after canning of six small white bean cultivars from 17 localities (2002/03 season)

Cultivar	Replicate	Bergville	Bethlehem	Bethal	Cedara	Chrissies-meer	Clocolan	Coligny	Cradock	Delmas	Ermelo	Ficksburg	Greytown	Harrismith	Kokstad	Lichten-burg	Reitz	Vryheid	Mean
PAN 120	1	45.67	44.39	42.91	45.09	43.57	47.41	44.99	44.70	45.44	44.97	47.34	42.43	45.05	45.61	46.32	45.75	45.31	45.11
PAN 120	2	46.18	46.89	43.89	44.13	44.26	47.07	46.52	47.50	45.49	45.18	47.08	40.59	46.38	45.15	46.35	45.81	45.62	45.53
PAN 120	3	43.92	42.74	43.86	46.05	44.66	46.93	45.57	47.84	45.25	45.14	47.13	41.66	45.72	44.69	43.74	45.25	45.77	45.05
PAN 121	1	45.71	45.48	41.43	46.24	43.54	45.70	42.43	46.32	42.25	43.55	44.82	39.95	43.48	45.03	44.06	43.39	44.10	43.97
PAN 121	2	42.10	45.21	41.64	43.09	42.19	45.70	44.00	45.08	44.71	43.07	42.64	40.39	42.84	44.67	44.47	45.36	43.55	43.57
PAN 121	3	43.04	45.93	43.12	41.89	44.61	44.44	47.65	45.72	43.07	43.54	43.93	39.09	43.59	44.30	42.57	44.11	43.53	43.77
PAN 123	1	42.59	44.12	43.68	43.95	43.15	46.52	44.15	46.66	45.03	44.20	46.83	41.11	44.10	43.49	45.45	44.50	43.74	44.31
PAN 123	2	46.02	44.81	43.01	44.39	43.28	45.24	46.13	46.45	43.87	43.50	46.41	41.04	45.88	43.20	44.99	45.15	45.08	44.61
PAN 123	3	44.92	45.98	41.03	45.00	45.67	46.11	45.78	46.26	43.42	42.89	45.66	39.70	43.60	42.91	44.04	45.21	43.42	44.21
PAN 185	1	45.94	48.48	44.99	46.55	43.98	48.35	44.91	47.91	46.25	46.46	46.61	43.36	45.02	46.24	46.56	47.49	44.93	46.12
PAN 185	2	45.45	47.79	43.99	44.34	43.87	47.99	47.59	47.85	46.84	46.08	46.86	43.23	46.67	46.34	46.40	46.93	45.60	46.11
PAN 185	3	45.85	47.21	42.14	44.75	44.88	48.45	45.58	46.92	46.07	46.36	46.22	42.31	46.94	46.43	46.16	47.76	45.87	45.88
Teebus	1	45.26	45.68	41.53	43.91	45.85	42.98	44.80	45.68	45.35	43.69	45.44	42.18	44.71	45.25	45.92	44.97	44.48	44.57
Teebus	2	44.76	47.92	41.76	46.20	42.10	45.10	43.01	44.99	45.11	42.77	45.91	41.32	43.41	44.52	43.89	44.38	46.75	44.35
Teebus	3	44.78	44.34	41.05	43.78	44.07	45.92	45.33	46.62	44.78	44.24	45.05	41.50	44.58	44.89	44.89	45.49	42.95	44.37
Teebus RR1	1	43.56	43.38	41.25	44.38	44.74	43.39	44.85	46.68	45.39	44.26	47.17	42.22	43.04	45.73	44.88	43.79	44.95	44.33
Teebus RR1	2	43.38	45.48	41.96	45.13	42.72	45.98	43.81	46.87	44.65	43.29	45.64	40.21	43.66	45.23	45.03	45.19	44.36	44.27
Teebus RR1	3	44.38	44.62	45.58	44.99	43.37	46.27	44.34	44.97	44.42	44.07	45.12	40.60	43.96	44.79	45.05	45.43	42.74	44.39
Mean		44.64	45.58	42.71	44.66	43.92	46.09	45.08	46.39	44.86	44.29	45.88	41.27	44.59	44.91	45.04	45.33	44.60	
Min		42.10	42.74	41.03	41.89	42.10	42.98	42.43	44.70	42.25	42.77	42.64	39.09	42.84	42.91	42.57	43.39	42.74	
Max		46.18	48.48	45.58	46.55	45.85	48.45	47.65	47.91	46.84	46.46	47.34	43.36	46.94	46.43	46.56	47.76	46.75	
Range		4.08	5.74	4.55	4.66	3.75	5.47	5.22	3.21	4.59	3.69	4.70	4.27	4.10	3.52	3.99	4.37	4.01	

cultivar (n = 6); replicate (n = 3); localities (n = 17), % CV = 2.22

Table 4.15.1 The a_L- values 14 days after canning of four small white bean cultivars from 16 localities (2001/02 season)

Cultivar	Replicate	Arnot	Bergville	Clocolan	Coligny	Delmas	Ermelo	Harrismith	Koedoes-kop	Kroonstad	Lichten-burg	Maseru	Potchef-stroom	Reitz	Syferbult	Ukulinga	Wildebees-fontein	Mean
OPS-KW1	1	9.93	10.30	10.62	9.33	9.57	9.53	9.73	8.81	7.96	9.29	10.18	9.82	9.56	9.04	9.21	9.49	9.52
OPS-KW1	2	9.86	10.52	9.61	9.17	9.64	9.39	9.99	7.40	9.13	8.75	10.75	9.23	9.66	8.56	9.39	9.28	9.43
OPS-KW1	3	10.04	10.35	9.12	9.21	9.23	8.53	9.47	8.80	8.92	9.33	9.93	9.33	9.82	9.22	9.00	9.54	9.35
PAN 185	1	9.45	9.52	9.27	8.68	8.95	7.85	9.20	9.86	7.70	8.28	10.20	10.11	9.05	8.71	9.13	9.01	9.08
PAN 185	2	9.27	9.98	10.30	8.06	8.75	8.88	8.93	9.87	8.54	9.37	9.79	9.15	8.76	8.60	9.30	9.31	9.21
PAN 185	3	9.50	9.90	9.03	7.44	8.52	8.88	9.01	8.29	7.99	8.83	10.26	9.33	8.85	8.53	8.97	8.95	8.92
Teebus	1	10.82	10.88	10.54	9.54	10.72	8.64	9.01	8.53	9.22	9.23	9.71	10.07	10.68	9.83	9.21	9.73	9.72
Teebus	2	10.79	10.39	10.52	9.29	10.39	8.42	9.97	7.25	8.76	9.73	10.14	9.68	10.69	9.09	9.19	9.79	9.63
Teebus	3	10.66	10.21	9.56	9.31	9.83	10.49	9.95	7.12	10.27	9.83	9.43	9.56	10.66	9.38	9.27	9.47	9.67
Teebus RR1	1	10.22	10.29	10.22	9.14	10.26	8.57	9.15	8.52	8.48	9.18	9.87	8.77	10.01	9.19	9.35	9.86	9.43
Teebus RR1	2	10.40	10.10	10.48	9.22	9.18	9.98	9.64	8.59	10.09	9.93	9.85	10.23	10.07	9.30	9.52	9.46	9.74
Teebus RR1	3	11.35	10.10	9.94	7.68	9.97	9.63	9.75	8.10	9.61	8.93	10.86	9.70	9.64	8.82	9.34	9.60	9.58
Mean		10.19	10.21	9.93	8.84	9.58	9.07	9.48	8.43	8.89	9.22	10.08	9.58	9.79	9.04	9.24	9.46	
Min		9.27	9.52	9.03	7.44	8.52	7.85	8.93	7.12	7.70	8.28	9.43	8.77	8.76	9.04	8.97	8.95	
Max		11.35	10.88	10.62	9.54	10.72	10.49	9.99	9.87	10.27	9.93	10.86	10.23	10.69	9.04	9.52	9.86	
Range		2.08	1.36	1.59	2.10	2.20	2.64	1.06	2.75	2.57	1.65	1.43	1.46	1.93	9.04	0.55	0.91	

cultivar (n = 4); replicate (n = 3); localities (n = 16), % CV = 4.93

Table 4.15.2 The a_L- values 14 days after canning of six small white bean cultivars from 17 localities (2002/03 season)

Cultivar	Replicate	Bergville	Bethlehem	Bethal	Cedara	Chrissies-meer	Clocolan	Coligny	Cradock	Delmas	Ermelo	Ficksburg	Greytown	Harrismith	Kokstad	Lichten-burg	Reitz	Vryheid	Mean
PAN 120	1	8.50	8.90	9.16	8.83	9.41	8.29	9.26	8.61	9.34	8.59	8.07	9.66	8.67	8.96	8.37	9.23	8.66	8.85
PAN 120	2	8.34	8.10	8.88	8.51	9.09	8.21	8.82	8.32	8.96	8.29	7.92	9.52	8.37	9.16	8.14	8.87	8.38	8.58
PAN 120	3	9.13	9.31	8.76	9.14	9.00	8.35	9.15	8.25	8.77	8.62	7.81	9.74	8.52	9.36	9.64	9.20	8.40	8.89
PAN 121	1	8.02	8.80	9.32	8.69	9.43	8.78	10.15	8.51	9.76	8.69	8.85	10.16	9.23	8.57	8.63	9.39	8.87	9.05
PAN 121	2	9.58	8.48	9.67	8.99	9.56	8.48	9.87	8.87	8.93	8.70	9.38	9.91	9.39	8.90	9.20	8.87	8.40	9.13
PAN 121	3	9.59	8.29	8.79	9.84	9.33	8.86	8.02	8.48	8.77	8.50	8.90	10.08	8.87	9.23	9.75	9.32	9.13	9.04
PAN 123	1	9.19	8.83	9.21	9.21	9.23	8.46	9.81	8.42	8.60	8.63	8.13	10.22	8.79	9.43	8.55	9.09	8.95	8.99
PAN 123	2	8.62	8.63	9.17	8.24	9.29	8.83	9.25	8.07	9.29	8.85	8.02	9.91	8.70	9.57	8.70	8.75	8.38	8.84
PAN 123	3	8.75	8.04	9.73	9.23	8.49	8.62	9.37	8.42	9.40	9.54	8.49	10.38	8.77	9.71	8.73	8.76	9.18	9.04
PAN 185	1	8.23	7.41	8.31	8.04	9.07	7.99	8.60	8.01	8.73	7.86	8.14	9.04	8.95	8.34	8.96	8.46	8.71	8.40
PAN 185	2	8.58	7.52	8.66	8.67	9.18	7.76	8.22	7.95	8.39	8.09	7.92	9.14	8.29	8.37	8.75	8.47	7.31	8.31
PAN 185	3	8.23	7.71	9.25	9.15	8.79	7.54	9.01	8.75	8.33	7.96	8.34	9.52	8.40	8.40	8.74	7.88	8.23	8.48
Teebus	1	8.44	8.41	9.62	9.25	8.14	9.60	9.73	8.51	8.60	8.97	8.76	9.90	9.10	8.64	8.25	8.95	9.07	8.94
Teebus	2	8.81	7.74	9.32	8.26	9.72	8.60	9.74	8.80	8.79	9.19	8.45	9.95	9.16	9.43	9.06	9.54	8.59	9.01
Teebus	3	8.76	8.96	9.46	9.45	9.31	8.69	9.33	8.39	8.81	8.56	8.49	10.37	8.86	9.04	8.84	8.64	9.44	9.02
Teebus RR1	1	9.13	8.77	9.68	9.17	8.55	9.28	9.57	8.59	8.32	8.27	8.20	10.05	9.33	8.31	8.96	9.58	8.52	8.96
Teebus RR1	2	8.83	8.95	9.18	7.99	9.49	8.24	9.35	8.44	9.06	8.79	8.51	10.17	9.23	8.88	9.02	9.24	8.89	8.96
Teebus RR1	3	8.69	8.46	8.47	9.05	9.23	8.56	9.21	9.12	9.02	8.66	8.48	10.61	9.47	9.17	8.81	8.90	9.55	9.03
Mean		8.75	8.41	9.15	8.87	9.13	8.51	9.25	8.47	8.88	8.60	8.38	9.91	8.89	8.97	8.84	8.95	8.70	
Min		8.02	7.41	8.31	7.99	8.14	7.54	8.02	7.95	8.32	7.86	7.81	9.04	8.29	8.31	8.14	7.88	7.31	
Max		9.59	9.31	9.73	9.84	9.72	9.60	10.15	9.12	9.76	9.54	9.38	10.61	9.47	9.71	9.75	9.58	9.55	
Range		1.57	1.90	1.42	1.85	1.58	2.06	2.13	1.17	1.44	1.68	1.57	1.57	1.18	1.40	1.61	1.70	2.24	

cultivar (n = 6); replicate (n = 3); localities (n = 17), % CV = 4.29

Table 4.16.1 The b_L- values 14 days after canning of four small white bean cultivars from 16 localities (2001/02 season)

Cultivar	Replicate	Arnot	Bergville	Clocolan	Coligny	Delmas	Ermelo	Harrismith	Koedoes-kop	Kroonstad	Lichten-burg	Maseru	Potchef-stroom	Reitz	Syferbult	Ukulinga	Wildebees-fontein	Mean
OPS-KW1	1	15.72	15.54	17.02	16.03	16.00	16.36	16.70	16.90	15.16	16.40	15.72	16.47	16.42	16.03	15.59	15.55	16.10
OPS-KW1	2	15.79	14.90	16.69	16.14	16.00	16.28	16.56	16.76	16.48	16.48	15.79	16.65	16.22	16.06	15.92	15.24	16.12
OPS-KW1	3	15.83	15.21	16.96	16.18	16.10	16.36	16.93	16.52	16.65	16.59	15.83	16.55	15.98	15.82	15.33	15.70	16.16
PAN 185	1	16.09	15.62	17.14	16.44	16.25	16.80	16.80	16.02	15.71	16.75	16.09	16.90	16.82	16.56	17.01	16.19	16.45
PAN 185	2	16.17	15.31	16.80	16.15	16.46	16.82	16.43	16.39	17.18	16.58	16.17	17.05	16.47	16.62	17.11	15.95	16.48
PAN 185	3	16.04	15.09	17.39	15.86	16.39	17.05	16.71	16.63	15.72	16.67	16.04	17.14	16.52	16.31	17.09	16.25	16.43
Teebus	1	15.79	15.89	16.86	16.50	16.78	16.22	16.17	16.63	16.86	16.96	15.79	17.00	16.70	16.48	16.18	16.26	16.44
Teebus	2	16.40	15.83	16.60	16.66	16.87	16.44	16.60	16.89	15.31	16.89	16.40	16.84	17.12	16.72	16.45	15.96	16.50
Teebus	3	16.50	15.18	16.62	16.60	16.88	16.46	16.48	16.48	16.22	16.71	16.50	17.18	17.04	15.84	16.41	15.87	16.44
Teebus RR1	1	16.29	16.21	17.13	16.80	16.69	16.56	16.53	16.41	14.83	16.86	16.29	16.95	15.88	16.57	16.11	15.75	16.37
Teebus RR1	2	15.84	15.98	16.54	15.97	16.63	16.81	16.54	16.58	16.64	16.59	15.84	17.05	16.15	16.33	16.12	15.65	16.33
Teebus RR1	3	15.27	15.41	16.78	15.65	16.29	16.39	16.10	16.51	17.02	16.98	15.27	16.95	16.28	15.63	16.22	15.63	16.15
Mean		15.98	15.51	16.88	16.25	16.45	16.55	16.55	16.56	16.15	16.70	15.98	16.89	16.47	16.25	16.30	15.83	
Min		15.27	14.90	16.54	15.65	16.00	16.22	16.10	16.02	14.83	16.40	15.27	16.47	15.88	15.63	15.33	15.24	
Max		16.50	16.21	17.39	16.80	16.88	17.05	16.93	16.90	17.18	16.98	16.50	17.18	17.12	16.72	17.11	16.26	
Range		1.23	1.31	0.85	1.15	0.88	0.83	0.83	0.88	2.35	0.58	1.23	0.71	1.24	1.09	1.78	1.02	

cultivar (n = 4); replicate (n = 3); localities (n = 16), % CV = 2.02

Table 4.16.2 The b_L- values 14 days after canning of six small white bean cultivars from 17 localities (2002/03 season)

Cultivar	Replicate	Bergville	Bethlehem	Bethal	Cedara	Chrissies-meer	Clocolan	Coligny	Cradock	Delmas	Ermelo	Ficksburg	Greytown	Harrismith	Kokstad	Lichten-burg	Reitz	Vryheid	Mean
PAN 120	1	16.80	16.68	16.13	16.78	16.64	17.18	16.55	17.14	16.88	16.92	16.82	16.49	16.52	16.61	16.43	16.82	16.07	16.67
PAN 120	2	17.20	16.76	16.33	16.31	16.42	16.41	16.72	16.63	16.78	16.40	16.84	16.40	17.25	16.78	16.67	16.64	16.18	16.63
PAN 120	3	16.71	16.58	16.17	17.25	16.87	16.50	16.70	16.53	16.37	16.55	16.76	16.54	16.89	16.94	16.33	16.65	16.48	16.64
PAN 121	1	16.56	16.72	16.01	17.40	16.93	17.40	16.30	16.77	16.32	16.65	16.56	16.09	16.73	16.87	16.15	16.42	16.31	16.60
PAN 121	2	16.81	17.17	15.81	16.48	16.24	16.60	16.74	16.40	16.87	16.16	16.25	16.11	16.57	17.06	16.27	17.09	16.00	16.51
PAN 121	3	17.07	16.70	16.03	16.74	16.80	16.48	16.38	16.63	15.99	16.33	16.34	16.11	16.53	17.25	16.21	16.94	16.54	16.53
PAN 123	1	16.37	16.86	16.67	16.91	16.93	17.14	16.67	17.00	17.02	16.80	16.84	16.33	16.41	16.68	16.22	16.67	16.40	16.70
PAN 123	2	17.48	16.53	16.37	16.26	16.85	16.67	16.94	16.86	16.96	16.52	16.91	16.54	17.26	16.68	16.32	16.84	16.54	16.74
PAN 123	3	17.10	16.95	15.87	17.25	16.81	16.59	16.91	16.92	16.52	16.59	16.71	16.16	16.40	16.68	16.05	16.79	16.50	16.64
PAN 185	1	16.38	16.68	16.37	16.85	16.52	16.90	16.01	17.10	16.69	16.97	16.62	16.44	16.79	16.40	16.64	16.86	16.03	16.60
PAN 185	2	16.75	16.59	16.04	16.14	16.59	16.70	16.24	16.97	16.86	16.72	16.75	16.59	16.82	16.66	16.52	16.72	15.68	16.55
PAN 185	3	17.05	16.39	15.94	16.80	16.51	16.66	16.76	16.61	16.84	16.67	16.63	16.47	16.71	16.92	16.57	16.56	16.31	16.61
Teebus	1	16.51	16.70	15.85	16.77	16.25	16.54	16.77	16.70	16.55	16.57	16.50	16.49	16.79	16.16	16.47	16.55	16.35	16.50
Teebus	2	16.73	16.83	16.02	16.50	16.44	16.02	16.21	16.80	16.57	16.33	16.48	16.20	16.34	16.86	16.21	16.47	16.33	16.43
Teebus	3	16.88	16.55	15.78	16.71	16.67	16.58	16.83	16.47	16.67	16.48	16.51	16.66	16.67	16.51	16.10	16.59	16.20	16.52
Teebus RR1	1	16.17	16.44	15.75	16.76	16.12	16.48	16.75	16.54	16.43	16.33	16.71	16.46	16.42	16.30	16.29	16.39	16.28	16.39
Teebus RR1	2	16.51	16.90	16.02	16.34	16.50	16.17	16.39	16.47	16.71	16.27	16.47	15.92	16.38	16.92	16.28	16.54	16.40	16.42
Teebus RR1	3	16.74	16.51	16.44	16.99	16.59	16.33	16.99	16.68	16.57	16.36	16.40	16.42	16.62	16.85	16.52	16.68	16.12	16.58
Mean		16.77	16.70	16.09	16.74	16.59	16.63	16.60	16.73	16.64	16.53	16.62	16.36	16.67	16.73	16.35	16.68	16.26	
Min		16.17	16.39	15.75	16.14	16.12	16.02	16.01	16.40	15.99	16.16	16.25	15.92	16.34	16.16	16.05	16.39	15.68	
Max		17.48	17.17	16.67	17.40	16.93	17.40	16.99	17.14	17.02	16.97	16.91	16.66	17.26	17.25	16.67	17.09	16.54	
Range		1.31	0.78	0.92	1.26	0.81	1.38	0.98	0.74	1.03	0.81	0.66	0.74	0.92	1.09	0.62	0.70	0.86	

cultivar (n = 6); replicate (n = 3); localities (n = 17), % CV = 1.48

Table 4.17.1 Viscosity (cP) 14 days after canning of four small white bean cultivars from 16 localities (2001/02 season)

Cultivar	Replicate	Arnot	Bergville	Clocolan	Coligny	Delmas	Ermelo	Harrismith	Koedoes-kop	Kroonstad	Lichten-burg	Maseru	Potchef-stroom	Reitz	Syferbult	Ukulinga	Wildebees-fontein	Mean
OPS-KW1	1	1120.50	1872.50	1698.25	1654.00	1812.00	3040.00	2032.00	3109.00	1017.00	2886.50	2983.50	2779.00	7038.00	1836.50	7759.50	1943.50	2786.36
OPS-KW1	2	1223.00	2716.00	1908.00	1745.00	1922.00	2242.50	1679.00	3003.00	972.50	3255.00	2454.50	3252.50	7035.50	1622.75	7255.00	1661.00	2746.70
OPS-KW1	3	1155.00	1247.50	1488.50	1467.50	2001.00	2954.50	1963.50	2897.00	1152.50	4208.00	1770.00	2582.50	7033.00	1482.00	7945.00	1878.50	2701.63
PAN 185	1	1541.00	6005.50	1359.50	2620.50	2265.00	2644.50	2296.50	7384.00	1990.50	2692.50	4233.00	2636.50	2306.00	2003.50	3375.00	2161.50	2969.69
PAN 185	2	1636.50	5014.50	1481.00	2427.50	2427.50	2065.00	2969.50	5089.50	1508.00	2868.50	3633.00	2207.50	2802.00	3726.00	3322.00	2213.50	2836.97
PAN 185	3	1510.00	5510.00	1238.00	2230.50	2248.00	2977.50	2136.50	6717.50	1494.00	2291.50	3691.50	2636.50	3621.00	3886.50	3339.50	2511.00	3002.47
Teebus	1	1507.50	1738.90	1487.50	1625.00	2057.00	2590.50	1987.50	1714.75	1971.00	2163.50	1396.50	2615.00	2642.00	1381.00	5105.00	1849.50	2114.51
Teebus	2	1725.00	1774.95	1929.00	1762.50	2289.00	3639.50	2190.00	1888.50	1973.00	2581.00	1620.50	2580.50	2839.50	1956.50	5370.00	1689.00	2363.03
Teebus	3	1396.00	1811.00	2172.00	1725.00	2589.00	3887.00	1903.50	1541.00	1689.50	2717.00	1714.00	2491.00	2779.00	1666.50	5635.00	1558.00	2329.66
Teebus RR1	1	1822.50	1594.50	2725.25	2867.00	2922.50	2608.00	2150.25	2382.50	1351.00	3860.50	2339.50	2972.50	2629.00	2168.50	3871.50	1876.00	2508.81
Teebus RR1	2	1466.50	1750.00	2776.50	2930.00	2167.00	3428.00	2292.50	1757.50	1221.00	4031.00	2343.50	2551.00	2742.50	1750.00	3174.50	1869.00	2390.66
Teebus RR1	3	1670.00	1430.50	2674.00	2750.00	1852.50	2423.00	2008.00	2291.00	1215.00	3893.50	2896.00	2455.00	2086.50	1181.00	3073.50	1971.50	2241.94
Mean		1481.13	2705.49	1911.46	2150.38	2212.71	2875.00	2134.06	3314.60	1507.50	3120.71	2589.63	2646.63	3796.17	2055.06	4935.46	1931.83	
Min		1120.50	1247.50	1238.00	1467.50	1812.00	2065.00	1679.00	1541.00	972.50	2163.50	1396.50	2207.50	2086.50	1181.00	3073.50	1558.00	
Max		1822.50	6005.50	2776.50	2930.00	2922.50	3887.00	2969.50	7384.00	1990.50	4208.00	4233.00	3252.50	7038.00	3886.50	7945.00	2511.00	
Range		702.00	4758.00	1538.50	1462.50	1110.50	1822.00	1290.50	5843.00	1018.00	2044.50	2836.50	1045.00	4951.50	2705.50	4871.50	953.00	

cultivar (n = 4); replicate (n = 3); localities (n = 16), % CV = 14.33

Table 4.17.2 Viscosity (cP) 14 days after canning of six small white bean cultivars from 17 localities (2002/03 season)

Cultivar	Replicate	Bergville	Bethlehem	Bethal	Cedara	Chrissies-meer	Clocolan	Coligny	Cradock	Delmas	Ermelo	Ficksburg	Greytown	Harrismith	Kokstad	Lichten-burg	Reitz	Vryheid	Mean
PAN 120	1	910.50	1716.00	1716.00	2037.00	2674.50	2024.43	3428.00	3283.00	2917.00	2588.30	562.00	3172.65	1435.00	1817.50	2024.43	2261.00	1728.50	2135.05
PAN 120	2	936.00	1416.00	1416.00	2837.50	2893.50	2122.90	3342.50	2363.50	2274.00	2683.85	636.00	3480.40	1170.50	2125.00	2122.90	2312.00	1742.50	2110.30
PAN 120	3	923.25	1648.00	1648.00	2113.50	2950.50	1925.95	3204.00	2871.00	2235.50	2288.65	488.00	3675.75	1590.00	2515.00	1925.95	2959.00	1767.00	2160.53
PAN 121	1	1530.00	1271.00	1271.00	3130.00	2050.50	2548.30	4633.50	2677.00	3624.50	2423.85	2903.50	2221.05	1711.50	1928.00	2548.30	3365.50	3816.00	2567.85
PAN 121	2	1106.50	1395.00	1395.00	3341.00	1848.25	2223.65	4266.75	2838.50	3612.50	1864.20	2145.00	2109.90	2058.00	2455.00	2223.65	2019.50	3657.00	2385.85
PAN 121	3	1200.00	1397.00	1333.00	3197.50	1646.00	2310.75	3900.00	2793.00	3742.50	2299.05	1386.50	1998.75	2409.00	2191.50	2310.75	2887.50	3677.50	2392.96
PAN 123	1	1744.00	1640.50	1640.50	2332.00	1492.00	2640.30	3659.50	2570.00	2056.00	2367.95	1815.50	3384.55	1314.00	3290.50	2640.30	3573.50	1442.00	2329.59
PAN 123	2	1177.50	1660.00	1660.00	1794.00	1275.50	2486.90	3883.00	2549.00	1952.00	2497.95	1220.00	3211.98	1860.00	5000.50	2486.90	2459.00	1456.50	2272.40
PAN 123	3	1171.00	1650.25	1650.25	2788.50	1059.00	2810.60	3436.00	2604.00	2361.00	2514.20	918.50	3039.40	1693.50	4018.00	2810.60	3266.00	1493.00	2310.81
PAN 185	1	921.00	1541.00	1541.00	2001.00	1675.00	2018.25	2234.50	3246.50	1955.00	1547.00	1713.00	3132.03	1570.00	2270.00	2018.25	1332.00	1917.00	1919.56
PAN 185	2	1190.00	1371.00	1371.00	901.00	1723.75	2312.70	1978.00	3053.50	2008.50	2130.05	2150.50	3263.00	1114.00	1940.50	2312.70	1386.50	1820.00	1883.92
PAN 185	3	1027.00	1348.50	1348.50	2029.50	1772.50	1898.00	3524.00	3439.50	1981.75	1890.85	1600.00	3001.05	2124.00	3649.50	1898.00	1601.50	1844.50	2116.39
Teebus	1	848.50	1290.00	1290.00	1900.50	1206.50	2718.30	3174.00	2843.00	2660.50	2024.75	2498.00	2296.45	1378.00	2790.00	2718.30	2090.50	1280.50	2059.28
Teebus	2	715.50	1536.00	1536.00	2317.00	1852.00	2865.20	3367.00	3367.00	2886.00	1707.55	2193.50	1901.25	1331.50	2772.00	2865.20	2088.50	1193.50	2146.75
Teebus	3	868.50	1044.00	1044.00	2988.00	1694.00	2137.20	3560.00	2214.50	2773.25	1528.15	2345.75	2098.85	1511.00	2707.50	2137.20	2086.50	1971.50	2041.76
Teebus RR1	1	854.50	1669.00	1669.00	2761.50	1090.50	2350.40	4005.00	3502.50	2219.00	1925.95	2531.50	3413.80	1050.50	2039.00	2350.40	1567.50	1824.00	2166.12
Teebus RR1	2	1117.50	1819.75	1818.25	983.50	2421.50	2564.25	3953.50	3441.00	2299.75	2193.10	2103.00	3533.65	1219.50	2332.00	2564.25	2212.50	1352.00	2231.12
Teebus RR1	3	1395.50	1970.50	1967.50	2436.00	1791.50	2444.35	3910.50	3511.00	2380.50	2202.85	2180.50	3666.00	1529.50	2625.00	2444.35	2133.00	1992.00	2387.09
Mean		1090.93	1521.31	1517.50	2327.17	1839.83	2355.69	3525.54	2953.75	2552.18	2148.79	1743.93	2922.25	1559.42	2692.58	2355.69	2311.19	1998.61	
Min		715.50	1044.00	1044.00	901.00	1059.00	1898.00	1978.00	2214.50	1952.00	1528.15	488.00	1901.25	1050.50	1817.50	1898.00	1332.00	1193.50	
Max		1744.00	1970.50	1967.50	3341.00	2950.50	2865.20	4633.50	3511.00	3742.50	2683.85	2903.50	3675.75	2409.00	5000.50	2865.20	3573.50	3816.00	
Range		1028.50	926.50	923.50	2440.00	1891.50	967.20	2655.50	1296.50	1790.50	1155.70	2415.50	1774.50	1358.50	3183.00	967.20	2241.50	2622.50	

cultivar (n = 6); replicate (n = 3); localities (n = 17), % CV = 14.75

Table 4.18 Mean, minimum and maximum values and the F-values pertaining to main and interaction effects of the canning quality of four small white bean cultivars (2001/02 season) from 16 localities

Canning quality	Mean	Minimum	Maximum	F-value			
				Cultivar (df = 3)	Locality (df = 15)	Replicates (df = 2)	Cultivar x locality (df = 45)
Hydration coefficient	1.76	1.32	2.10	502.91***	97.38***	0.33ns	10.05***
Washed drained weight (%)	55.40	50.84	60.95	22.09***	37.76***	1.71ns	1.68*
Visual appearance (1 to 10)	9.47	6.00	10.00	24.16***	5.62***	0.39ns	1.68*
Splits (1 tot 10)	9.56	5.00	10.00	5.58**	3.77***	0.42ns	2.31***
Size (1 to 7)	6.15	4.00	7.00	133.89***	3.21***	0.04ns	2.24***
Texture (kg.100 g^{-1}.12 s^{-1})	73.46	44.80	118.00	16.77***	27.38***	0.68ns	5.46***
Clumping (1 to 3)$^{\#}$	3.00	3.00	3.00	-	-	-	-
L-values	43.01	37.22	50.70	30.49***	30.66***	0.79ns	2.31***
a_L-values	9.44	7.12	11.35	18.04***	15.01***	0.96ns	1.99***
b_L-values	16.33	14.83	17.39	11.07***	15.79***	0.64ns	1.54*
Viscosity (cP)	2582.71	972.50	7945.00	33.95***	70.56***	0.08ns	26.99***

#no variation in data

*** $P <$ 0 .01; ** $P <$ 0.05; ns > P 0.05

Table 4.19 Mean, minimum and maximum values and F-values pertaining to main and interaction effects of the canning quality of six small white bean cultivars (2002/03 season) from 17 localities

Canning quality	Mean	Minimum	Maximum	F-value			
				Cultivar (df = 5)	Locality (df = 16)	Replicates (df = 2)	Cultivar x locality (df = 80)
Hydration coefficient	1.73	1.25	2.01	277.29***	48.73***	0.30ns	6.97***
Washed drained weight (%)	56.67	50.32	64.60	20.19***	52.00***	1.29ns	1.43*
Visual appearance (1 to 10)	7.70	4.00	10.00	41.39***	23.94***	1.57ns	4.57***
Splits (1 tot 10)	8.01	4.00	9.00	25.86**	19.20***	5.59ns	2.63***
Size (1 to 7)	6.17	5.00	7.00	41.35***	4.80***	0.05ns	1.30ns
Texture (kg.100 g^{-1}.12 s^{-1})	72.63	39.05	156.85	54.47***	85.37***	1.84ns	8.32***
Clumping (1 to 3)	2.73	1.00	3.00	2.53*	4.11***	1.80ns	1.48*
L-values	44.69	39.09	48.48	33.44***	27.53***	0.54ns	0.97ns
a_L-values	8.86	7.41	10.61	21.53***	17.40***	2.28ns	1.02ns
b_L-values	16.57	15.75	17.48	6.79***	11.06***	0.74ns	0.94ns
Viscosity (cP)	2200.96	488.00	5000.50	14.13***	66.61***	0.98ns	6.83***

*** $P <$ 0.01; * $P <$ 0.1; ns > P 0.05

All R^2-values were significant, indicating that similar data would be successfully measured by these parameters (Table 4.20). The RMSE (< 5.0) and CV (< 10.0) for both seasons were low, except for those of viscosity with unacceptably high values. Viscosity data are therefore not suitable to be used as canning quality parameter and variation in data was unreliable although differences between replicates were not significant. Balasubramanian *et al*. (1999) found a mean viscosity value for the brine of canned navy beans to be 212.5 cP, while CV (34.3 %) was higher than in the present study. A possible reason for the high RMSE in the present study could be that tomato sauce was used as canning medium, as compared to the brine used by Balasubramanian *et al*. (1999). Differences in the tomato puree from different batches used could have influenced viscosity values after canning. Different tomato cultivars, or the origin of tomatoes in terms of locality or season of harvest used for different batches, probably caused these differences. Another reason could have been the high order of viscosity values for 2001/02 (972.50 to 7945.00 cP; Table 4.18) and 2002/03 (488.00 to 5 000.50 cP; Table 4.19), which increased RMSE and CV values. Due to the unreliable viscosity data, viscosity was not considered as a canning parameter for the rest of the present study. Root mean square error and CV were also slightly higher in the case of texture (Table 4.20). Table 4.21 provides the relative effects of environment and cultivar on the canning quality of small white beans. The relative effects of E and G on canning quality parameters were the same for both seasons, except for L-value (Table 4.21). L-value was mostly affected by environment in 2001/02 (E/G ratio >1) and by cultivar in 2002/03 (E/G ratio <1).

Table 4.20 R^2-values, root mean square errors and coefficients of variation pertaining to canning quality parameters of small white bean cultivars from 33 localities (2001/02 and 2002/03 seasons)

Canning quality	$^{\#}R^2$		Root mean square error		Coefficient of variation	
	2001/02	2002/03	2001/02	2002/03	2001/02	2002/03
Hydration coefficient	0.96***	0.93***	0.04	0.05	2.08	2.74
Washed drained weight (%)	0.81***	0.84***	1.20	1.38	2.17	2.44
Visual appearance (1 to 10)	0.65***	0.83***	0.70	0.80	7.35	10.42
Splits (1 tot 10)	0.58***	0.77***	0.85	0.63	8.84	7.88
Size (1 to 7)	0.81***	0.66***	0.38	0.50	3.14	8.06
Texture (kg.100 g^{-1}.12 s^{-1})	0.85***	0.92***	7.46	7.05	10.15	9.71
Clumping (1 to 3)$^{\#\#}$	-	0.50***	-	0.41	-	14.9
L-values	0.84***	0.77***	1.13	0.99	2.62	2.22
a_L-values	0.75***	0.70***	0.47	0.38	4.93	4.29
b_L-values	0.73***	0.59***	0.33	0.25	2.02	1.48
Viscosity (cP)	0.95***	0.89***	370.12	324.60	14.33	14.75

\# R^2 = Sum square model / Sum square total

\#\# no variation in data for 2001/02

*** $P < 0.01$

Table 4.21 The relative effects of growth environment and cultivar on canning quality of small white beans from different localities

Canning quality	2001/02			2002/03		
	Mean square		Ratio	Mean square		Ratio
	Cultivar (G) (df =3)	Locality (E) (df = 15)	(E/G)	Cultivar (G) (df = 5)	Locality (E) (df =16)	(E/G)
Hydration coefficient	0.67	0.14	0.21	0.62	0.11	0.18
Washed drained weight (%)	32.07	37.76	1.18	38.61	99.44	2.58
Visual appearance (scale 1 to 10)	11.69	2.72	0.23	26.63	15.40	0.58
Splits (scale 1 tot 10)	3.99	2.69	0.67	10.29	7.64	0.74
Size (scale 1 to 7)	19.11	0.46	0.02	10.23	1.19	0.12
Clumping (scale 1 to 3)#	-	-	-	0.42	0.68	1.62
Texture (kg.100 g^{-1}.12 s^{-1})	923.39	1521.90	1.65	2707.99	4243.96	1.57
L-value	38.69	38.90	1.01	33.06	27.21	0.82
a_L-value	3.91	3.25	0.83	3.12	2.52	0.81
b_L-value	1.20	1.72	1.43	0.41	0.67	1.63

no variation in data for 2001/02

4.3.2.1 Effect of cultivar on canning quality

4.3.2.1.1 Effect of cultivar on hydration coefficient

Hydration coefficient values ranged between 1.32 to 2.10 and 1.25 to 2.01 for 2001/02 and 2002/03 respectively, with mean values of 1.76 and 1.73 (Tables 4.18 & 4.19). During 2000/01 (Chapter 2, Table 2.14) HC values were found to range between 1.71 and 1.89 with a higher mean value of 1.82. Higher HC values would improve canning yield (Ghaderi *et al.*, 1984), which is indicated by the PWDWT (Varner & Uebersax, 1995). Lower PWDWT values would therefore also be expected during 2001/02 and 2002/03. PAN 185 had significantly better HC values than other cultivars (Figures 4.5a & b). This is in agreement with results from Chapter 2, where PAN 185 was also indicated to have higher HC values than Teebus during 2000/01 (Figure 2.8). PAN 185 had significantly smaller seeds than other cultivars for the last two seasons (Figure 4.2a & b), which improved WU ability (Del Valle *et al.*, 1992).

Teebus (HC = 1.63 and 1.69 respectively) and Teebus RR1 (HC = 1.68 and 1.69 respectively) had significantly lower HC values than other cultivars for 2001/02 and 2002/03 (Figures 4.5a & b). During 2002/03 PAN 121 (HC = 1.56) had the lowest mean HC value. All cultivars had lower mean HC values than the choice grade standard defined in Chapter 2 (Table 2.17). This could have been caused by the effect that larger seed sizes (Figures 4.2a & b) have on hydration (Del Valle *et al*., 1992).

In Chapter 3 it was shown that Teebus (reference standard) was able to reach the 80 % WU (Table 3.5) required by USA regulations (Hosfield *et al*., 1984a; Hosfield, 1991) during industrial canning, despite low HC values with laboratory canning. Since all cultivars, except for PAN 121, had higher HC than the Teebus during 2001/02 and 2002/03, all would be expected to reach acceptable WU levels during industrial canning. PAN 121 would need longer soaking periods than Teebus to reach the required 80 % WU under industrial conditions.

Hydration coefficient was found to be more affected by genotype (cultivar) than by environment, since the E/G ratios were < 1 (Table 4.21). In Chapter 3 (Table 3.11) it was seen that HC of laboratory canned beans was more affected by environment. This could have been caused by the fact that only four cultivars and environments were used. The variation in environments could have been more than those between cultivars, since regional values were the average of nine localities.

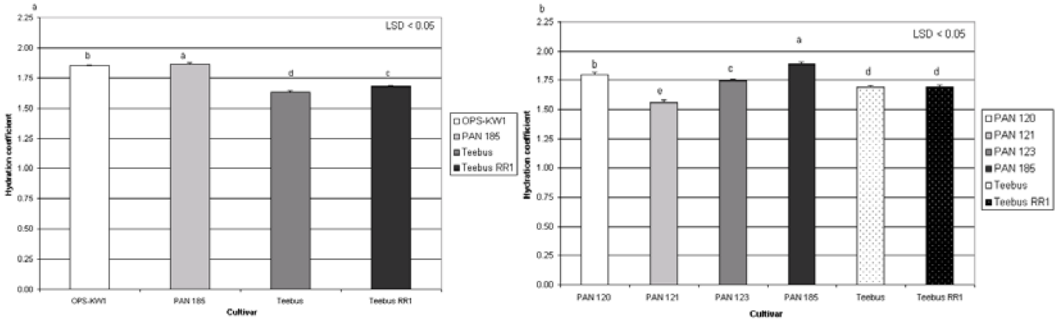


Figure 4.5 Mean hydration coefficients of canned small white bean cultivars from 33 localities for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

4.3.2.1.2 Effect of cultivar on percentage washed drained weight

Percentage washed drained weight values for cultivars (2001/02 and 2002/03) are provided in Figures 4.6a & b. No cultivar (2001/02 and 2002/03) was able to reach the

PWDWT value of 58.51 % (Figure 4.6) for the choice grade reference standard defined in Chapter 2 for 2000/01 (Table 2.17). This could be attributed to the lower HC values during the last two seasons (Figure 4.5), which lowered the yield of canned beans (De Lange & Labuschagne, 2000). Secondly, lower PWDWT values could have been caused by seasonal effects and by more and different localities used for the last two seasons. Significant cultivar x locality interactions (Tables 4.18 & 4.19) indicate that cultivars do not perform consistently over localities (Ghaderi *et al*., 1984) and differences in PWDWT was more affected by locality than by cultivar (E/G ratio > 1) (Table 4.21). PAN 185 had similar values for 2001/02 (PWDWT = 56.25 %) and 2002/03 (PWDWT = 56.33 %). During 2001/02, values for PAN 185 were significantly higher than for Teebus and Teebus RR1, but not during 2002/03, since new cultivars (PAN 120 and PAN 123) were indicated to have higher values than PAN 185.

The PWDWT values of Teebus RR1 were again close to those of Teebus, as it is a Teebus derived cultivar, which is rust resistant. As with HC, Teebus RR1 displayed significantly higher PWDWT values than Teebus during 2001/02 (Figure 4.6).

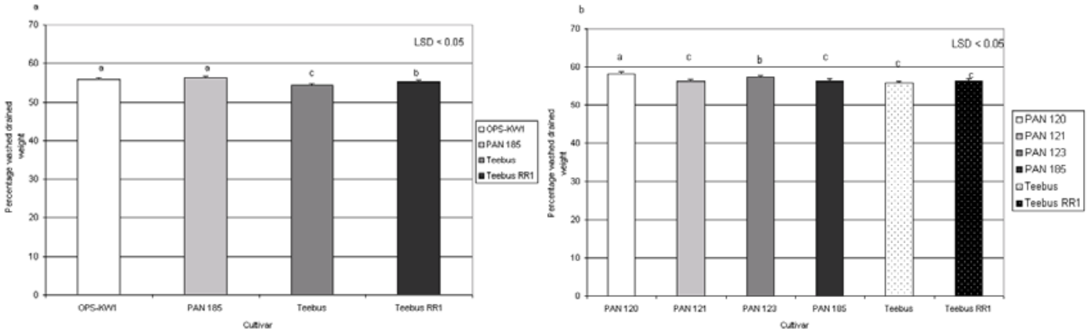


Figure 4.6 Mean percentage washed drained weight values of canned small white bean cultivars from 33 localities for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

4.3.2.1.3 Effect of cultivar on visual appearance

Visual appearance values for cultivars (2001/02 and 2002/03) are provided in Figures 4.7a & b. Both Teebus (VA = 9.79) and Teebus RR1 (VA = 9.79) during 2001/02 (Figure 4.7a) reached the VA value of 9.74 set for choice grade beans in Chapter 2

(Table 2.17), but were unable to reach this value during 2002/03. As during 2000/01 (Figure 2.10) PAN 185 had significantly lower VA values than Teebus (Figure 4.7a & b). In Chapter 2 (Table 2.16) significant negative correlations between HC and VA were found (r = -0.40, $P < 0.01$), which are illustrated by the poor HC, but good VA values of Teebus and Teebus RR1 during 2002/03. PAN 120 was the only other cultivar to have higher VA values than PAN 185 (VA = 7.54), but was unable to meet choice grade requirements (Table 2.17). The smaller seed size of PAN 185 (Figure 4.2) would also have influenced the VA of these beans, as the larger sized seeds of Teebus are considered as the norm by both industry and the consumer.

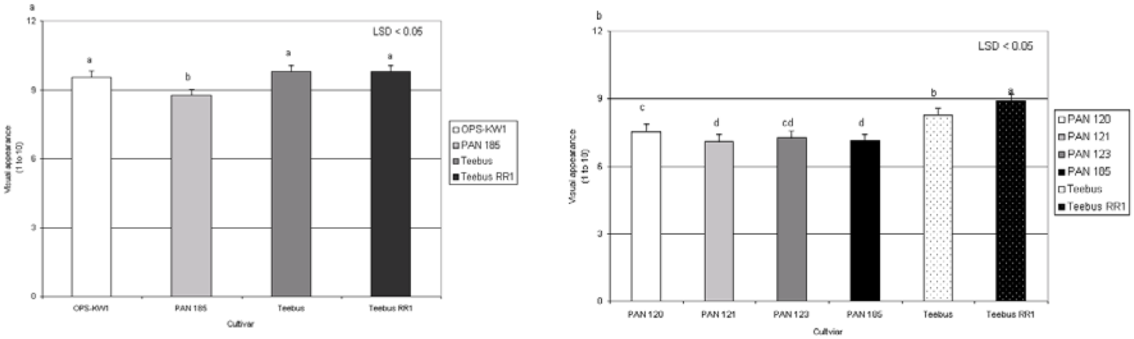


Figure 4.7 Mean visual appearance values of canned small white bean cultivars from 33 localities for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

Visual appearance of these beans was mostly determined by cultivar (E/G ratio < 1) (Table 4.21). In Chapter 3 (Table 3.11) where four regions (average of nine localities) and four cultivars with more variation were used, VA of laboratory canned beans was more affected by region. When the E/G ratios for canning quality are considered the number of cultivars and localities, as well as the variation between cultivars and localities should also be taken into consideration.

4.3.2.1.4 Effect of cultivar on splits

Split values for cultivars (2001/02 and 2002/03) are provided in Figures 4.8a & b. Although not significantly different from Teebus RR1, Teebus had the highest split values (splits = 9.92) for 2001/02 (Figure 4.8a) and met the values of 9.67 (Table

2.17) identified for choice grade beans in Chapter 2. Teebus RR1 (splits = 9.67) was the only other cultivar to meet this value. As during 2000/01 (Figure 2.11), PAN 185 and OPS-KW1 did not differ significantly in split values during 2001/02 (Figure 4.8a).

Samples for 2002/03 ranged from 4 to 9 in split values (Table 4.19) and 5 to 10 during 2001/02. Mean split values of Teebus did not reach the choice grade value (Table 2.17) during 2002/03. During 2002/03 PAN 185 had significantly higher split values than Teebus and Teebus RR1 (Figure 4.8b). Although split values are mostly affected by cultivar (E/G ratio < 1) (Table 4.21), the reason for lower split values of Teebus and Teebus RR1 in 2002/03 could be due to the significant cultivar x locality interaction (Table 4.19). Teebus and Teebus RR1 had unacceptably low split values at Greytown and Lichtenburg (Table 4.9.2), which lowered the mean split values. Splits of canned beans are influenced by environment, cultivar and the cultivar x environment interaction, while chemical traits (N, Ca and K) are also affected by environment (De Lange & Labuschagne, 2000). Differences in the chemical properties of beans, as a result of differences in seasonal conditions, could therefore have caused more splitting during 2002/03.

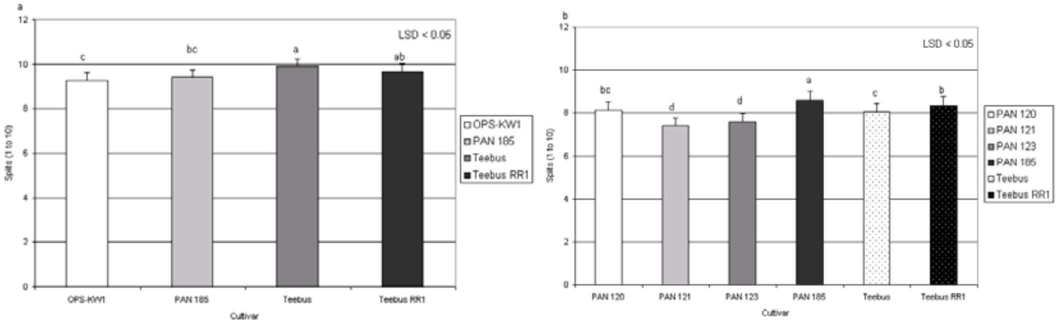


Figure 4.8 Mean split values of canned small white bean cultivars from 33 localities for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

PAN 121 and PAN 123 had significantly more splits than other cultivars during 2002/03, while PAN 120 was not significantly different from Teebus in split values

(Figure 4.8b). As found with HC (Figure 4.5) and PWDWT (Figure 4.6), Teebus RR1 had higher split values than Teebus during 2002/03.

As mentioned, differences in split values of beans were mostly caused by genotype (E/G < 1) in 2001/02 and 2002/03 (Table 4.21). During 2000/01 splits of laboratory canned beans were mostly caused by environment (Table 3.11). Once again, this observation could be due to the low number of cultivars and regions used during this season.

4.3.2.1.5 Effect of cultivar on size

The size values for cultivars (2001/02 and 2002/03) are provided in Figures 4.9a & b. During both 2001/02 and 2002/03, no cultivar was able to reach the choice grade value of 6.89 (Table 2.17). Teebus RR1 came the closest to this value, with mean values of 6.81 and 6.73 respectively (Figures 4.9a & b). Teebus was ranked second with size values of 6.50 and 6.49 respectively. PAN 121 did not differ significantly from Teebus in size values (2002/03), with a mean value of 6.33. The reason for this would be that the original seed size of this cultivar was the same as that of Teebus (reference standard), which is acceptable (Figure 4.2b). Although Teebus and Teebus RR1 did not reach the choice grade size values for the last two seasons, both performed well above the standard grade value of 5.72 (Table 2.17). The lower size values of Teebus in the last two seasons could have been caused by seasonal effects or the fact that different and more localities were introduced to the trials. Although size as a canning parameter was mostly affected by cultivar (E/G ratio < 1) (Table 4.21), the 100SM of dry beans were mostly affected by environment in 2002/03 (E/G ratio = 1.14), but by genotype in 2001/02 (E/G ratio = 0.04) (Table 4.6). The differences in the relative effects of cultivar and locality of 100SM over the two seasons illustrates that seasonal effects could have affected size as a canning parameter.

As during 2000/01 (Figure 2.12) PAN 185 and OPS-KW1 had significantly lower size values than those of Teebus. The reason would be that the original dry bean sizes (Figure 4.2a & b) were significantly different from that of Teebus and would remain unacceptable after canning.

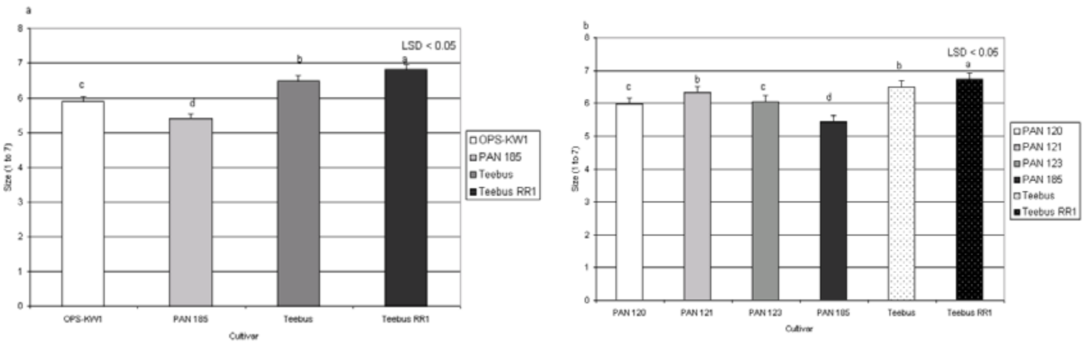


Figure 4.9 Mean size values of canned small white bean cultivars from 33 localities for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

4.3.2.1.6 Effect of cultivar on texture

The texture values for cultivars (2001/02 and 2002/03) are provided in Figures 4.10a & b. The texture of canned small white beans correlated negatively (r = -0.57) with PWDWT (Table 2.16). Texture values for Teebus was higher (texture = 79.34 and 75.46 kg.100 g^{-1}.12 s^{-1} respectively) during 2001/02 and 2002/03 (Figure 4.10a & b) than the requirements for choice grade beans of 70.21 kg.100 g^{-1}.12 s^{-1} defined in Chapter 2 (Table 2.17). This could be attributed to the low PWDWT found for Teebus during these seasons (Figure 4.6). The values of Teebus for 2001/02 and 2002/03 were still within the range of 59.1 and 89.9 kg $100g^{-1}$ found for small white beans by Hosfield & Uebersax, (1980). Teebus RR1, PAN 185 and OPS-KW1 all had closer texture values to the choice grade requirement (Figure 4.10a) during 2001/02. Teebus RR1 and PAN 185 also had texture values close to this value during 2002/03 (Figure 4.10b). This could have been caused by the possibility of a cultivar x environment interaction (Tables 4.18 & 4.19) that could have caused the harder beans of Teebus during the last two seasons. Harder beans of Teebus were found at Arnot, Kroonstad and Maseru during 2001/02 and at Bethal during 2002/03 (Tables 4.11.1 & 4.11.2). Ghaderi *et al*., (1984) also found the cultivar x locality interaction to be significant for canned beans, while Table 4.21 also indicates that texture values were mostly affected by environment (E/G ratio > 1).

PAN 121 was the hardest cultivar having a mean texture value (texture = 85.29 kg.100 g^{-1}.12 s^{-1}) significantly higher than both that of Teebus (Figure 4.10b) and the choice grade value. Softer beans are usually preferred by members of sensory panels (Uebersax & Bedford, 1980) due to the known correlation (r = 0.92) between acceptability and texture of beans (Rodríguez-Sosa *et al*., 1984). The phytin, Ca, Mg, free pectin, thickness of the palisade layer of the seed coat, lignin and alpha-cellulose in the seed coat, all influence the firmness of beans after processing (Muller, 1967). Texture is mostly determined by environment (Table 4.21), while some of these components that affect texture could be mostly affected by genotype. A reason for this could be that factors, such as Ca and Mg, could be more affected by environments (e.g. differences in soil fertility, fertilization). Ca and other divalent ions plays an important role in bean firmness (Quenzer *et al*., 1978), since these ions have the ability to form salt bridges between adjacent polymer chains in the middle lamella in beans (Nelson & Hsu, 1985). The hardness of PAN 121 and softness of PAN 120 and PAN 123 could have been caused by cultivar differences in one or more of these properties. This in turn could have been caused by the cultivar x locality interaction (Table 4.18), since PAN 121 was harder at Bethal, Bethlehem, Coligny and Reitz (Table 4.11.2).

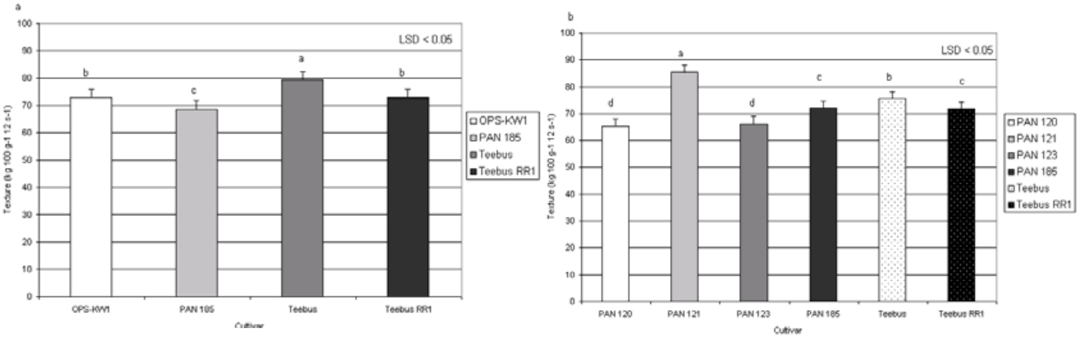


Figure 4.10 Mean texture values of canned small white bean cultivars from 33 localities for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

4.3.2.1.7 Effect of cultivar on clumping

The clumping values for cultivars (2001/02 and 2002/03) are provided in Figures 4.11a & b. No clumping was found in beans of 2001/02. Teebus and Teebus RR1 had better clumping values than most cultivars during 2002/03, although not significantly different from PAN 185 and PAN 121 (Figure 4.11b). During 2001/02 all beans had higher values than the choice grade value of 2.89 (Table 2.17). For 2002/03 Teebus (clumping = 2.82) and Teebus RR1 (clumping =2.80) had slightly lower values than the choice grade value, but values were above the 2.72 of standard grade beans (Table 2.17). The only cultivars with values below the standard grade value were PAN 120 and PAN 123 (Figure 4.11b).

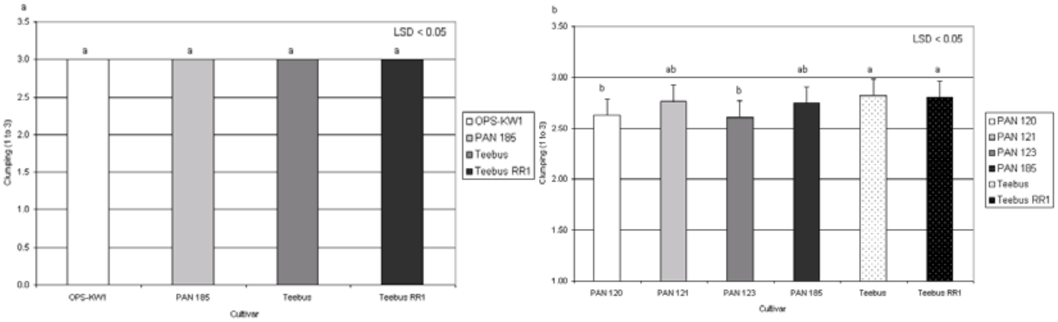


Figure 4.11 Mean clumping values of canned small white bean cultivars from 33 localities for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

Lower clumping values of beans during 2002/03 than during 2000/01 and 2001/02 could have been caused by the significant cultivar x locality effects on clumping (Table 4.18), since clumping values at Cradock (Table 4.13.2) were low for this season. Secondly, seasonal effects or the differences in environments over the two seasons could have lowered clumping values during 2002/03. Lu & Chang (1996) also noticed the importance of environment when significant differences in correlation coefficients between starchiness of the bean medium and clumping at two difference localities, were found. Table 4.21 also indicated clumping to be more affected by environment with a high E/G ratio of 1.62. Chemical analysis traits (N, Ca and K) that are significantly influenced by environment (De Lange and Labuschagne, 2000) might play a role here. The differences in environments over seasons could also have affected the starch or protein properties of the beans, which would have changed the tendency of beans to clump.

4.3.2.1.8 Effect of cultivar on colour (L-value, a_L-value and b_L-value)

The L-, a_L- and b_L- values for cultivars are provided in Figures 4.12, 4.13 and 4.14 respectively. Teebus and Teebus RR 1 (L-values of 42.38 and 42.23 respectively) were the two cultivars with L-values (Figure 4.12a) the closest to the choice grade value of 40.31 (Table 2.17) during 2001/02. During 2002/03 all cultivars were lighter coloured than the choice grade standard value. In 2000/01 PAN 185 and OPS-KW1 were not significantly different from Teebus in L-value means (Figure 2.15), while higher values than for Teebus were found over the last two seasons for PAN 185 (2001/02 and 2002/03) and OPS-KW1 (2001/02).

In 2000/01 (Chapter 2) L-values ranged from 37.47 to 43.08 with a mean of 40.60 (Table 2.14). L-values for 2001/02 and 2002/03 ranged from 37.22 to 50.70 (Table 4.18) and 39.09 to 48.48 (Table 4.19) with respective mean values of 43.01 and 44.69. An increase in the lightness of beans was recorded over the three seasons. Chung *et al*., (1995) also found the lightness values of beans to be affected by seasonal effects in the case of red kidney beans. Differences in the mean values over seasons could also have been caused by the different cultivars and localities used for each season. During 2001/02 L-values were mostly affected by locality (E/G ratio > 1), while cultivar affected L-values more during 2002/03 (E/G ratio < 1) (Table 4.21).The reason for the different relative effects of genotype and environments over the two seasons, could be that more cultivars were available during the second season, resulting in more variation. During the 2000/01 season (Chapter 3, Table 3.11), where few cultivars were also used the E/G ratio was also < 1, as in 2001/02. These contrasting results indicate the important effect that season has on the relative effects of genotype and environment on canning quality. The cultivar x locality interaction for L-values was significant for 2001/02 (Table 4.18), but not for 2002/03 (Table 4.19). That cultivar x locality interactions influence the L-values of canned beans significantly was also shown by Ghaderi *et al*. (1984).

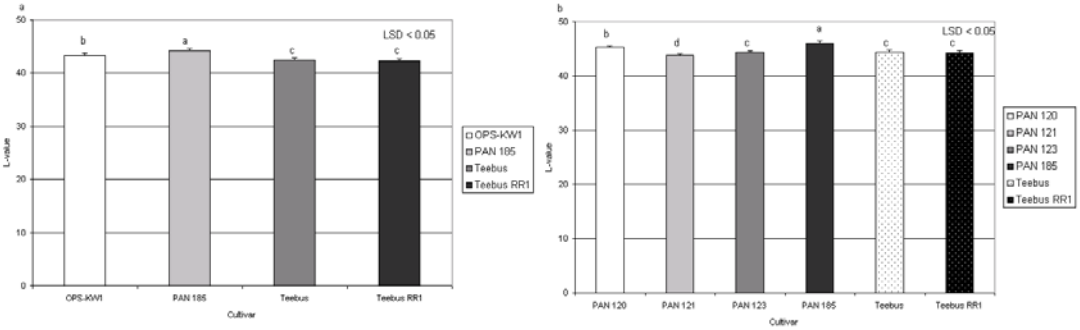


Figure 4.12 Mean L-values of canned small white bean cultivars from 33 localities for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

Al cultivars had lower a_L-values during 2001/02 and 2002/03 (Figure 4.13a & b) than the choice grade value of 11.12 (Table 2.17) identified during 2000/01. Beans also had lower HC and PWDWT values during the last two seasons (4.3.2.1.1 & 4.3.2.1.2), which confirms the significant correlations of a_L-values with HC and PWDWT identified in Chapter 2 (Table 2.16). In Chapter 2 (2.3.2.8) it was mentioned that more water absorbed by beans in the can would lead to more red-coloured beans. The colour of cultivars during the last two seasons was therefore more reddish than in the previous season. The more intense red colour of the processed beans could also have been caused by seasonal effects on the tomatoes, which is in turn expressed in the sauce. Some of the red pigments of the tomato sauce are absorbed by the beans together with moisture.

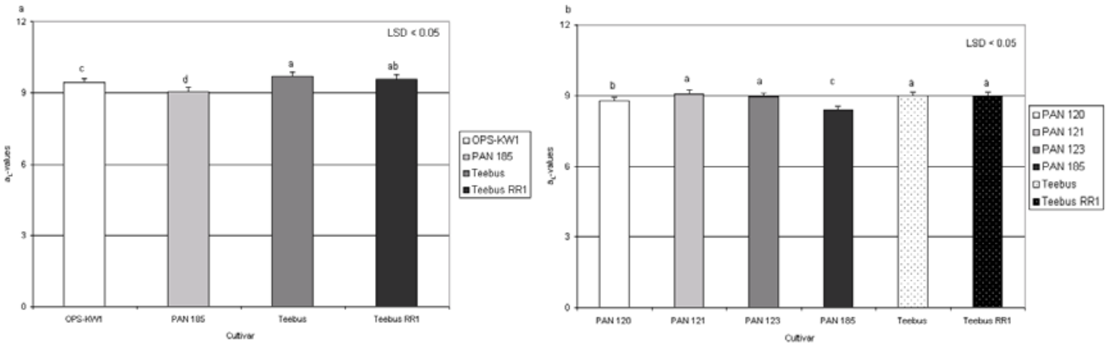


Figure 4.13 Mean a_L-values of canned small white bean cultivars from 33 localities for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

Teebus and Teebus RR1 had significantly higher a_L-values than PAN 185 for both 2001/02 and during 2002/03 (Figures 4.13a & b). During 2000/01 Teebus also had significantly higher a_L-values than PAN 185 (Figure 2.16). Ghaderi *et al*. (1984) also found that cultivar has a significant effect on the a_L-values and b_L-values of canned navy beans. Most of the variation between the a_L-values of beans was due to cultivar, since E/G ration were < 1 for both seasons (Table 4.21). This stronger genotypic effect of a_L-values was also found in 2000/01 (Table 3.11).

Canned beans during 2000/01 (Table 2.14) had a range in a_L-values of 9.52 to 11.97 with a mean value of 10.85. During 2001/02 and 2002/03 a_L-values of beans ranged from 7.12 to 11.35 and 7.41 to 10.61 respectively. Respective mean values for these seasons were 9.44 and 8.86 (Tables 4.18 & 4.19). Differences in a_L-values were therefore recorded over seasons, as was the case with L-values.

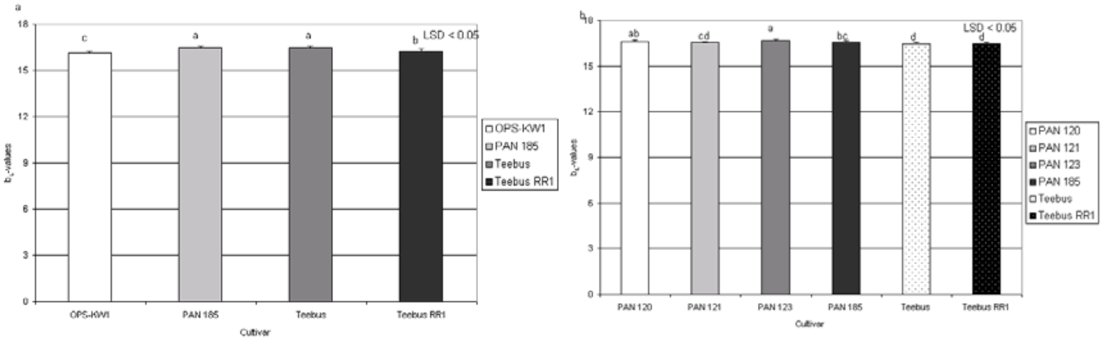


Figure 4.14 Mean b_L-values of canned small white bean cultivars from 33 localities for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

All cultivars had b_L-values (Figure 4.14a & b) close to that of the standard grade value of 16.79 during 2001/02 and 2002/03 (Table 2.18). Mean values for Teebus were 16.45 for 2001/02 and 16.48 for 2002/03. OPS-KW1 had significantly lower b_L-values than other cultivars during 2001/02 (Figure 4.14a). Split values correlated significantly with b_L-values (Table 2.16), illustrated by the significantly lower split values of OPS-KW1 during 2001/02 (Figure 4.8a). In Chapter 2 it was shown that the b_L-value of beans is more sensitive to the effect of splits on bean colour and that beans with fewer splits would appear more blue (2.3.2.8). The b_L-values of canned beans are, contrary to a_L-values, more affected by locality than cultivar (E/G ratio > 1) (Table 4.21) and this effect was also found in 2000/01 (Table 3.11).

From the data of cultivars, it is clear that defining of choice and standard grade values for the reference standard is not a process that could be based on one year's data alone, as seasonal effects have a marked influence on these values. The average values for choice and standard grade beans based on data from 2000/01, 2001/02 and 2002/03 are shown in Table 4.22. Teebus was used as choice grade standard, since the industry only recommends this cultivar to be used as such. PAN 185 and OPS-KW1 (determined as standard grade in Chapter 2) were used to determine standard grade values in 2001/02 and PAN 185 in 2002/03, since Helderberg was no longer available during these seasons. Values for 2000/01 were obtained from Chapter 2 (Table 2.17).

Table 4.22 Canning quality values for laboratory evaluation of the reference standard of "choice" and "standard" grade canned beans in tomato sauce

Canning quality	2000/01	2001/02	2002/03	Mean	Standard deviation
Choice grade					
Hydration coefficient	1.75	1.63	1.69	1.69	0.06
Percentage washed drained weight	58.51	54.39	55.79	56.23	2.09
Visual appearance (scale 1 to 10)	9.74	9.79	8.25	9.26	0.88
Splits (scale 1 tot 10)	9.67	9.92	8.04	9.21	1.02
Size (scale 1 to 7)	6.89	6.50	6.49	6.63	0.23
Texture (kg.100 g^{-1}.12 s^{-1})	70.21	79.34	75.46	75.00	4.58
Clumping (scale 1 to 3)	2.89	3.00	2.82	2.90	0.09
L-values	40.31	42.38	44.43	42.37	2.06
aL-values	11.12	9.70	8.90	9.91	1.12
bL-values	16.79	16.46	16.48	16.58	0.19
Standard grade					
Hydration coefficient	1.84	1.86	1.89	1.86	0.03
Percentage washed drained weight	58.12	56.05	56.33	56.83	1.12
Visual appearance (scale 1 to 10)	9.15	9.15	7.12	8.47	1.17
Splits (scale 1 tot 10)	9.56	9.34	8.59	9.16	0.51
Size (scale 1 to 7)	5.72	5.65	5.65	5.67	0.04
Texture (kg 100 g^{-1}.12 s^{-1})	75.26	70.81	71.97	72.68	2.31
Clumping (scale 1 to 3)	2.72	3.00	2.75	2.82	0.15
L-value	41.46	43.71	46.03	43.73	2.29
a_L-value	10.54	9.24	8.40	9.39	1.08
b_L-value	16.81	16.29	16.59	16.56	0.26

4.3.2.1.9 Canonical variate analysis for the effect of cultivar on canning quality

It is difficult to determine the overall canning quality of cultivars based on the interpretation of the results of individual canning properties. The CVA is a tool that enables the simultaneous interpretation of data from different canning parameters to indicate the total canning quality of cultivars with respect to the choice or standard grade groups. Canonical variate analysis is used when it is of more interest to show differences between groups than individuals (Digby *et al*., 1989). Canonical variate analysis also enables the comparison of data from different seasons when the cultivars and / or localities used in each season differ and gives an indication of the relative positioning of groups to each other. According to the CVA, using all canning parameters, the contribution of CV 1 (75.04 %) and CV 2 (21.56 %) to the variation in the canning quality of cultivars were 96.6 %. The latent roots for CV 1 (1.87) and CV 2 (0.54) were only > 1 in the case of CV 1. Latent roots of < 1 indicate the presence of more within group variation than between group variation (Digby *et al*., 1989). From the latent vectors the following discriminating equations for CV 1 and CV 2 are derived:

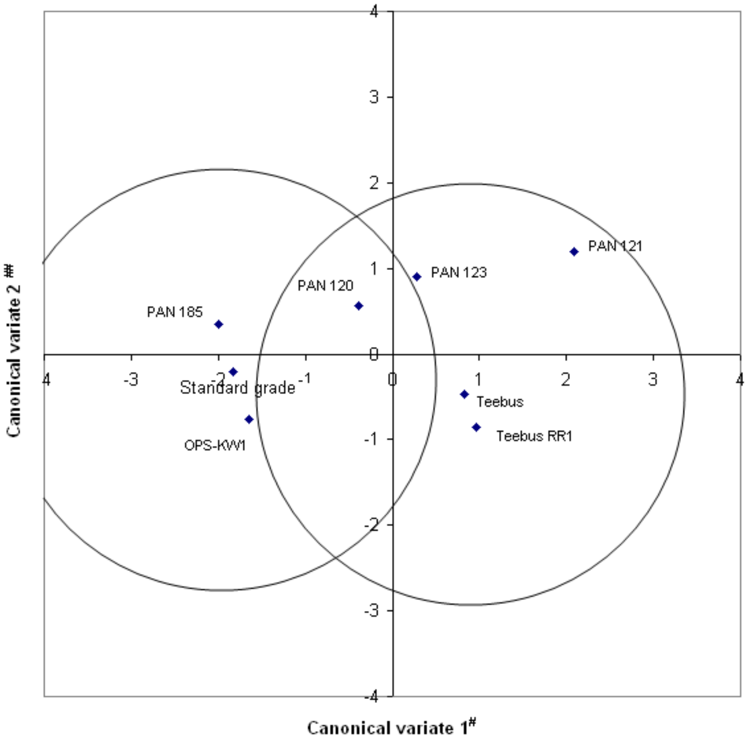
CV 1 = -7.296 (HC) - 0.107 (Splits) + 1.497 (Size) – 0.314 (VA) + 7.02 (1)

CV 2 = -1.809 (HC) – 0.336 (Splits) – 0.678 (Size) – 0.448 (VA) + 13.97 (2)

Hydration coefficient correlated negatively (r = -0.82) and size positively (r = 0.72) with CV 1 (Table 4.23). Splits (r = -0.70) and VA (r = -0.93) both correlated negatively with CV 2. Figure 4.15 displays the plot of the scores for cultivars for CV 1 and CV 2. The 95 % confidence circles on the plot indicate choice and standard grade group cultivars. Teebus served as the reference standard for choice grade and the mean value of PAN 185 and OPS-KW1 as reference standard for standard grade cultivars, since these cultivars did not differ significantly from Helderberg in Chapter 3 (3.3.4.1). Helderberg was no longer commercially available. Teebus did not differ significantly in canning quality from Teebus RR1, PAN 121 and PAN 123. OPS-KW1 and PAN 185 were the only cultivars within the standard grade group, except for PAN 120, which fell within both the choice and standard grade groups (Figure 4.15)

Table 4.23 Correlation matrix of canonical variates 1 and 2 with canning quality parameters of seven small white bean cultivars from 33 localities over two seasons

	Hydration coefficient	Splits	Size	Visual appearance
Canonical variate 1	-0.82	-0.28	0.72	0.01
Canonical variate 2	0.00	-0.70	-0.55	-0.93



#Canonical variate 1 = (-) Hydration coefficient; Size

##Canonical variate 2 = (-) Visual appearance; (-) Splits

Figure 4.15 Plot of canonical variates 1 vs. 2 for seven small white beans cultivars from 33 localities and two seasons, to indicate groupings between cultivars (groups within the same circle indicate no significant differences at *P* = 0.05).

The plot of CV 1 vs. CV 2 indicates that cultivars with good size, but lower HC values would be found to the right side of the plot (Figure 4.15). Those with low split and VA values would be found at the top half of the plot. The high CV 1 scores for the choice grade cultivars were due to low HC and high size values (equation 1). In Chapter 3 Teebus was also found in the area with poor HC values (Figure 3.6), but it was found to still be able to reach acceptable WU levels under industrial canning conditions (Figure 3.1). The negative CV 2 scores of Teebus and Teebus RR 1 were the result of good VA (Figures 4.7a & b) and split (Figure 4.8a) values (equation 2). The positive CV 2 scores of other choice grade cultivars were the result of lower VA (Figure 4.7b) and splits (Figure 4.8b) values (equation 2). Low VA and split values of these cultivars could have been the consequence of the 2002/03 seasonal effects, since Teebus and Teebus RR 1 also had lower values during this season than during the 2001/02 season. It is suggested that PAN 123 and PAN 121 should be evaluated over another season to indicate whether split and VA values would improve during normal crop seasons.

The slightly negative CV 1 score of PAN 120 was caused by the good HC value (Figure 4.5b) (equation 1). The size of these beans was similar to that of PAN 123 (Figure 4.9b). The positive CV 2 score of these beans were due to lower VA (Figure 4.7b) and splits (Figure 4.8b) (equation 2), although these values were mostly higher than those of PAN 123 and PAN 121. Since PAN 120 performed better than PAN 123 and PAN 121, but had low VA values it should be tested again during a normal crop season to indicate whether these values could improve. Since this cultivar performed better than PAN 123 and PAN 120 it should also be considered as choice grade.

The low CV 1 scores for standard grade cultivars were due to good HC, but low size values (equation 1). This group of cultivars had significantly lower size values than both Teebus and Teebus RR1 (Figure 4.9a & b) and could have been acceptable if it was not for the poor size values. Consumers of baked beans are sensitive to a deviation from the regular size of beans. These beans were therefore downgraded to the standard grade. During 2000/01 OPS-KW1 and PAN 185 were also situated in the area of poor size values (Figure 3.6).

The use of CVA with the assistance of 95 % confidence circles is not an absolute statistical measurement such as ANOVA. Canonical variate analysis gives an indication of the relative groupings of cultivars. This would explain why some cultivars within the 95 % confidence circle of Teebus would have some properties that are different from Teebus. The closer the cultivars are to Teebus within the circle, the closer the properties would be to that of Teebus. E.g. Teebus RR1 was closer to Teebus RR1 within the circle and its similarity to Teebus was also clear from the discussion in 4.3.2.1.1 to 4.3.2.1.8. The decision will lie with the industrial canner to decide how close choice grade cultivars should be to Teebus within the 95 % confidence circle.

From the discriminative equations for CV 1 and CV 2 (equations 1 & 2) the X- and Y-coordinates for cultivars, not included in these trials, could be calculated to predict the canning quality. In order for this to be done cultivars have to be grown under similar conditions. This would be investigated in Chapter 5.

4.3.2.2 Effect of environment on canning quality

4.3.2.2.1 Effect of locality on hydration coefficient

The HC values for localities (2001/02 and 2002/03) are provided in Figures 4.16a & b. During 2001/02 Koedoeskop was found to deliver beans with significantly higher HC values (HC = 1.92) than those of other localities (Figure 4.16a). Mean values of beans from this locality were therefore higher than the 1.80 required by USA regulations (Hosfield, 1991). High WU of beans from Koedoeskop was caused by the low 100SM values (smaller beans) (Figure 4.4a), since seed size influences WU levels (Del Valle *et al*., 1992). Other localities with a higher than the 1.80 value for HC during 2001/02 was Coligny, Harrismith and Ukulinga.

Hydration coefficient values of beans from Cradock and Greytown were significantly higher than for most other localities during 2002/03 (Figure 4.16b). High values of Greytown were caused by the small seed sizes of beans from this locality (Figure 4.4b), as indicated by Del Valle *et al*., (1992), but Cradock delivered mainly large-sized seeds (Figure 4.4b). High HC values at Cradock could have been due to the development of good quality beans with good starch and protein properties, as a result of good soil fertility and fertilization at this locality (Appendix A, Table 4).

Beans from Potchefstroom had the lowest ($P < 0.05$) mean HC value (HC = 1.42) during 2001/02, despite its small seed sizes (Figure 4.4a). Low HC of this locality could be the result of the low initial MC of beans (Figure 4.3a), since too low MC values at time of processing leads to water imbibition problems during processing (Nordstrom & Sistrunk, 1979). This locality was also the only locality with a lower mean value than the newly calculated value of 1.69 for choice grade beans (Table 4.20). Due to the very low HC value, samples from this locality would not meet the 80 % WU needed during industrial canning and would be unsuitable for canning.

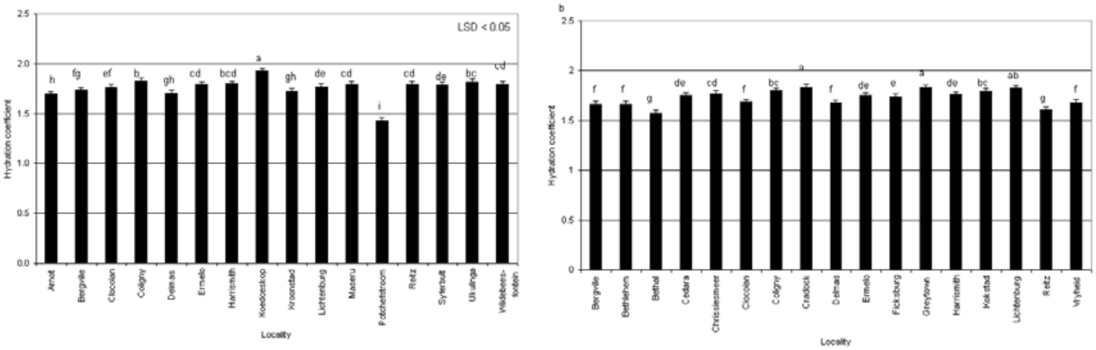


Figure 4.16 Mean hydration coefficient values pertaining to localities of canned small white bean cultivars for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at $P = 0.05$).

Beans from Bethal and Reitz had significantly lower HC values than those from other localities during 2002/03 (Figure 4.16b). Low values at Bethal were due to the low initial MC values of beans (Figure 4.3b), causing WU problems (Nordstrom & Sistrunk, 1979), but MC values at Reitz were high. Stress factors, such as low rainfall, together with absence of irrigation during this season at Reitz, could have caused water imbibition problems (Appendix A, Table 2).

4.3.2.2.2 Effect of locality on percentage washed drained weight

Table 4.21 indicated that PWDWT was mostly affected by environment for 2001/02 and 2002/03 (E/G ratio > 1). This effect was more pronounced during the last season (E/G ratio = 2.58) than during 2001/02 (E/G ratio = 1.18). The differences in the relative effects of genotype and environment of PWDWT in different trials and seasons were also illustrated by the E/G ratio < 1 found during 2000/01 where four cultivars and four regions were considered. As mentioned these effects should always be considered at the background of the number of cultivars and localities used, which affect these values. The PWDWT values for localities (2001/02 and 2002/03) are provided in Figures 4.17a & b. Low PWDWT values were found for Syferbult, Arnot and Kroonstad during 2001/02 (Figure 4.17a). The low values of beans from the first two were due to lower HC values (Figure 4.16a), which lowered the yield of canned beans (De Lange & Labuschagne, 2000). This was also the case with beans from Bergville during 2002/03 (Figures 4.17b & 4.6b). Low PWDWT values of beans from Kroonstad (2001/02) (Figure 4.17 a) indicates water imbibition problems inside the can as a result of low initial MC values of beans (Figure 4.3a) (Nordstrom & Sistrunk, 1979). The same was found with beans from Bethal during 2002/03 (Figure 4.17b & 4.3b).

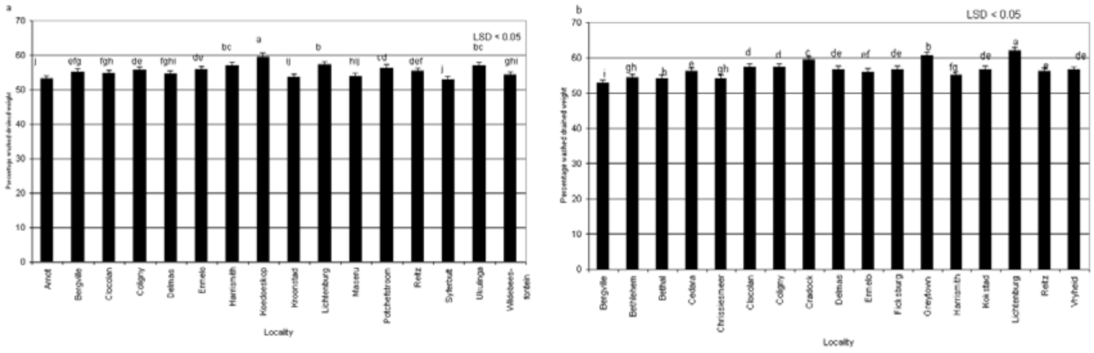


Figure 4.17 Mean percentage washed drained values pertaining to localities of canned small white bean cultivars for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

The PWDWT represents water uptake of beans inside the can and values would be affected by the same factors as HC values. Beans from Koedoeskop and Lichtenburg had significantly higher PWDWT values during 2001/02 (Figure 4.17a), caused by smaller seed sizes before canning (Figure 4.4a), which enhanced hydration (Del Valle *et al.*, 1992) inside the can. As during 2001/02, beans from Lichtenburg had high PWDWT values during 2002/03 (Figure 4.17b), due to smaller bean sizes (Figure 4.4b). The same was found for Greytown during the last season. During this season, environment was also found to affect seed size more than cultivar (Table 4.4), which explains why the E/G ratio for PWDWT was also larger during the same season (Table 4.6).

4.3.2.2.3 Effect of locality on visual appearance

The VA values for localities (2001/02 and 2002/03) are provided in Figures 4.18a & b. Visual appearance of canned beans correlates negatively with PWDWT (Walters *et al.*, 1995). This was illustrated by the low VA values of beans from Koedoeskop during 2001/02, as well as Greytown and Lichtenburg during 2002/03 (Figures 4.18a & b). These beans also had high PWDWT values during the same seasons (Figures 4.17a & b).

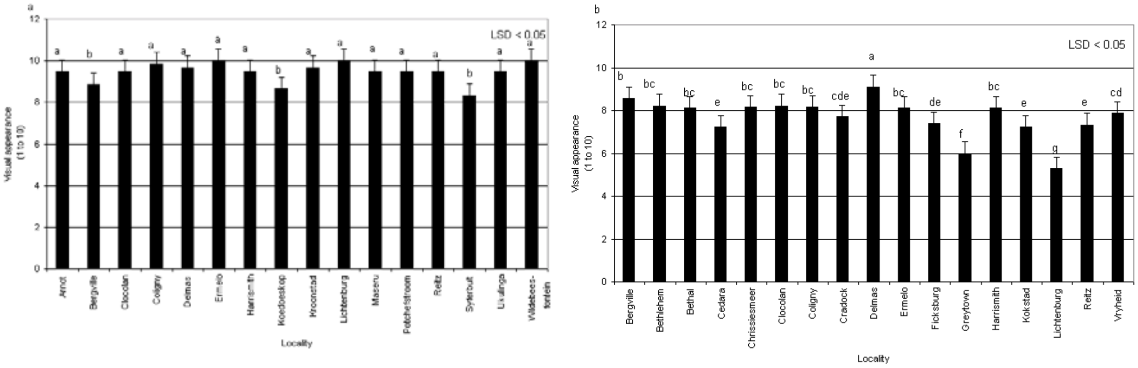


Figure 4.18 Mean visual appearance values for localities of canned small white bean cultivars for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

Beans from Delmas had good VA values during 2002/03 (Figure 4.18b), as a result of low PWDWT values (Figures 4.17b). Bergville (2001/02), Syferbult (2001/02) and Cedara (2002/03) also had low VA values (Figures 4.18a & b), despite low PWDWT values (Figure 4.17a & b). Poor VA values in these cases could have been due to the smaller sized beans that differed from the reference standard (Figure 4.4b). The same was found for Koedoeskop (2001/02), Greytown and Lichtenburg (2002/03) (Figures 4.4 & 4.17).

4.3.2.2.4 Effect of locality on splits

The split values for localities (2001/02 and 2002/03) are provided in Figures 4.19a & b. The incidence of bean splits after canning is lower in beans with low PWDWT values (Van Buren *et al*., 1986). The low PWDWT values (Figures 4.17a & b) would therefore explain the better split values of beans from Arnot, Delmas, Ermelo, Reitz and Wildebeesfontein during 2001/02, as well as Bergville, Bethlehem, Chrissiesmeer, Clocolan, Delmas and Reitz during 2002/03 (Figures 4.19a & b). Larger sized beans also have fewer splits, due to a larger volume-to-surface ratio (Faris & Smith, 1964). Larger seeds (Figures 4.4a & b) would be a second reason for the fewer splits of beans from Delmas, Ermelo, Wildebeesfontein (2001/02), Bergville, Bethlehem, Chrissiesmeer and Delmas (2002/03).

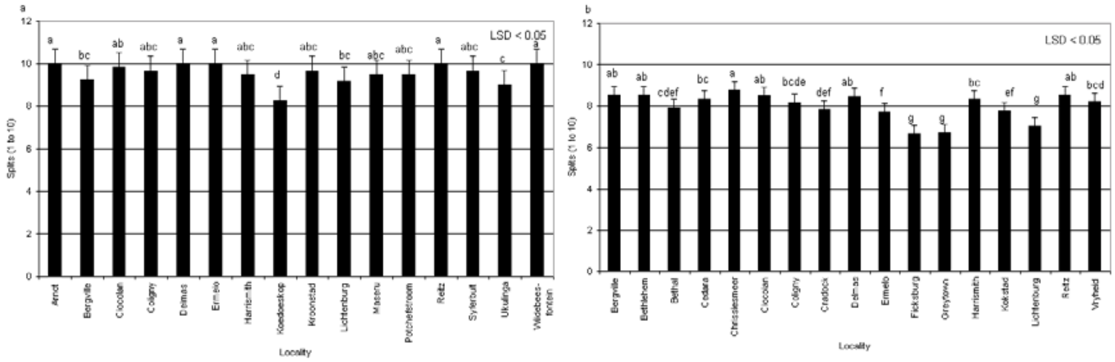


Figure 4.19 Mean split values for localities of canned small white bean cultivars for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

Poor split values were found for beans from Koedoeskop and Ukulinga during 2001/02, as well as Greytown and Lichtenburg during 2002/03 (Figures 4.19a & b), due to the effect of high PWDWT values on splits (Figures 4.17a & b) (Van Buren *et al*., 1986). Beans from Ficksburg (2002/03) also had low split values (Figure 4.19b), although PWDWT values were low (Figure 4.17b). Low VA values at Ficksburg could be ascribed to small-sized seeds (Figures 4.4b) (Faris & Smith, 1964).

4.3.2.2.5 Effect of locality on seed size

The size values for localities (2001/02 and 2002/03) are provided in Figures 4.20a & b. According to the South African canned bean industry, consumers of small white beans in tomato sauce are sensitive to bean size. Beans that deviate too much in size from the regular bean (reference standard) would be rejected by consumers.

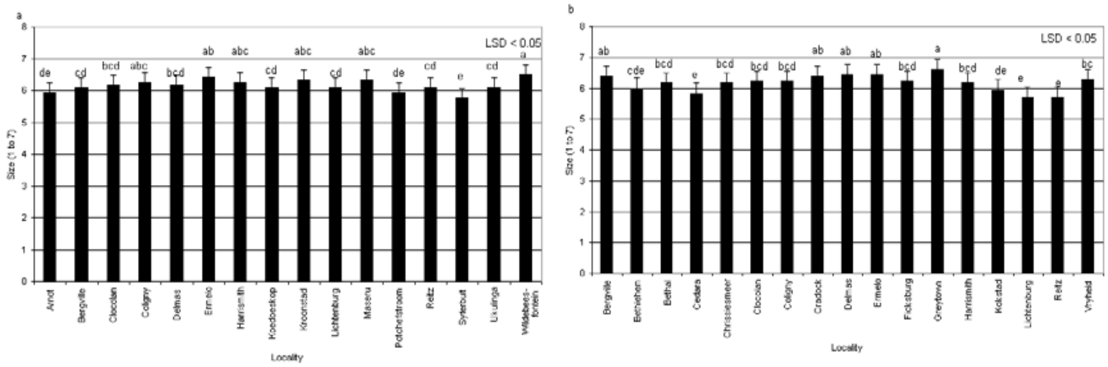


Figure 4.20 Mean seed size values for localities of canned small white bean cultivars for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

Beans from Wildebeesfontein (Figure 4.20a) and Greytown (Figure 4.20b) were more acceptable than those from most other localities. Those from Syferbult (2001/02), Cedara, Lichtenburg and Reitz (2002/03) had significantly lower size values than most other beans (Figures 4.20a & b). Beans from Wildebeesfontein also had significantly better VA values (Figure 4.18a), since acceptability by the consumer depends on acceptability in size. The opposite was found for beans from Syferbult (2001/02), Cedara, Lichtenburg and Reitz (2002/03) (Figures 4.18a & b) which had less acceptable VA values due to poor seed sizes. Although beans from Greytown had better size values than other beans, VA values of these beans were poor (Figure 4.18b). In this case poor VA values were caused by severe splitting (Figure 4.19b).

4.3.2.2.6 Effect of locality on texture

The texture values for localities (2001/02 and 2002/03) are provided in Figures 4.21a & b. The softest beans were from Harrismith, Koedoeskop, Ukulinga (Figure 4.21a) and Cradock (Figure 4.21b). All these also had good PWDWT (Figures 4.17a & b) and HC values (Figures 4.16a & b), which softened the beans (Balasubramanian *et al.*, 1999). Due to the softness of beans from Koedoeskop and Cradock, the VA values (Figures 4.21a & b) were lower (Walters *et al.*, 1995).

Texture of beans was mostly influenced by locality (E/G ratio > 1) (Table 4.21). The effect of environment on texture values was even stronger during 2000/01, where the E/G ratio was 10.82 (Table 3.11). As mentioned texture of beans is affected by PWDWT, which is confirmed by the fact that the latter was also more affected by locality than by genotype (Table 4.21).

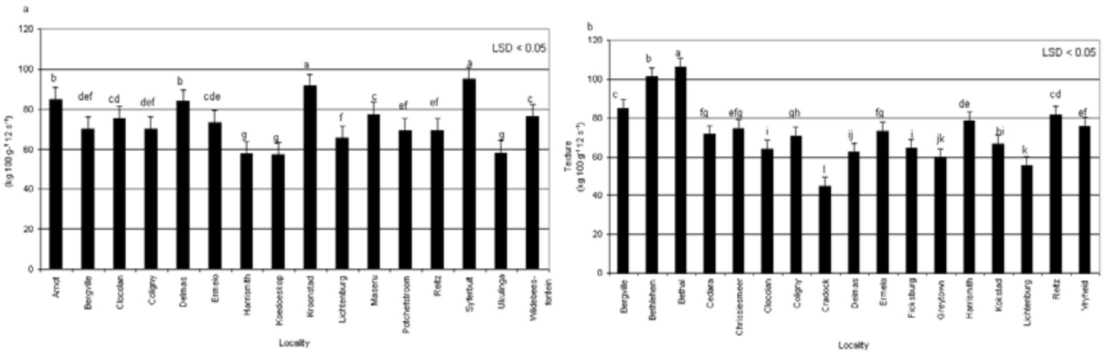


Figure 4.21 Mean texture values for localities of canned small white bean cultivars from for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

4.3.2.2.7 Effect of locality on clumping

As in 2000/02 (Table 3.11), clumping of beans were more affected by locality than by cultivar during 2002/03 (E/G > 1) (Table 4.21). The clumping values for localities (2001/02 and 2002/03) are provided in Figures 4.22a & b. No differences in clumping of beans from different localities were found during 2001/02 (Figure 4.22a).

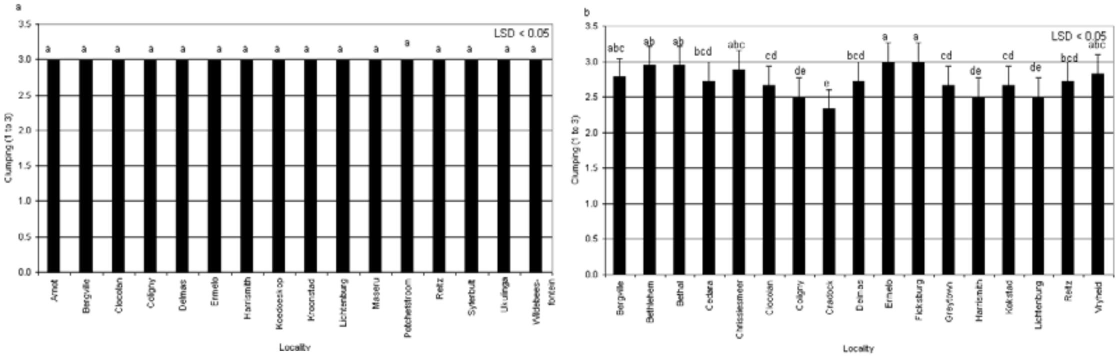


Figure 4.22 Mean clumping values for localities of canned small white bean cultivars for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

Beans with excessive breakage during cooking would result in starch exudation into the canning medium, with consequential clumping of individual beans (Hosfield & Uebersax, 1980). This was found to be the case with beans from Cradock, Kokstad and Lichtenburg (Figure 4.22b). The low clumping scores of these beans were accompanied by low values for splitting (Figure 4.19b). Balasubramanian *et al*., (1999) showed that beans with low HC values also clump more during canning. This was found to be the case for beans from Harrismith and Clocolan (Figures 4.16b & 4.22b).

According to Wang *et al*. (1988), beans that display severe clumping would also have lower PWDWT, as starch from the clumped portion would leach through the screen during washing. This was found to be true for beans from Clocolan, Coligny, Harrismith and Kokstad with low clumping (Figure 4.22b) and PWDWT values (Figure 4.17b). Since clumping affects PWDWT, it would explain why both were more affected by locality than by cultivar (Table 4.21).

4.3.2.2.8 Effect of locality on colour (L-, a_L- and b_L-values)

The colour (L-, a_L- and b_L-values) values for localities (2001/02 and 2002/03) are provided in Figures 4.23a & b to 4.25a & b. Visual appearance of canned beans correlated significantly with L-values (Chapter 2, Table 2.16). Beans from Koedoeskop (2001/02), Cradock, Clocolan and Ficksburg (2002/03) had significantly higher L-values than most other beans (Figures 4.23a & b). From these localities, only beans from Clocolan had good VA values (Figure 4.18b). L-values were more affected by locality than by cultivar during 2001/02 (E/G > 1), while the opposite were found for 2002/02 (Table 4.21). The reason for this could be that more cultivars were used during the last season, resulting in more variation. During 2000/01 where only four cultivars were used, environment also contributed more to the variation in L-values.

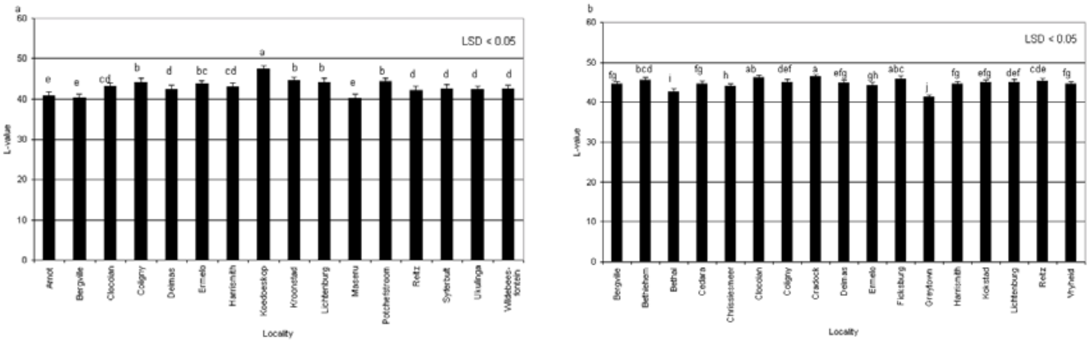


Figure 4.23 Mean L-values for localities of canned small white bean cultivars for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

The a_L-values of beans correlated significantly with HC and with PWDWT, as a_L-values were more sensitive to changes in the MC of beans (Chapter 2, Table 2.16). Beans from Bethlehem and Ficksburg, on the other hand, had low a_L-values (Figure 4.24b), accompanied by low PWDWT (Figure 4.17b) values. Beans from Greytown had high a_L (Figure 4.24b)- and PWDWT (Figure 4.17b) values during 2002/03.

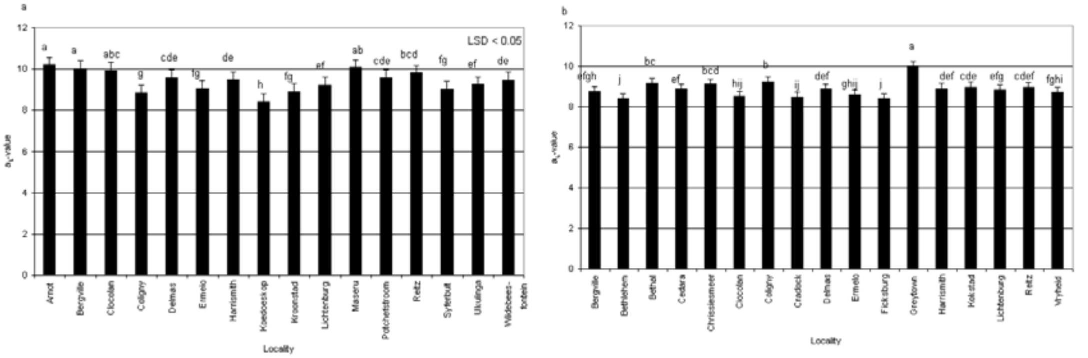


Figure 4.24 Mean a_L-values for localities of canned small white bean cultivars for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

The b_L-value of beans correlated significantly with splits (Chapter 2, Table 2.16). The low b_L- values (Figure 4.25b) of beans from Bethal were caused by splitting, as shown in the low split values (Figure 4.19b). The higher b_L-values of beans from Cloclolan, Lichtenburg, Potchefstroom (Figure 4.25a), Bergville, Bethlehem, Delmas, Harrismith and Reitz (Figure 4.25b) were the result of fewer splits (Figure 4.19a & b). The b_L-values were mostly affected by locality during 2001/02 and 2002/03 (E/G ratio > 1) (Table 4.21), which was also the case during 2000/01 (Table 3.11)

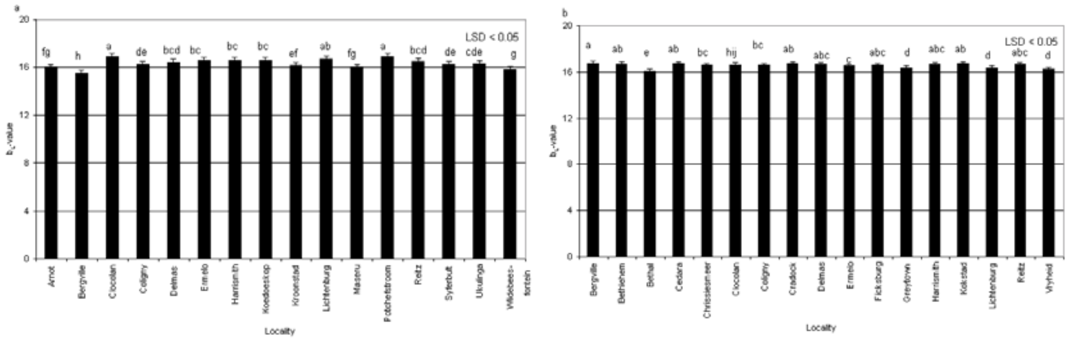


Figure 4.25 Mean b_L-values for localities of canned small white bean cultivars for the a) 2001/02 and b) 2002/03 seasons (Different letters indicate significant differences at *P* = 0.05).

4.3.2.2.9 Canonical variate analysis for the effect of environment on canning quality

The CVA for cultivar on environment (locality x season) indicated that CV 1 (43.20 %) and CV 2 (26.77 %) contributed only 69.97 % to the variation in environments. The latent roots for CV 1 (2.63) and CV 2 (1.63) were > 1, indicating that for both variations in canning quality was mostly within groups (Digby *et al.*, 1989). From the latent vectors followed the following discriminating equations for CV 1 and CV 2:

$$\text{CV 1} = -0.295\,(\text{PWDWT}) + 0.499\,(\text{Splits}) + 0.126\,(\text{VA}) - 0.598\,(\text{L-value}) - 0.606\,(a_L\text{-value}) + 43.07 \qquad (3)$$

$$\text{CV 2} = -0.489\,(\text{PWDWT}) - 0.448\,(\text{Splits}) + 0.226\,(\text{VA}) + 0.438\,(\text{L-value}) - 0.594\,(a_L\text{-value}) + 15.58 \qquad (4)$$

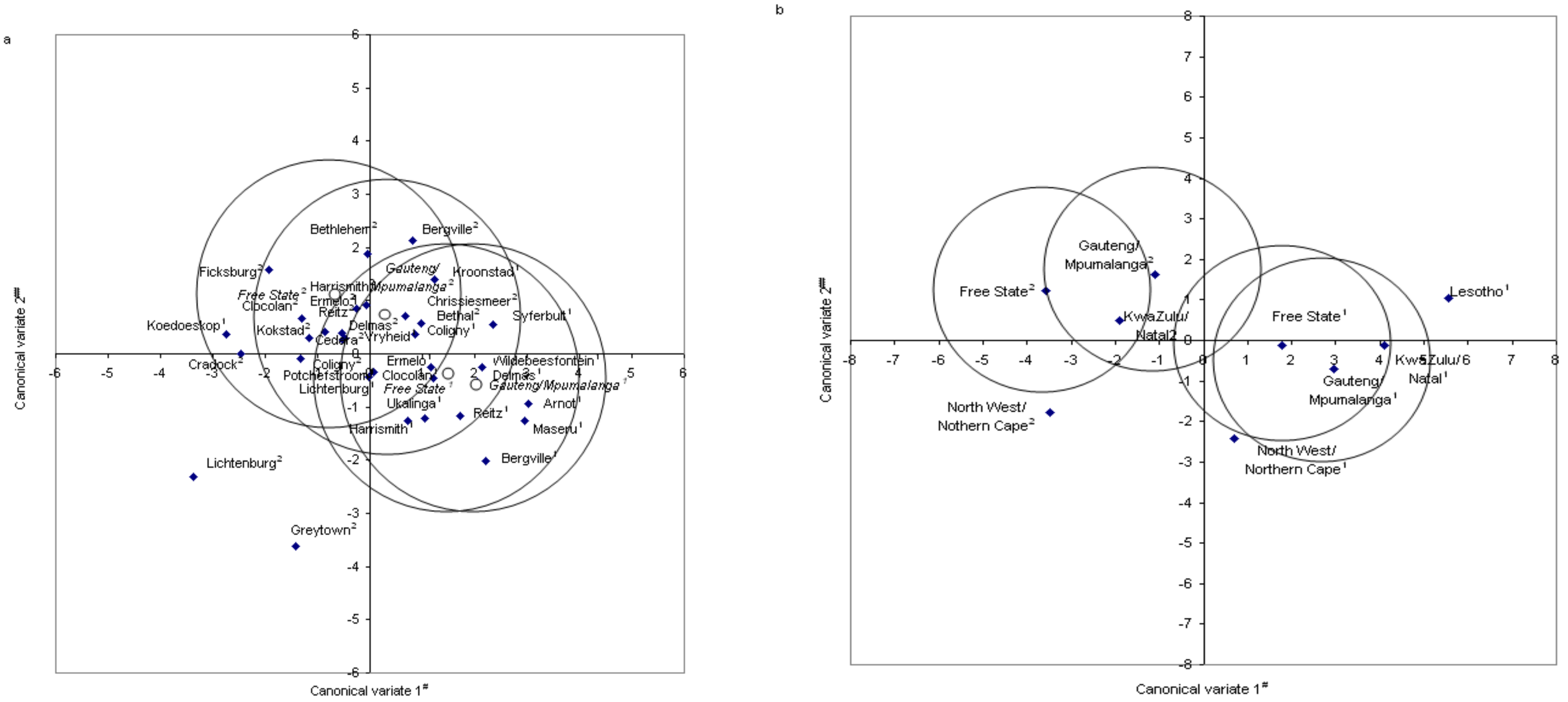
From Table 4.24 it is apparent that PWDWT (r = -0.79), splits (r = 0.69), VA (r = 0.60) and L-value (r = -0.69) correlated with CV 1, while a_L-value (r = -0.63) correlated with CV 2. Figure 4.26a provides a plot of the scores of CV 1 vs. CV 2. 95 % Confidence circles were drawn around the most important dry bean production areas (3.3.4.2). Beans with good split and VA, but poor PWDWT and low L-values would be found to the right side (Figure 4.26a). Beans with high a_L-values would be found at the bottom half of the plot.

Table 4.24 Correlation matrix of canonical variates 1 and 2 with canning quality parameters for 33 environments (locality x season) of seven small white bean cultivars

	Percentage washed drained weight	Splits	Visual appearance	L-value	a_L-value
Canonical variate 1	-0.79	0.69	0.60	-0.69	0.52
Canonical variate 2	-0.54	0.02	0.16	0.59	-0.63

Beans from Lichtenburg and Greytown during 2002/03 were the only localities outside the 95 % confidence circles for the most important production areas. The low scores for CV 1 of Lichtenburg and Greytown were due to high PWDWT (Figure 4.17b), but low VA (Figure 4.18b) and split values (Figure 4.19b) (equation 3). Lichtenburg also had higher L-values (Figure 4.23b) than Greytown, resulting in its lower CV 1 value (equation 3). The lower score of Greytown than Lichtenburg for CV 2 was due to higher a_L-values (Figure 4.24b) found at Greytown (equation 4). Beans from Lichtenburg and Greytown would therefore be the most unacceptable in canning quality and most different from those of other localities during 2002/03.

Beans with the best canning quality would be those with positive scores for CV 1 (good VA and splits), but these values should not be too high (too low PWDWT values) (equation 3). Beans with very low PWDWT values would be too hard (Balasubramanian *et al.*, 1999). Score for CV 2 should be close to the average (not too high positive or negative) to prevent too much colour deviation from the average colour of beans (a_L-values) (equation 4).



#Canonical variate 1 = (-) Percentage washed drained weight; (-) L-value; Splits, Visual appearance
##Canonical variate 2 = (-) a_L-value
[1] 2001/02 season
[2] 2002/03 season
○Names in italics indicates most important dry bean production areas

#Canonical variate 1 = (-) L-value; (-) b_L-value; Splits, Visual appearance; a_L-value; Clumping
##Canonical variate 2 = (-) Percentage washed drained weight; (-) Hydration coefficient
[1] 2001/02 season
[2] 2002/03 season

Figure 4.26 Plot of canonical variates 1 vs. 2 for a) 33 environments (locality x season) of seven small white beans cultivars b) nine environments (region x season) to indicate groupings between environments (groups within the same circles indicate no significant differences at *P* = 0.05).

As beans from different localities were not significantly different in canning quality and some were within acceptable and unacceptable groups simultaneously, interpretation of the results was difficult. Bean canning quality in industry is usually defined in terms of dry bean production areas and not according to localities, since some localities might be found in between poor and good regions. In industry canning companies buy beans from producers in a particular area, since beans from different localities are combined at regional silos. This would explain the fact that locality x season did not differ significantly (Figure 4.26a), although the range over which they were spread on the plot was high. The effect of environment on canning quality was therefore tested on a second CVA, representing dry bean production regions.

The CVA for region x season accounted for 84.22 % of the variation in canning quality, as compared to only 69.97 % for locality x season. Canonical variate 1 accounted for 71.37 % and CV 2 for 12.85 % of the variation. The use of regions instead of localities would therefore discriminate better between dry bean quality in relation to environments. The latent roots for CV 1 (10.21) and CV 2 (1.84) were > 1, indicating that for both variations in canning quality was mostly within groups (Digby *et al*., 1989). From the latent vectors followed the following discriminating equations for CV 1 and CV 2:

$$\text{CV 1} = -0.112\ (\text{PWDWT}) + 0.477\ (\text{Splits}) + 0.121\ (\text{VA}) -1.681\ (\text{L-value}) - 1.256\ (a_L\text{-value}) + 0.774\ (b_L\text{-value}) + 1.695\ (\text{Clumping}) + 10.784\ (\text{HC}) + 49.38 \qquad (5)$$

$$\text{CV 2} = -0.614\ (\text{PWDWT}) - 0.439\ (\text{Splits}) - 0.094\ (\text{VA}) -0.655\ (\text{L-value}) – 2.367\ (a_L\text{-value}) + 0.838\ (b_L\text{-value}) + 0.000\ (\text{Clumping}) – 1.409\ (\text{HC}) + 78.51 \qquad (6)$$

Table 4.25 indicates that splits (r = 0.70), VA (r = 0.70), a_L- (r = 0.78) and clumping (r = 0.63) correlated positively and b_L- (r = -0.70) and L- (r = -0.86) negatively with CV 1. Percentage washed drained weight (r = -0.84) and HC (r = -0.61) correlated negatively with CV 2. Figure 4.26b provides a plot of the scores of CV 1 vs. CV 2, as well as 95 % confidence circles for the most important dry bean production regions (GP / MP and FS) for both seasons. Regions with beans with high splitting, VA, clumping and a_L-values and low L- and b_L-values would be found to the right side of the plot. Regions with beans with high HC and PWDWT values would be found to the lower half of the plot. When CVA is performed with regions, eight canning parameters were found to correlate with CV 1 and CV 2 (Table 4.25). When CVA is performed using localities only five canning parameters correlated with CV 1 and CV 2 (Table 4.24), which confirms that the use of regions would better distinguish between the canning quality of different environments, than localities.

Table 4.25 Correlation matrix of canonical variates 1 and 2 with canning quality parameters of nine region x season interactions of seven small white bean cultivars

	Percentage washed drained weight	Splits	Visual appearance	L-value	a_L-value	b_L-value	Clumping	Hydration coefficient
Canonical variate 1	-0.42	0.70	0.73	-0.86	0.78	-0.70	0.63	0.28
Canonical variate 2	-0.84	-0.12	0.04	-0.17	-0.07	0.00	0.14	-0.61

Beans from all regions had better canning quality properties during 2001/02 than during 2002/03, due to the higher CV 1 scores (higher HC, splits, VA and clumping) (Tables 4.18 & 4.19) of regions from the first season (equation 5). In Appendix A, Tables 1 and 2, it is shown that the total average rainfall during 2002/03 was lower than in the previous season. Mean irrigation levels were also lower during these seasons. Levels of P in the soil (Appendix, Tables 3 & 4) were also lower. Conditions were therefore more optimal during 2001/02 for cultivation of good quality beans for canning purposes. The significance of difference between these two seasons could not be determined, since different cultivars and localities were mostly used. With the assistance of the CVA, differences in canning quality over seasons could be identified statistically.

The canning quality of beans from FS, KZN and GP / MP was not significantly different during 2001/02 (Figure 4.26b). The same was found for laboratory canned beans in 2000/01 (Figure 3.8). Beans from Lesotho and NW / NC were significantly different from beans from the most important productions areas in 2001/2002, as was the case with NW / NC for laboratory canned beans in 2000/01 (Figure 3.8). The high CV 1 scores of beans from FS (Cloclolan, Harrismith, Kroonstad and Reitz), GP / MP (Arnot, Delmas, Ermelo and Wildebeesfontein) and KZN (Ukulinga) (Figure 4.26b) in 2001/02 were due to good split and VA values (Figures 4.18a & 4.19a) (equation 5). The slightly negative CV 2 scores of these regions were due to mean HC and

PWDWT of regions that were mostly around the average (Figures 4.16a & 4.17a) (equation 6).

The lower CV 2 scores for beans from NW / NC in 2001/02 could be ascribed to higher HC (Koedoeskop and Coligny) and PWDWT (Koedoeskop, Lichtenburg and Potchefstroom) during 2001/02 (Figures 4.16a & 4.17a) (equation 6), while CV 1 scores were in agreement with those of FS and GP / MP. The softer beans of NW / NC caused more splitting of beans in 2000/01 (Figure 3.8), which was confirmed by the softer texture (Koedoeskop, Potchefstroom and Coligny) (Figure 4.121a) and split values (Koedoeskop) (Figure 4.19a) of these beans in 2001/02. Softer beans were the result of higher PWDWT values (Chapter 2, Table 2.16). The higher CV 1 score of beans from Lesotho (Maseru) was due to low L-values (Figure 4.23a) (equation 5), while CV 2 was high due to the low PWDWT values (Figure 4.17a) (equation 6).

During 2002/03 the CV 1 scores for the canning quality of beans from all regions were lower, but different regions kept their relative positioning to each other (Figure 4.26b). As found during 2001/02 beans from GP / MP, FS and KZN were not significantly different in canning quality during 2002/03 (Figure 4.26b). Scores for CV 1 were lower due to lower VA and split values (Figures 4.18b & 4.19b) of many of the localities in these regions (equation 5). Scores for CV 2 were higher in 2002/03, due to low HC and PWDWT values at some localities (Figures 4.16b & 4.17b)(equation 6). These beans were therefore unacceptable. Reasons for unacceptability of beans at these localities were discussed in 4.3.2.2.1 to 4.3.2.2.4. Better VA values (Figures 4.18a & b) were found at GP / MP, FS and KZN during 2001/02 than during 2002/03, explaining the different positioning on the plot during the last season.

As during 2002/03, beans from NW / NC were significantly different in canning quality to those of the most important dry bean production areas during the same season and kept its lower score for CV 2, relative to other regions. The lower CV 2 score for beans from this region was once again, the result of good HC (Coligny and Lichtenburg) and PWDWT (Lichtenburg) values (Figures 4.16b & 4.17b) (equation 6). The lower CV 1 scores for 2002/03 were due to lower VA and split values (Lichtenburg) (Figures 4.18 & 4.19) than during 2001/02 (equation 5). Poor VA could have been the result of smaller sized seeds during this season as compared to the previous season (Figures 4.4a & b). Higher PWDWT values during 2002/03 could have resulted in more splits found during this season (Figures 4.17a & b). The difference in the performance of bean producing regions over the two seasons is an indication of a region x season interactions.

4.4 Conclusions

These results indicated that physical properties (MC and 100SM) were significantly influenced by locality. Contrary to what was found for 100SM, MC was not significantly influenced by cultivar and cultivar x locality interactions. Moisture content of dry beans was therefore a function of environmental conditions before harvest and was more affected by environment than genotype effects (E/G ratio > 1). Seed size of dry beans affected canning quality directly, since it affects HC, PWDWT, splits and size values. Seed size could be more affected by genotype or environment, depending on the season, cultivars and localities under consideration.

Cultivar, locality and cultivar x locality interaction significantly influenced canning quality parameters of dry beans. Viscosity of bean tomato sauce was not suitable to be used as a canning quality parameter (high CV and RMSE values). Teebus and Teebus RR1 were similar in all canning quality aspects, and had poor HC and PWDWT values, as was also found for Teebus during 2000/01. The VA of these beans was significantly better than that of other cultivars. PAN 121 had low HC and PWDWT values and harder texture values. PAN 185 had lower VA and size values. OPS-KW1 had low split and size values. PAN 120 and PAN 123 had lower VA and split values than Teebus and Teebus RR1. Beans had higher L-values during 2001/02 and 2002/03 than during the 2000/01 season. The a_L-values were lower during the last two seasons, because of lower HC and PWDWT values. The significantly lower b_L-values of OPS-KW1 were caused by a higher incidence of splits.

Hydration coefficient, VA, split, size and a_L-values were more affected by cultivar (genotype) than by locality (environment) (E/G ratios < 1). Percentage washed drained weight, clumping, texture and b_L-values were more affected by environment

(E/G ratio > 1). L-values were affected mostly by cultivar during 2001/02 and by locality during 2002/03.

According to the CVA, Teebus RR1, PAN 120, PAN 121 and PAN 123 met the choice grade standard canning quality of Teebus. Although the separate canning parameters of these beans were different from Teebus, they still met the choice grade standard by being within the 95 % confidence circle of Teebus on the CVA. Standard grade quality cultivars were PAN 185 and OPS-KW1. Poor sizes of these beans could lead to consumer rejection when a choice grade product is desired. The discriminative equations for CV 1 and CV 2, derived from the CVA, could be employed as a model to predict the canning quality of samples not included in these trials, but grown under similar conditions, which would be tested in Chapter 5.

Regarding the effect of locality, hydration coefficients and PWDWT values of beans were higher at Koedoeskop (2001/02) and Greytown (2002/03), due to the small sized seeds from these localities. Beans from these localities also had poor VA and split values, due to high PWDWT values. The latter also caused softness of these beans. The poor HC and PWDWT values of beans from Kroonstad (2001/02) and Bethal (2002/03) were indicative of water imbibition problems, caused by low initial MC levels. This was illustrated by their hardness, while VA values were acceptable. Beans from Kroonstad also had few splits and acceptable size values.

The CVA of locality x season indicated only beans from Lichtenburg and Greytown (2002/03) to be significantly different from the most important dry bean production areas of South Africa (FS and GP /MP). Despite high PWDWT values of these beans, split and VA values were poor, while colour deviated from the average colour of canned beans. These beans were therefore most unacceptable in terms of canning quality. As the CVA of locality x season was unable to provide clear distinctions between the canning quality of beans from different environments and more canning parameters correlated with CV 1 and CV 2 when regions were used than with localities, a CVA for canning regions x season was used. From this CVA beans from 2002/03 were identified to have significantly lower canning quality properties than those of 2001/02. Beans from NW / NC had significantly different canning quality to those of the most important dry beans production areas in 2001/02 and 2002/03, as high PWDWT and HC values caused too soft beans. During 2001/02 beans from FS, GP / MP and KZN were not significantly different in canning quality and performed better than those of NW / NC. The canning quality of dry bean cultivars from different environments can therefore be successfully determined using CVA. In Chapter 5 the prediction model for CV 1 and CV 2 will be evaluated and tested, using cultivar samples from seasons and lines selected for breeding which were not included in Chapter 4.

CHAPTER 5

A CANNING QUALITY PREDICTION MODEL FOR SMALL WHITE BEAN LINES SELECTED FOR BREEDING

5.1 INTRODUCTION

Small white bean cultivars intended for canning in tomato sauce are classified in South Africa either as “choice” or “standard” grade. From the choice grade cultivars, Teebus, Arctic and Kosi (De Lange & Labuschagne, 2000), only Teebus is still commercially available. Teebus is therefore considered as the reference standard for testing the canning quality of small white beans, both on small scale and by industry (Chapters 2 & 3). Teebus RR1, PAN 120, PAN 123 and PAN 121 are the other commercially available small white bean cultivars with canning quality comparable to that of Teebus (Chapter 4). Dry beans breeders in South Africa are continuously attempting to produce more cultivars with acceptable canning quality properties. The need therefore exists to identify a simple model to classify lines selected for breeding as choice or standard grade canning beans.

Canning quality of dry beans is determined by using various canning quality parameters (Hosfield & Uebersax, 1980; Hosfield *et al*., 1984b; Balasubramanian *et al*., 1999; De Lange & Labuschagne, 2000; Chapter 2). Analysis of variance proved to be useful in interpreting the different canning parameters separately, but does not indicate the grouping of variates. Canonical variate analysis indicates both the grouping of variates and the most important parameters to discriminate between them (De Lange & Labuschagne, 2000). Van Lill *et al*. (1995) used a principal component analysis to group the bread baking and yield characteristics of wheat. Canonical variate analysis was used by Osborne *et al*. (1993) to discriminate between quality types in wheat breeding lines. De Lange & Labuschagne (2000) used CVA to discriminate between chemical, yield and canning quality properties of dry beans.

Van Lill & Smith (1997) made use of discriminating equations obtained from CVA to contrast the milling, mixing and fermentation quality of wheat genotypes. De Lange & Labuschagne (2000) also used CVA for canning quality, chemical analysis and yield to identify two equations to determine the coordinates of CV 1 and CV 2 on a plot to indicate the positioning in cultivars with respect to these properties. In the latter case the model was not validated. In Chapter 4 of the present study the canning quality of dry bean cultivars from different localities and seasons were evaluated, using the small-scale canning and evaluation procedures with the assistance of CVA (Chapter 4). From the CVA, equations were then obtained (4.3.2.1.9) to predict the canning quality of small white beans not included in the original trials from which the model was developed. The model indicated that HC, splits, size and VA would be the most important canning quality parameters to discriminate between cultivars or entries.

The ARC–GCI annually evaluates the canning quality of beans derived from its breeding program. Information generated by these evaluations is used by breeders to identify suitable breeding lines for the breeding program. The scientific accuracy and comparability of these results are therefore of utmost importance, due to the high costs of maintaining a breeding program. The objective of this chapter is therefore to validate the model for the prediction of the canning quality of small white beans by testing it on samples that were not included in the development of the model.

5.2 MATERIALS AND METHODS

5.2.1 Dry bean samples

Four cultivars from four regions from the 2000/01 season used in Chapter 2 (2.2.1) with known laboratory canning quality were firstly used to test the model. The reason for using this data was to test the model on known cultivar samples from a season not used in the development of the model.

Since the purpose of the model is to test the samples selected for breeding, the model was also tested on breeding material. Twenty-four small white bean entries from the pilot breeding trials of the ARC-GCI were used. These entries included Teebus, which served as the reference standard for acceptability in canning quality for choice grade. Samples represented three localities, namely Bethlehem, Delmas and Potchefstroom. The entries were planted in a randomized block design with three replicates during 2002/03. Four-row plots (5-m long and 750 mm apart) were planted with a self-driven planter and beans were planted at 75 mm spacing within rows. Fertilization was applied at recommended rates for each locality. Samples were harvested manually from the middle two rows of individual plots. Three replicates of small white bean entries were used for canning purposes. All samples were kept refrigerated at 4 °C for not longer than two months before canning.

5.2.2 Determination of canning quality

Canning quality of cultivar samples from 2000/01 was obtained by using regional data of these cultivars from Chapter 3 (Tables 3.2.1 to 3.2.10).

Canning of breeding samples was done according to the MCT described in Chapter 2 (2.2.2.3). Canning quality was determined as was done in Chapter 2. The HC (2.2.3.2.1), PWDWT (2.2.3.1.1), VA (2.2.3.1.2), splits (2.2.2.1.3), size (2.2.3.2.6), texture (2.2.3.2.5), clumping (2.2.3.2.7) and colour (2.2.3.2.8) were determined.

5.2.3 Statistical analysis of data

The CVA for cultivar data used in Chapter 3 was considered for cultivar samples (Figure 3.6).

Analysis of variance was performed on data from the pilot breeding trials (Costat, Cohort Version 6). Canning data of these trials were subjected to CVA to identify groupings between entries (Genstat 5). Samples not significantly different ($P > 0.05$) from Teebus (reference standard for choice grade) in canning quality at a specific locality were identified by using a 95 % confidence circle on the plot of the CVA and prediction model. The radius of the circle (2.45) was determined by the square root of the 95 % point of a chi-squared variable. The degrees of freedom were 2, since the plot is two-dimensional (Digby *et al.*, 1989).

5.2.4 Evaluation of a canning prediction model

Values for CV 1 and CV 2 were calculated from cultivar and breeding trial data over regions and localities respectively and for breeding trial entries at individual localities by using the discriminative equations derived from the CVA for six cultivars from 33 localities and two seasons in Chapter 4 (4.3.2.1.9):
CV 1 = -7.296 (HC) - 0.107 (splits) + 1.497 (size) – 0.314 (VA) + 7.02
CV 2 = -1.809 (HC) – 0.336 (splits) – 0.678 (size) – 0.448 (VA) + 13.97
Confidence circles (95 %) were used on the plot as for the CVA (5.2.3).

The entries not significantly different from Teebus on the plots derived from the model were compared to the entry positioning on the CVA performed with Genstat 5 on the data.

5.3 RESULTS AND DISCUSSION

5.3.1 Cultivar samples

In Chapter 3 (3.3.4.1) the CVA for cultivars (Figure 3.6) indicated that Teebus was the only cultivar to qualify for the choice grade class beans. Helderberg, PAN 185 and OPS-KW 1 fell within the standard grade group of cultivars.

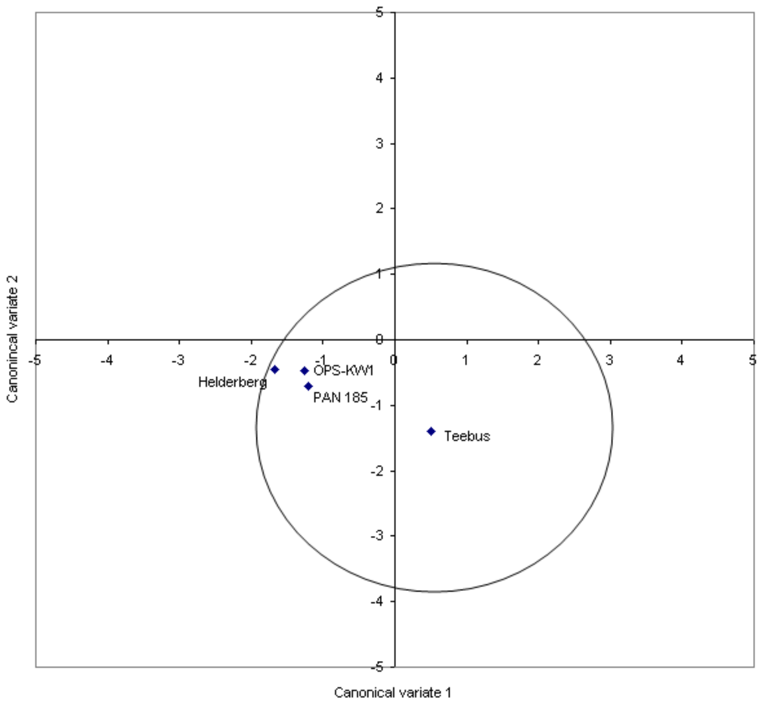
Figure 5.1 provides the plot of the scores of CV 1 vs. CV 2 of cultivars as predicted by the prediction model. The latent roots for CV 1 and CV 2 were only > 1 in the case of CV 1 (4.3.2.1.9). Therefore CV 1 would be most important to discriminate between groups. From the latent vectors the following discriminating equations for CV 1 and CV 2 were derived, as described in Chapter 4 (4.3.2.1.9):

$$\text{CV 1} = -7.296\,(\text{HC}) - 0.107\,(\text{Splits}) + 1.497\,(\text{Size}) - 0.314\,(\text{VA}) + 7.02 \qquad (1)$$

$$\text{CV 2} = -1.809\,(\text{HC}) - 0.336\,(\text{Splits}) - 0.678\,(\text{Size}) - 0.448\,(\text{VA}) + 13.97 \qquad (2)$$

Once again Teebus was used as the reference standard for choice grade cultivars. The 95 % confidence circle of Teebus on the plot of the scores for CV 1 vs. CV 2 (Figure 5.1) indicates that all entries are classified as choice grade class for canning.

In Chapter 4 (Table 4.23) it was shown that CV 1 discriminated between entries based on HC and size values and CV 2 on VA and split values, but the latter had latent roots < 1. The high CV 1 score of Teebus was caused by high size and low HC values (equation 1) and the low CV 2 score was the result of good VA and split values (equation 2). According to the model, PAN 185, OPS-KW1 and Helderberg were within the 95 % confidence circles of Teebus. Although the standard grade cultivars were grouped together and distant from Teebus, the model was not able to predict them to be outside the 95 % confidence circle of Teebus. Lower CV 1 scores of the standard grade cultivars were caused by their low size and high HC values (equation 1). This indicates that the model lacks the sensitivity that the CVA has to discriminate between cultivars based on canning quality grades. The model could therefore be used as a preliminary tool to indicate groupings of cultivars in the National Cultivar Trials by determining only HC, VA, splits and size values, but not to classify cultivars as choice or standard grade. When the goal is to do the latter, all canning properties should be determined and a CVA performed.



#Canonical variate 1 = (-) Hydration coefficient; Size
##Canonical variate 2 (-) Visual appearance; (-) Splits

Figure 5.1 Plot of canonical variates 1 vs. 2 for four small white bean cultivars from four regions as predicted by the CVA model (95 % confidence circle indicates entries not significantly different from Teebus).

Although the model was unable to classify cultivars specifically as choice or standard grade, the objective of the model was to assist breeders in selecting lines to continue with in the next phase of their breeding programs. Therefore the model was tested on breeding lines as would be discussed in 5.3.2.

5.3.2 Breeding samples

Tables 5.1 to 5.10 provide canning quality properties of small white beans from the pilot breeding trials. The mean, minimum, maximum and F-values for the main and interaction effects are provided in Table 5.11. Significant differences in entries were found for all parameters, while the influence of locality on HC was not significant. Entry x locality interactions were significant for all canning parameters, except for splits. Significant differences in replicates for size, L- and b_L-values were found, which may be ascribed to the small ranges found for these values. Any difference in values within such a small range would be significant. F-values indicated that canning quality parameters were more significantly affected by locality, except for HC.

The R^2-values, CV and RMSE are provided in Table 5.12. R^2-values were significant and CV-values lower than 10. The slightly higher RMSE values of texture (> 5.0) were due to the wide range in texture values (Table 5.11). All other RMSE values approached zero. These results indicate that enough variation in data occurred to be valid for testing a model and that data were significant to be used.

The relative effects of genotype (entry) and environments (locality) on canning quality parameters are indicated in Table 5.13. All canning properties, except for HC were more affected by environment than genotype (G/E ratio > 1). Clumping, texture, L-value and b_L-value were also identified to be mainly affected by locality in Chapter 3 and 4 where different number of genotypes and environments were used (Tables 3.11 & 4.21). PWDWT was also mostly affected by locality in Chapter 4 (Table 4.21). Visual appearance and splits were mostly affected by cultivar (genotype) in Chapter 4 (Table 4.21), where more differences between cultivars were found for these particular seasons. In Chapter 5 VA and splits were more influenced by environment, due to small differences between entries for these values (Tables 5.3 & 5.4). The pilot breeding trials is the final stages of the breeding program and most of the variation between entries for VA and splits could have been excluded at this stage. Chapter 3 also indicated E/G ratios > 1 for VA and splits, due to more variation in four regions (composed of nine localities) than the four cultivars (Table 3.11). In the present chapter, environment was also found to affect size and a_L-values more (Table 5.13) than was the case in Chapters 3 & 4 (Tables 3.11 & 4.21). Differences between these values for entries could also have been limited at this late stage of a breeding program.

Table 5.1 **Hydration coefficient of 24 small white bean samples from the pilot breeding trials from three localities (2002/03 season)**

Entry no	Replicate	Hydration coefficient			
		Bethlehem	Delmas	Potchefstroom	Mean
1	1	1.76	1.75	1.75	1.75
1	2	1.65	1.81	1.85	1.77
1	3	1.74	1.93	1.82	1.83
2	1	1.94	1.90	1.84	1.89
2	2	1.85	1.88	1.91	1.88
2	3	1.88	1.75	1.95	1.86
3	1	1.67	1.75	1.69	1.70
3	2	1.64	1.67	1.67	1.66
3	3	1.70	1.77	1.75	1.74
4	1	1.79	1.76	1.69	1.75
4	2	1.68	1.85	1.73	1.75
4	3	1.73	1.95	1.71	1.80
5	1	1.34	1.91	1.58	1.61
5	2	1.18	1.92	1.40	1.50
5	3	1.29	1.91	1.54	1.58
6	1	1.97	1.94	1.92	1.94
6	2	1.97	1.86	1.94	1.92
6	3	1.97	1.95	1.93	1.95
7	1	1.93	1.89	1.86	1.89
7	2	1.93	1.88	1.91	1.91
7	3	1.93	1.91	1.88	1.90
8	1	1.94	1.89	1.90	1.91
8	2	1.98	1.92	1.93	1.94
8	3	1.94	1.89	1.89	1.91
9	1	1.94	1.92	1.86	1.91
9	2	1.96	1.91	1.90	1.92
9	3	1.95	1.93	1.87	1.92
10	1	1.96	1.88	1.88	1.91
10	2	1.93	1.89	1.89	1.90
10	3	1.97	1.92	1.87	1.92
11	1	1.94	1.89	1.89	1.91
11	2	1.94	1.89	1.92	1.92
11	3	1.96	1.94	1.89	1.93
12	1	1.95	1.90	1.91	1.92
12	2	1.94	1.90	1.94	1.93
12	3	1.95	1.92	1.92	1.93
13	1	1.93	1.88	1.93	1.91
13	2	1.93	1.91	1.91	1.91
13	3	1.92	1.92	1.88	1.91

Sample no	Replicate	Hydration coefficient			
		Bethlehem	Delmas	Potchefstroom	Mean
14	1	1.95	1.92	1.92	1.93
14	2	1.90	1.96	1.92	1.93
14	3	1.90	1.87	1.89	1.89
15	1	2.01	1.84	1.96	1.94
15	2	2.03	1.88	1.94	1.95
15	3	1.98	1.98	1.90	1.95
16	1	1.96	1.84	1.90	1.90
16	2	1.95	1.85	1.89	1.90
16	3	1.94	1.90	1.90	1.91
17	1	1.95	1.65	1.91	1.84
17	2	1.96	1.66	1.89	1.84
17	3	1.93	1.66	1.86	1.82
18	1	1.50	1.60	1.69	1.60
18	2	1.67	1.59	1.69	1.65
18	3	1.46	1.70	1.73	1.63
19	1	1.77	1.46	1.75	1.66
19	2	1.74	1.40	1.74	1.63
19	3	1.70	1.52	1.73	1.65
20	1	1.38	1.53	1.54	1.48
20	2	1.42	1.63	1.62	1.56
20	3	1.54	1.40	1.51	1.48
21	1	1.72	1.39	1.73	1.61
21	2	1.69	1.28	1.75	1.57
21	3	1.72	1.50	1.73	1.65
22	1	1.15	1.83	1.90	1.63
22	2	1.19	1.88	1.26	1.44
22	3	1.16	1.31	1.24	1.24
23	1	1.95	1.45	1.20	1.53
23	2	1.97	1.60	1.87	1.82
23	3	1.91	1.80	1.91	1.87
24	1	1.34	1.88	1.61	1.61
24	2	1.54	1.90	1.66	1.70
24	3	1.39	1.41	1.58	1.46
Mean		1.78	1.78	1.79	1.78
Min		1.15	1.28	1.20	1.24
Max		2.03	1.98	1.96	1.95
Range		0.89	0.70	0.76	0.72

breeding line entries (n = 24); replicate (n = 3); localities (n = 3), % CV = 5.42

Table 5.2 **Percentage washed drained weight of 24 small white bean samples from the pilot breeding trials from three localities (2002/03 season)**

Entry no	Replicate	Percentage washed drained weight			
		Bethlehem	Delmas	Potchefstroom	Mean
1	1	61.12	58.55	57.46	59.04
1	2	59.77	58.13	57.79	58.57
1	3	59.89	58.97	56.83	58.56
2	1	62.27	57.38	57.05	58.90
2	2	62.13	59.46	56.77	59.45
2	3	59.94	59.30	60.14	59.79
3	1	62.04	55.23	59.53	58.93
3	2	59.84	55.26	57.30	57.46
3	3	58.04	55.24	58.07	57.12
4	1	61.37	57.65	58.56	59.19
4	2	58.99	57.82	53.96	56.93
4	3	57.52	57.47	56.36	57.12
5	1	57.38	55.30	56.54	56.41
5	2	52.18	54.93	56.53	54.55
5	3	52.52	55.68	56.75	54.98
6	1	62.33	54.96	55.71	57.67
6	2	61.55	54.96	54.61	57.04
6	3	59.39	55.06	56.65	57.03
7	1	63.26	52.47	56.14	57.29
7	2	61.12	58.23	56.93	58.76
7	3	59.39	55.32	56.67	57.13
8	1	62.86	56.93	57.70	59.16
8	2	61.15	57.06	55.75	57.99
8	3	59.43	56.81	57.06	57.77
9	1	63.29	53.74	55.96	57.66
9	2	61.65	56.99	56.23	58.29
9	3	59.41	54.46	57.18	57.02
10	1	62.28	54.09	56.18	57.52
10	2	59.96	54.66	55.36	56.66
10	3	58.91	54.98	54.35	56.08
11	1	62.50	55.52	56.30	58.11
11	2	61.14	56.99	56.01	58.05
11	3	61.85	54.27	56.26	57.46
12	1	62.99	55.00	56.85	58.28
12	2	61.06	56.63	55.75	57.82
12	3	62.03	56.73	55.70	58.16
13	1	61.34	54.45	56.92	57.57
13	2	61.25	55.88	55.47	57.53
13	3	61.10	56.35	57.00	58.15

Sample no	Replicate	Percentage washed drained weight			
		Bethlehem	Delmas	Potchefstroom	Mean
14	1	60.99	57.29	57.30	58.53
14	2	61.58	58.93	55.50	58.67
14	3	61.10	58.11	55.59	58.27
15	1	61.80	57.98	57.11	58.97
15	2	60.95	60.34	56.56	59.28
15	3	60.90	59.16	56.00	58.69
16	1	61.86	58.16	55.81	58.61
16	2	59.99	59.65	55.70	58.44
16	3	60.54	58.90	56.99	58.81
17	1	61.82	58.46	55.56	58.61
17	2	59.84	58.85	55.29	57.99
17	3	60.03	58.76	56.75	58.51
18	1	57.61	56.38	54.39	56.13
18	2	57.13	57.65	54.71	56.50
18	3	55.31	56.84	56.50	56.22
19	1	59.45	56.01	54.70	56.72
19	2	56.70	57.34	53.20	55.74
19	3	57.87	56.08	54.09	56.01
20	1	55.34	54.60	56.03	55.32
20	2	54.91	54.41	55.84	55.05
20	3	56.85	53.74	55.94	55.51
21	1	59.64	56.95	52.21	56.27
21	2	57.81	57.79	52.67	56.09
21	3	59.64	56.95	54.87	57.15
22	1	52.97	58.69	57.56	56.40
22	2	51.69	52.84	57.89	54.14
22	3	58.24	51.93	53.54	54.57
23	1	61.78	51.82	54.84	56.15
23	2	60.62	60.18	56.10	58.97
23	3	60.26	60.65	57.33	59.41
24	1	55.22	55.18	54.97	55.13
24	2	57.14	58.56	55.26	56.99
24	3	55.58	57.22	53.95	55.58
Mean		59.57	56.60	56.10	57.43
Min		51.69	51.82	52.21	54.14
Max		63.29	60.65	60.14	59.79
Range		11.60	8.82	7.93	5.65

breeding line entries (n = 24); replicate (n = 3); localities (n = 3), % CV = 2.50

Table 5.3 Visual appearance of 24 small white bean samples from the pilot breeding trials from three localities (2002/03 season)

Entry no	Replicate	Visual appearance (scale 1 to 10)			
		Bethlehem	Delmas	Potchefstroom	Mean
1	1	7.00	6.00	7.00	6.67
1	2	7.00	6.00	7.00	6.67
1	3	7.00	6.00	7.00	6.67
2	1	8.00	6.00	7.00	7.00
2	2	8.00	6.00	7.00	7.00
2	3	8.00	6.00	7.00	7.00
3	1	8.00	8.00	6.00	7.33
3	2	8.00	8.00	6.00	7.33
3	3	8.00	8.00	6.00	7.33
4	1	8.00	8.00	9.00	8.33
4	2	8.00	8.00	9.00	8.33
4	3	8.00	8.00	9.00	8.33
5	1	8.00	6.00	7.00	7.00
5	2	7.00	6.00	7.00	6.67
5	3	7.00	6.00	7.00	6.67
6	1	7.00	6.00	8.00	7.00
6	2	7.00	6.00	8.00	7.00
6	3	7.00	6.00	8.00	7.00
7	1	8.00	7.00	7.00	7.33
7	2	8.00	7.00	7.00	7.33
7	3	8.00	7.00	7.00	7.33
8	1	6.00	8.00	9.00	7.67
8	2	6.00	8.00	9.00	7.67
8	3	6.00	8.00	9.00	7.67
9	1	7.00	6.00	9.00	7.33
9	2	7.00	6.00	9.00	7.33
9	3	7.00	6.00	9.00	7.33
10	1	8.00	6.00	9.00	7.67
10	2	8.00	6.00	9.00	7.67
10	3	8.00	6.00	9.00	7.67
11	1	7.00	6.00	7.00	6.67
11	2	7.00	6.00	7.00	6.67
11	3	7.00	6.00	7.00	6.67
12	1	7.00	6.00	9.00	7.33
12	2	7.00	6.00	9.00	7.33
12	3	7.00	6.00	9.00	7.33
13	1	7.00	6.00	9.00	7.33
13	2	7.00	6.00	9.00	7.33
13	3	7.00	6.00	9.00	7.33
Sample no	**Replicate**	**Bethlehem**	**Delmas**	**Potchefstroom**	**Mean**
14	1	7.00	6.00	8.00	7.00
14	2	7.00	6.00	8.00	7.00
14	3	7.00	6.00	8.00	7.00
15	1	9.00	6.00	8.00	7.67
15	2	9.00	6.00	7.00	7.33
15	3	9.00	6.00	7.00	7.33
16	1	8.00	6.00	7.00	7.00
16	2	8.00	8.00	7.00	7.67
16	3	8.00	8.00	7.00	7.67
17	1	8.00	8.00	7.00	7.67
17	2	8.00	9.00	7.00	8.00
17	3	8.00	9.00	7.00	8.00
18	1	8.00	9.00	8.00	8.33
18	2	8.00	8.00	8.00	8.00
18	3	8.00	8.00	8.00	8.00
19	1	9.00	8.00	9.00	8.67
19	2	9.00	8.00	9.00	8.67
19	3	9.00	8.00	9.00	8.67
20	1	8.00	8.00	8.00	8.00
20	2	8.00	8.00	8.00	8.00
20	3	8.00	8.00	8.00	8.00
21	1	7.00	6.00	8.00	7.00
21	2	7.00	8.00	7.00	7.33
21	3	6.00	6.00	6.00	6.00
22	1	6.00	6.00	8.00	6.67
22	2	7.00	7.00	7.00	7.00
22	3	7.00	8.00	7.00	7.33
23	1	6.00	9.00	7.00	7.33
23	2	7.00	10.00	8.00	8.33
23	3	7.00	8.00	7.00	7.33
24	1	7.00	6.00	8.00	7.00
24	2	8.00	8.00	8.00	8.00
24	3	8.00	8.00	8.00	8.00
Mean		7.50	6.97	7.79	7.42
Min		6.00	6.00	6.00	6.00
Max		9.00	10.00	9.00	8.67
Range		3.00	4.00	3.00	2.67

breeding line entries (n = 24); replicate (n = 3); localities (n = 3), % CV = 5.08

Table 5.4 Splits of 24 small white bean samples from the pilot breeding trials from three localities (2002/03 season)

Entry no	**Replicate**	**Splits (scale 1 to 10)**			
		Bethlehem	**Delmas**	**Potchefstroom**	**Mean**
1	1	6.00	8.00	7.00	7.00
1	2	8.00	7.00	7.00	7.33
1	3	7.00	9.00	9.00	8.33
2	1	6.00	9.00	7.00	7.33
2	2	8.00	9.00	6.00	7.67
2	3	7.00	7.00	7.00	7.00
3	1	8.00	8.00	8.00	8.00
3	2	8.00	8.00	8.00	8.00
3	3	8.00	8.00	9.00	8.33
4	1	8.00	8.00	9.00	8.33
4	2	8.00	9.00	7.00	8.00
4	3	8.00	9.00	8.00	8.33
5	1	9.00	9.00	9.00	9.00
5	2	9.00	9.00	8.00	8.67
5	3	9.00	9.00	8.00	8.67
6	1	7.00	9.00	9.00	8.33
6	2	7.00	9.00	8.00	8.00
6	3	8.00	9.00	9.00	8.67
7	1	9.00	9.00	8.00	8.67
7	2	8.00	8.00	7.00	7.67
7	3	7.00	9.00	8.00	8.00
8	1	6.00	9.00	9.00	8.00
8	2	7.00	9.00	8.00	8.00
8	3	8.00	9.00	7.00	8.00
9	1	7.00	9.00	8.00	8.00
9	2	8.00	9.00	8.00	8.33
9	3	9.00	9.00	9.00	9.00
10	1	8.00	9.00	9.00	8.67
10	2	7.00	9.00	8.00	8.00
10	3	9.00	9.00	8.00	8.67
11	1	8.00	9.00	9.00	8.67
11	2	7.00	9.00	8.00	8.00
11	3	7.00	9.00	9.00	8.33
12	1	7.00	9.00	9.00	8.33
12	2	7.00	8.00	7.00	7.33
12	3	7.00	9.00	9.00	8.33
13	1	8.00	9.00	9.00	8.67
13	2	7.00	9.00	7.00	7.67
13	3	7.00	9.00	8.00	8.00

Sample no	**Replicate**	**Splits (scale 1 to 10)**			
		Bethlehem	**Delmas**	**Potchefstroom**	**Mean**
14	1	8.00	9.00	8.00	8.33
14	2	8.00	9.00	8.00	8.33
14	3	8.00	9.00	9.00	8.67
15	1	7.00	9.00	9.00	8.33
15	2	9.00	9.00	8.00	8.67
15	3	8.00	9.00	9.00	8.67
16	1	8.00	9.00	7.00	8.00
16	2	9.00	9.00	7.00	8.33
16	3	7.00	9.00	7.00	7.67
17	1	7.00	8.00	7.00	7.33
17	2	8.00	9.00	8.00	8.33
17	3	8.00	9.00	8.00	8.33
18	1	7.00	9.00	8.00	8.00
18	2	9.00	9.00	8.00	8.67
18	3	8.00	9.00	7.00	8.00
19	1	7.00	8.00	8.00	7.67
19	2	9.00	9.00	7.00	8.33
19	3	8.00	9.00	7.00	8.00
20	1	9.00	8.00	9.00	8.67
20	2	9.00	9.00	7.00	8.33
20	3	8.00	8.00	8.00	8.00
21	1	7.00	9.00	8.00	8.00
21	2	8.00	8.00	8.00	8.00
21	3	6.00	8.00	7.00	7.00
22	1	10.00	9.00	8.00	9.00
22	2	10.00	8.00	7.00	8.33
22	3	7.00	9.00	9.00	8.33
23	1	7.00	9.00	9.00	8.33
23	2	7.00	9.00	8.00	8.00
23	3	7.00	8.00	7.00	7.33
24	1	8.00	9.00	9.00	8.67
24	2	8.00	9.00	8.00	8.33
24	3	8.00	8.00	8.00	8.00
Mean		7.76	8.72	7.99	8.16
Min		6.00	7.00	6.00	7.00
Max		10.00	9.00	9.00	9.00
Range		4.00	2.00	3.00	2.00

breeding line entries (n = 24); replicate (n = 3); localities (n = 3), % CV = 8.57

Table 5.5 **Size of 24 small white bean samples from the pilot breeding trials from three localities (2002/03 season)**

Entry no.	Replicate	Size (scale 1 to 7)			
		Bethlehem	Delmas	Potchefstroom	Mean
1	1	7.00	6.00	6.00	6.33
1	2	7.00	6.00	6.00	6.33
1	3	7.00	6.00	5.00	6.00
2	1	6.00	5.00	5.00	5.33
2	2	6.00	5.00	5.00	5.33
2	3	6.00	5.00	6.00	5.67
3	1	6.00	6.00	5.00	5.67
3	2	6.00	5.00	6.00	5.67
3	3	6.00	6.00	6.00	6.00
4	1	7.00	7.00	6.00	6.67
4	2	7.00	6.00	6.00	6.33
4	3	7.00	7.00	5.00	6.33
5	1	7.00	6.00	6.00	6.33
5	2	7.00	6.00	5.00	6.00
5	3	7.00	6.00	5.00	6.00
6	1	5.00	5.00	5.00	5.00
6	2	5.00	6.00	6.00	5.67
6	3	5.00	6.00	5.00	5.33
7	1	6.00	6.00	5.00	5.67
7	2	6.00	6.00	6.00	6.00
7	3	6.00	6.00	5.00	5.67
8	1	6.00	6.00	6.00	6.00
8	2	6.00	6.00	5.00	5.67
8	3	6.00	6.00	6.00	6.00
9	1	6.00	6.00	5.00	5.67
9	2	6.00	6.00	6.00	6.00
9	3	6.00	6.00	5.00	5.67
10	1	6.00	6.00	5.00	5.67
10	2	6.00	6.00	5.00	5.67
10	3	6.00	5.00	5.00	5.33
11	1	6.00	5.00	5.00	5.33
11	2	6.00	6.00	5.00	5.67
11	3	6.00	5.00	5.00	5.33
12	1	6.00	5.00	5.00	5.33
12	2	6.00	5.00	5.00	5.33
12	3	6.00	5.00	5.00	5.33
13	1	6.00	5.00	5.00	5.33
13	2	6.00	6.00	5.00	5.67
13	3	6.00	6.00	5.00	5.67
14	1	6.00	5.00	5.00	5.33
14	2	6.00	6.00	5.00	5.67
14	3	6.00	6.00	5.00	5.67
15	1	6.00	6.00	6.00	6.00
15	2	6.00	6.00	6.00	6.00
15	3	6.00	6.00	6.00	6.00
16	1	6.00	7.00	5.00	6.00
16	2	6.00	7.00	6.00	6.33
16	3	6.00	7.00	6.00	6.33
17	1	6.00	7.00	6.00	6.33
17	2	6.00	7.00	7.00	6.67
17	3	6.00	6.00	6.00	6.00
18	1	6.00	7.00	6.00	6.33
18	2	6.00	7.00	6.00	6.33
18	3	7.00	7.00	6.00	6.67
19	1	7.00	7.00	6.00	6.67
19	2	7.00	7.00	6.00	6.67
19	3	7.00	6.00	6.00	6.33
20	1	6.00	6.00	6.00	6.00
20	2	6.00	6.00	6.00	6.00
20	3	6.00	6.00	6.00	6.00
21	1	6.00	6.00	5.00	5.67
21	2	6.00	7.00	6.00	6.33
21	3	6.00	6.00	5.00	5.67
22	1	7.00	6.00	5.00	6.00
22	2	7.00	7.00	6.00	6.67
22	3	6.00	6.00	6.00	6.00
23	1	6.00	7.00	6.00	6.33
23	2	6.00	6.00	7.00	6.33
23	3	6.00	6.00	6.00	6.00
24	1	6.00	6.00	5.00	5.67
24	2	7.00	7.00	5.00	6.33
24	3	7.00	7.00	6.00	6.67
Mean		6.19	6.06	5.54	5.93
Min		5.00	5.00	5.00	5.00
Max		7.00	7.00	7.00	6.67
Range		2.00	2.00	2.00	1.67

breeding line entries (n = 24); replicate (n = 3); localities (n = 3), % CV = 8.92

Table 5.6 Texture of 24 small white bean samples from the pilot breeding trials from three localities (2002/03 season)

Entry no	Replicate	Texture (kg 100 g-1 12 s-1)			
		Bethlehem	Delmas	Potchefstroom	Mean
1	1	58.40	81.10	69.10	69.53
1	2	61.65	79.40	72.15	71.07
1	3	55.15	80.55	66.05	67.25
2	1	35.15	72.20	76.50	61.28
2	2	39.90	82.85	53.15	58.63
2	3	42.75	75.25	61.35	59.78
3	1	58.55	55.15	89.95	67.88
3	2	55.40	71.60	90.70	72.57
3	3	61.70	64.75	90.33	72.26
4	1	56.05	88.35	66.53	70.31
4	2	54.10	94.80	64.45	71.12
4	3	58.00	79.85	68.60	68.82
5	1	146.30	73.10	98.90	106.10
5	2	147.80	71.30	100.75	106.62
5	3	144.80	72.95	90.40	102.72
6	1	42.05	66.40	91.70	66.72
6	2	43.45	81.25	88.78	71.16
6	3	42.75	71.05	85.85	66.55
7	1	39.05	77.80	72.15	63.00
7	2	40.70	77.25	64.35	60.77
7	3	39.88	77.55	86.30	67.91
8	1	39.45	68.00	73.25	60.23
8	2	40.20	80.65	70.55	63.80
8	3	39.83	73.90	75.95	63.23
9	1	34.50	81.40	97.30	71.07
9	2	43.95	79.35	70.10	64.47
9	3	50.05	70.45	84.15	68.22
10	1	39.80	71.50	95.70	69.00
10	2	46.70	75.85	92.80	71.78
10	3	53.60	79.30	94.75	75.88
11	1	42.60	71.65	80.70	64.98
11	2	48.10	77.90	86.35	70.78
11	3	43.90	77.10	91.90	70.97
12	1	42.05	69.35	96.10	69.17
12	2	45.85	76.35	87.43	69.88
12	3	42.85	84.30	78.75	68.63
13	1	42.50	69.75	95.00	69.08
13	2	39.85	82.75	86.70	69.77
13	3	44.25	72.35	81.20	65.93
14	1	40.20	88.70	71.40	66.77
14	2	37.10	83.65	55.90	58.88
14	3	45.30	87.50	63.65	65.48
15	1	44.60	69.25	67.90	60.58
15	2	43.33	74.95	52.45	56.91
15	3	42.05	80.65	60.18	60.96
16	1	40.25	84.70	68.40	64.45
16	2	44.75	88.60	55.65	63.00
16	3	49.25	72.90	62.03	61.39
17	1	55.08	77.35	62.00	64.81
17	2	57.55	75.30	55.05	62.63
17	3	52.60	78.60	79.25	70.15
18	1	72.80	84.30	78.90	78.67
18	2	68.20	85.85	60.15	71.40
18	3	80.25	79.80	68.15	76.07
19	1	58.25	92.30	78.00	76.18
19	2	64.50	93.80	61.15	73.15
19	3	60.15	95.30	81.65	79.03
20	1	93.20	72.85	108.05	91.37
20	2	91.10	81.35	114.65	95.70
20	3	89.00	77.10	121.25	95.78
21	1	48.90	125.25	72.30	82.15
21	2	61.45	138.85	64.05	88.12
21	3	56.95	132.05	80.15	89.72
22	1	119.80	66.60	122.25	102.88
22	2	137.15	69.75	114.25	107.05
22	3	128.48	68.18	130.25	108.97
23	1	38.75	93.85	52.60	61.73
23	2	38.75	70.55	44.25	51.18
23	3	39.15	71.60	41.70	50.82
24	1	106.15	92.75	58.73	85.88
24	2	95.80	90.35	52.55	79.57
24	3	94.00	91.55	64.90	83.48
Mean		59.70	80.45	77.92	72.69
Min		34.50	55.15	41.70	50.82
Max		147.80	138.85	130.25	108.97
Range		113.30	83.70	88.55	58.15

breeding line entries (n = 24); replicate (n = 3); localities (n = 3), % CV = 8.34

Table 5.7 **Clumping of 24 small white bean samples from the pilot breeding trials from three localities (2002/03 season)**

Entry no	Replicate	Clumping (scale 1 to 3)			
		Bethlehem	Delmas	Potchefstroom	Mean
1	1	3.00	3.00	3.00	3.00
1	2	3.00	3.00	3.00	3.00
1	3	3.00	3.00	3.00	3.00
2	1	2.00	3.00	2.00	2.33
2	2	2.00	3.00	2.00	2.33
2	3	2.00	3.00	2.00	2.33
3	1	3.00	3.00	3.00	3.00
3	2	3.00	3.00	3.00	3.00
3	3	3.00	3.00	3.00	3.00
4	1	3.00	3.00	2.00	2.67
4	2	3.00	3.00	2.00	2.67
4	3	3.00	3.00	2.00	2.67
5	1	3.00	2.00	3.00	2.67
5	2	3.00	2.00	3.00	2.67
5	3	3.00	2.00	3.00	2.67
6	1	2.00	3.00	2.00	2.33
6	2	2.00	3.00	2.00	2.33
6	3	2.00	3.00	2.00	2.33
7	1	2.00	3.00	2.00	2.33
7	2	2.00	3.00	2.00	2.33
7	3	2.00	3.00	2.00	2.33
8	1	2.00	3.00	2.00	2.33
8	2	2.00	3.00	2.00	2.33
8	3	2.00	3.00	2.00	2.33
9	1	2.00	3.00	2.00	2.33
9	2	2.00	3.00	2.00	2.33
9	3	2.00	3.00	2.00	2.33
10	1	3.00	3.00	3.00	3.00
10	2	3.00	3.00	3.00	3.00
10	3	3.00	3.00	3.00	3.00
11	1	2.00	3.00	3.00	2.67
11	2	2.00	3.00	3.00	2.67
11	3	2.00	3.00	3.00	2.67
12	1	3.00	3.00	2.00	2.67
12	2	3.00	3.00	2.00	2.67
12	3	3.00	3.00	2.00	2.67
13	1	3.00	3.00	2.00	2.67
13	2	3.00	3.00	2.00	2.67
13	3	3.00	3.00	2.00	2.67
Sample no	**Replicate**	**Bethlehem**	**Delmas**	**Potchefstroom**	**Mean**
14	1	2.00	3.00	2.00	2.33
14	2	2.00	3.00	2.00	2.33
14	3	2.00	3.00	2.00	2.33
15	1	3.00	3.00	3.00	3.00
15	2	3.00	3.00	3.00	3.00
15	3	3.00	3.00	3.00	3.00
16	1	2.00	3.00	2.00	2.33
16	2	3.00	3.00	2.00	2.67
16	3	3.00	3.00	2.00	2.67
17	1	3.00	3.00	3.00	3.00
17	2	3.00	3.00	3.00	3.00
17	3	3.00	3.00	3.00	3.00
18	1	3.00	3.00	3.00	3.00
18	2	3.00	3.00	3.00	3.00
18	3	3.00	3.00	3.00	3.00
19	1	3.00	3.00	3.00	3.00
19	2	3.00	3.00	3.00	3.00
19	3	3.00	3.00	3.00	3.00
20	1	3.00	3.00	3.00	3.00
20	2	3.00	3.00	3.00	3.00
20	3	3.00	3.00	3.00	3.00
21	1	3.00	3.00	3.00	3.00
21	2	3.00	3.00	3.00	3.00
21	3	3.00	3.00	3.00	3.00
22	1	3.00	3.00	2.00	2.67
22	2	3.00	3.00	2.00	2.67
22	3	3.00	3.00	2.00	2.67
23	1	2.00	3.00	3.00	2.67
23	2	2.00	3.00	3.00	2.67
23	3	2.00	3.00	3.00	2.67
24	1	3.00	3.00	3.00	3.00
24	2	3.00	3.00	3.00	3.00
24	3	3.00	3.00	3.00	3.00
Mean		2.65	2.96	2.54	2.72
Min		2.00	2.00	2.00	2.33
Max		3.00	3.00	3.00	3.00
Range		1.00	1.00	1.00	0.67

breeding line entries (n = 24); replicate (n = 3); localities (n = 3), % CV = 2.50

Table 5.8 **L-values of 24 small white bean samples from the pilot breeding trials from three localities (2002/03 season)**

Entry no	Replicate	L-value			
		Bethlehem	Delmas	Potchefstroom	Mean
1	1	46.69	43.75	44.73	45.06
1	2	46.36	43.15	44.55	44.69
1	3	46.08	42.54	44.91	44.51
2	1	45.70	42.43	44.60	44.24
2	2	45.00	41.83	43.69	43.51
2	3	45.96	40.98	45.51	44.15
3	1	45.37	41.77	45.93	44.36
3	2	45.47	40.26	44.75	43.49
3	3	45.41	38.38	47.11	43.63
4	1	43.99	42.81	45.34	44.05
4	2	43.65	43.51	44.76	43.97
4	3	43.82	43.15	45.92	44.30
5	1	42.86	41.75	45.14	43.25
5	2	42.60	42.61	43.71	42.97
5	3	42.83	42.18	46.57	43.86
6	1	46.39	44.98	46.70	46.02
6	2	46.00	46.38	46.32	46.23
6	3	46.35	45.68	47.08	46.37
7	1	47.19	42.41	46.23	45.28
7	2	47.68	41.86	47.62	45.72
7	3	47.01	41.03	44.84	44.29
8	1	46.04	44.02	47.76	45.94
8	2	46.22	45.83	46.83	46.29
8	3	46.53	44.93	45.91	45.79
9	1	46.62	45.41	46.28	46.10
9	2	46.00	46.06	47.22	46.43
9	3	46.41	45.74	45.33	45.83
10	1	47.30	43.64	47.10	46.01
10	2	47.26	45.82	47.31	46.80
10	3	47.12	44.73	46.88	46.24
11	1	47.09	43.72	46.61	45.81
11	2	47.30	45.94	47.58	46.94
11	3	47.59	44.83	45.63	46.02
12	1	46.59	45.44	47.25	46.43
12	2	46.62	47.31	48.26	47.40
12	3	46.66	46.65	47.76	47.02
13	1	46.90	46.03	47.10	46.68
13	2	46.83	46.35	48.81	47.33
13	3	47.07	46.19	47.96	47.07

Sample no	Replicate	L-value			
		Bethlehem	Delmas	Potchefstroom	Mean
14	1	46.31	46.60	44.24	45.72
14	2	46.26	45.43	45.14	45.61
14	3	46.04	45.63	46.33	46.00
15	1	47.03	47.95	45.35	46.78
15	2	47.22	46.27	45.93	46.47
15	3	47.26	47.54	44.77	46.52
16	1	45.51	44.65	45.04	45.07
16	2	45.20	44.59	45.32	45.04
16	3	45.10	44.62	44.76	44.83
17	1	45.97	46.07	43.63	45.22
17	2	47.58	46.01	44.72	46.10
17	3	46.08	45.43	42.53	44.68
18	1	42.29	44.99	43.80	43.69
18	2	42.65	43.91	42.69	43.08
18	3	42.92	44.45	41.57	42.98
19	1	43.59	42.31	42.81	42.90
19	2	43.93	43.21	42.16	43.10
19	3	43.83	41.41	41.51	42.25
20	1	43.65	45.27	43.40	44.11
20	2	44.16	43.43	44.82	44.14
20	3	44.04	44.35	44.11	44.17
21	1	43.46	45.39	43.14	44.00
21	2	44.71	44.81	45.74	45.09
21	3	44.67	41.40	44.44	43.50
22	1	40.20	41.52	44.52	42.08
22	2	42.89	42.35	45.28	43.51
22	3	41.55	39.68	43.76	41.66
23	1	45.19	43.15	45.06	44.47
23	2	46.20	45.08	47.32	46.20
23	3	47.12	45.93	46.19	46.41
24	1	41.98	44.94	44.83	43.92
24	2	44.07	43.48	44.85	44.13
24	3	42.58	44.56	44.80	43.98
Mean		45.36	44.15	45.39	44.96
Min		40.20	38.38	41.51	41.66
Max		47.68	47.95	48.81	47.40
Range		7.48	9.57	7.30	5.74

breeding line entries (n = 24); replicate (n = 3); localities (n = 3), % CV = 2.10

Table 5.9 **The a_L-values of 24 small white bean samples from the pilot breeding trials from three localities (2002/03 season)**

Entry no	Replicate	a_L-value			
		Bethlehem	**Delmas**	**Potchefstroom**	**Mean**
1	1	8.48	9.02	8.17	8.56
1	2	8.40	9.23	8.28	8.64
1	3	8.31	9.44	8.05	8.60
2	1	8.55	9.46	8.44	8.82
2	2	8.59	9.53	8.81	8.98
2	3	8.63	9.60	8.07	8.77
3	1	8.93	9.43	8.38	8.91
3	2	8.97	9.50	8.50	8.99
3	3	8.14	9.32	8.25	8.57
4	1	8.64	8.92	8.37	8.64
4	2	8.87	8.45	8.52	8.61
4	3	8.68	8.69	8.22	8.53
5	1	9.79	9.52	8.76	9.36
5	2	9.62	9.30	8.72	9.21
5	3	9.71	9.41	8.78	9.30
6	1	8.56	8.54	8.08	8.39
6	2	8.94	8.38	8.60	8.64
6	3	8.42	8.46	8.34	8.41
7	1	8.07	9.49	7.82	8.46
7	2	8.59	9.49	7.30	8.46
7	3	8.33	9.49	7.56	8.46
8	1	8.75	8.58	7.64	8.32
8	2	8.96	8.21	7.91	8.36
8	3	8.16	8.40	7.37	7.98
9	1	8.63	8.08	7.71	8.14
9	2	8.82	7.99	7.34	8.05
9	3	8.38	8.04	7.07	7.83
10	1	8.24	8.70	7.63	8.19
10	2	8.37	8.07	7.41	7.95
10	3	8.31	8.39	7.84	8.18
11	1	8.28	8.22	7.81	8.10
11	2	8.35	8.44	7.42	8.07
11	3	8.33	8.33	7.19	7.95
12	1	8.24	8.28	7.49	8.00
12	2	8.79	8.28	7.25	8.11
12	3	8.38	8.28	7.73	8.13
13	1	8.28	8.07	7.75	8.03
13	2	8.18	7.96	7.33	7.82
13	3	8.23	8.02	7.54	7.93

Sample no	Replicate	a_L-value			
		Bethlehem	**Delmas**	**Potchefstroom**	**Mean**
14	1	8.53	8.57	8.68	8.59
14	2	8.44	8.30	8.68	8.47
14	3	8.46	8.22	8.68	8.45
15	1	8.45	7.33	8.33	8.04
15	2	8.27	7.33	8.12	7.91
15	3	8.08	7.33	8.54	7.98
16	1	8.82	8.39	8.15	8.45
16	2	8.40	8.85	8.31	8.52
16	3	8.61	8.62	8.48	8.57
17	1	8.74	8.44	8.80	8.66
17	2	8.69	8.51	8.26	8.49
17	3	8.79	8.47	8.53	8.60
18	1	9.72	8.09	9.38	9.06
18	2	9.66	8.72	9.38	9.25
18	3	9.59	9.66	9.38	9.54
19	1	9.01	9.48	8.94	9.14
19	2	8.93	9.39	8.27	8.86
19	3	8.85	9.56	8.61	9.01
20	1	9.05	8.99	8.85	8.96
20	2	9.02	8.85	8.46	8.78
20	3	9.07	8.79	8.24	8.70
21	1	8.76	8.44	8.83	8.68
21	2	8.69	8.44	8.92	8.68
21	3	8.83	8.44	8.74	8.67
22	1	9.50	9.50	8.52	9.17
22	2	9.32	9.23	8.40	8.98
22	3	9.71	9.12	8.64	9.16
23	1	8.79	8.92	8.72	8.81
23	2	8.49	8.23	8.08	8.27
23	3	8.23	8.24	8.35	8.27
24	1	9.54	8.22	8.47	8.74
24	2	9.35	8.03	8.59	8.66
24	3	9.73	8.59	8.53	8.95
Mean		8.91	8.58	8.60	8.70
Min		8.08	7.33	8.08	7.91
Max		9.73	9.66	9.38	9.54
Range		1.65	2.33	1.30	1.64

breeding line entries (n = 24); replicate (n = 3); localities (n = 3), % CV = 2.54

Table 5.10 **The b_L-values of 24 small white bean samples from the pilot breeding trials from three localities (2002/03 season)**

Entry no	Replicate	b_L-value				Sample no	Replicate	b_L-value			
		Bethlehem	Delmas	Potchefstroom	Mean			Bethlehem	Delmas	Potchefstroom	Mean
1	1	16.69	16.45	16.38	16.51	14	1	16.69	16.13	16.20	16.34
1	2	17.13	16.15	16.12	16.47	14	2	16.76	16.27	15.70	16.24
1	3	17.09	16.11	16.63	16.61	14	3	16.76	16.16	16.70	16.54
2	1	16.34	16.19	16.36	16.30	15	1	16.73	16.14	16.29	16.39
2	2	16.92	15.95	16.07	16.31	15	2	16.69	15.97	16.13	16.26
2	3	16.72	16.36	16.64	16.57	15	3	16.64	16.28	16.44	16.45
3	1	16.45	16.60	16.69	16.58	16	1	16.54	15.52	16.30	16.12
3	2	17.00	16.23	16.69	16.64	16	2	16.59	16.08	16.30	16.32
3	3	16.61	16.82	16.69	16.71	16	3	16.53	16.01	16.29	16.28
4	1	16.14	16.20	16.67	16.34	17	1	16.70	16.92	16.44	16.69
4	2	16.71	16.65	16.58	16.65	17	2	16.36	16.28	16.47	16.37
4	3	16.40	16.54	16.75	16.56	17	3	16.75	15.85	16.40	16.33
5	1	16.52	16.68	16.59	16.60	18	1	16.55	16.30	16.44	16.43
5	2	16.84	16.60	16.60	16.68	18	2	16.38	16.32	16.47	16.39
5	3	16.25	16.96	16.57	16.59	18	3	16.70	16.29	16.41	16.47
6	1	16.70	16.43	16.71	16.61	19	1	16.64	16.36	16.25	16.42
6	2	16.78	16.77	16.71	16.75	19	2	16.64	16.07	16.31	16.34
6	3	16.70	16.80	16.71	16.74	19	3	16.85	16.38	16.19	16.47
7	1	16.89	17.08	16.31	16.76	20	1	16.16	15.99	16.02	16.06
7	2	17.09	17.13	16.37	16.86	20	2	16.61	16.24	15.55	16.13
7	3	17.07	16.94	16.24	16.75	20	3	16.83	16.51	16.48	16.61
8	1	16.55	15.98	16.79	16.44	21	1	16.77	16.03	15.88	16.23
8	2	16.84	15.65	16.81	16.43	21	2	16.67	16.38	16.13	16.39
8	3	16.61	16.19	16.76	16.52	21	3	16.71	16.37	15.62	16.23
9	1	16.79	16.60	16.46	16.62	22	1	16.04	16.28	16.34	16.22
9	2	17.24	16.40	16.41	16.68	22	2	15.86	16.15	16.34	16.12
9	3	16.91	16.42	16.51	16.61	22	3	15.95	16.38	16.33	16.22
10	1	16.85	16.34	16.65	16.61	23	1	16.79	16.37	16.49	16.55
10	2	17.17	16.22	16.48	16.62	23	2	16.73	16.44	16.34	16.50
10	3	16.83	16.77	16.81	16.80	23	3	17.00	16.38	16.63	16.67
11	1	16.76	16.93	16.59	16.76	24	1	16.68	15.67	16.51	16.29
11	2	16.84	16.56	16.50	16.63	24	2	16.83	16.31	16.38	16.51
11	3	17.13	16.84	16.67	16.88	24	3	16.67	16.17	16.63	16.49
12	1	16.88	16.66	16.59	16.71	Mean		16.71	16.37	16.43	16.50
12	2	17.22	16.67	16.58	16.82	Min		15.86	15.52	15.55	16.06
12	3	16.86	16.79	16.59	16.75	Max		17.24	17.13	16.81	16.88
13	1	16.68	16.54	16.43	16.55	Range		1.38	1.61	1.26	0.82
13	2	17.03	16.17	16.46	16.55						
13	3	16.96	16.43	16.39	16.59						

breeding line entries (n = 24); replicate (n = 3); localities (n = 3), % CV = 1.19

Table 5.11 **Mean, minimum and maximum values and F-values of the main and interaction effects of the canning properties of small white beans from the pilot breeding trials from three localities (2002/03 season)**

Canning quality	Mean	Minimum	Maximum	F-value			
				Entry (df = 23)	Locality (df = 2)	Replicates (df = 2)	Entry x locality (df = 46)
Hydration coefficient	1.78	1.15	2.03	24.30 ***	0.23 ns	4.81 ns	0.13 ***
Washed drained weight (%)	57.43	51.69	63.29	6.66 ***	122.97 ***	0.92 ns	3.64 ***
Visual appearance (scale 1 to 10)	7.42	6.00	10.00	17.53 ***	87.38 ***	1.69 ns	17.41 ***
Splits (scale 1 tot 10)	8.16	6.00	10.00	2.05 **	37.05 ***	0.58 ns	1.21 ns
Size (scale 1 to 7)	5.93	5.00	7.00	9.16 ***	61.73 ***	3.93 *	3.03 ***
Texture (kg.100 g^{-1}.12 s-^{1})	72.69	34.50	147.80	44.19 ***	251.06 ***	0.77 ns	31.50 ***
Clumping (scale 1 to 3)	2.71	1.00	3.00	146.04 ***	724.00 ***	1.00 ns	97.91 ***
L-values	44.97	38.38	48.81	26.22 ***	58.00 ***	3.93 *	7.13 ***
a_L-values	8.54	7.07	9.79	30.99 ***	110.60 ***	2.28 ns	9.67 ***
b_L-values	16.50	15.52	17.24	9.05 ***	60.82 ***	4.98 **	3.48 ***

*** $P <$ 0.01; ** $P <$ 0.05; * $P <$ 0.1; ns = not significantly different at $P =$ 0.05

Table 5.12 **R^2-values, root mean square errors and coefficient of variations of the canning parameters of small white beans from the pilot breeding trials from three localities (2002/03 season)**

Canning quality	$^{\#}R^2$	Root mean square error	Coefficient of variation
Hydration coefficient	0.85 ***	0.10	5.42
Washed drained weight (%)	0.80 ***	1.44	2.50
Visual appearance (scale 1 to 10)	0.91 ***	0.38	5.08
Splits (scale 1 tot 10)	0.56 ***	0.70	8.57
Size (scale 1 to 7)	0.61 ***	0.53	8.92
Texture (kg.100 g^{-1}.12 s^{-1})	0.95 ***	6.06	8.34
Clumping (scale 1 to 3)	0.98 ***	0.07	2.50
L-values	0.84 ***	0.94	2.10
a_L-values	0.91 ***	0.22	2.54
b_L-values	0.76 ***	0.20	1.19

$\#R^2$ = Sum square model / Sum square total

*** $P <$ 0.01

Table 5.13 The relative effects of growth environment and genotype on canning quality of small white bean lines selected for breeding from different localities

Canning quality	Mean square Entry (G) (df = 23)	 Locality (E) (df = 2)	 Ratio (E/G)
Hydration coefficient	0.23	0.00	0.00
Washed drained weight (%)	13.76	254.07	18.46
Visual appearance (scale 1 to 10)	2.49	12.42	4.99
Splits (scale 1 tot 10)	1.00	18.12	18.12
Size (scale 1 to 7)	1.26	8.51	6.75
Clumping (scale 1 to 3)#	0.68	3.35	4.93
Texture (kg.100 g^{-1}.12 s^{-1})	1624.48	9228.76	5.68
L-value	16.39	36.27	2.21
a_L-value	1.46	5.23	3.58
b_L-value	0.27	2.33	8.63

no variation in data for 2001/02

Values > 1 attributed to E; Values < 1 attributed to G

In Chapter 4 it was shown that by using CVA, the interpretation of canning quality data was simplified, compared to ANOVA, by enabling the simultaneous interpretation of data from all canning quality parameters. Canonical variate analysis is also more often used where it is of interest to show differences between groups rather than individuals (Digby *et al.*, 1989). Van Lill & Smith (1997) used CVA and 95 % confidence circles to compare the milling quality of wheat based on a reference cultivar (Betta) to distinguish between acceptable and inferior milling quality. The CVA also proved to be a useful tool in the simultaneous interpretation of yield, chemical properties and canning quality data of small white beans (De Lange & Labuschagne, 2000).

The CVA for canning quality of entries from the pilot breeding trials over three localities indicated that CV 1 (65.24 %) and CV 2 (19.35 %) contributed 84.59 % to the variation between entries. The latent roots for CV 1 (2.41) and CV 2 (0.72) were only > 1 in the case of CV 1. Latent roots of < 1 indicate the presence of more within group variation than between group variation (Digby *et al.*, 1989). Therefore CV 1 would be most important to discriminate between groups. From the latent vectors the following discriminating equations for CV 1 and CV 2 were derived:

$$\text{CV 1} = 0.001\ (\text{Texture}) - 0.737\ (\text{Clumping}) - 0.354\ (\text{L-value}) + 0.681\ (a_L\text{-value}) - 5.555\ (\text{HC}) + 21.91 \qquad (3)$$

$$\text{CV 2} = -0.024\ (\text{Texture}) + 2.570\ (\text{Clumping}) + 0.068\ (\text{L-value}) - 1.074\ (a_L\text{-value}) - 3.422\ (\text{HC}) + 6.96 \qquad (4)$$

L-values (r = -0.80) and HC (r = -0.88) correlated negatively, while a_L-value correlated positively (r = 0.75) with CV 1. Clumping (r = 0.84) correlated positively with CV 2 (Table 5.14). Figure 5.2a displays the plot of the scores for cultivars for CV 1 vs. CV 2. The 95 % confidence circles on the plot with Teebus as center indicate choice grade group entries. Entries within the 95 % confidence circle were not significantly different from Teebus in canning quality. The high CV 1 value of Teebus was due to high a_L-values, but low HC and L-values were found (equation 3). Poor HC values of Teebus were also observed in Chapters 2 and 4. In Chapter 3 (Figure 3.1) it was shown that despite poor HC values found for Teebus under laboratory canning conditions, this cultivar was able to reach the recommended WU level of 80 % suggested by Balasubramanian *et al.* (1999) under industrial canning conditions. Entries 1, 3, 4, 5, 16, 17, 18, 19, 20, 21, 22 and 23 were found within the 95 % confidence circle of Teebus. This indicates that these entries were not significantly different from Teebus in canning quality ($P > 0.05$).

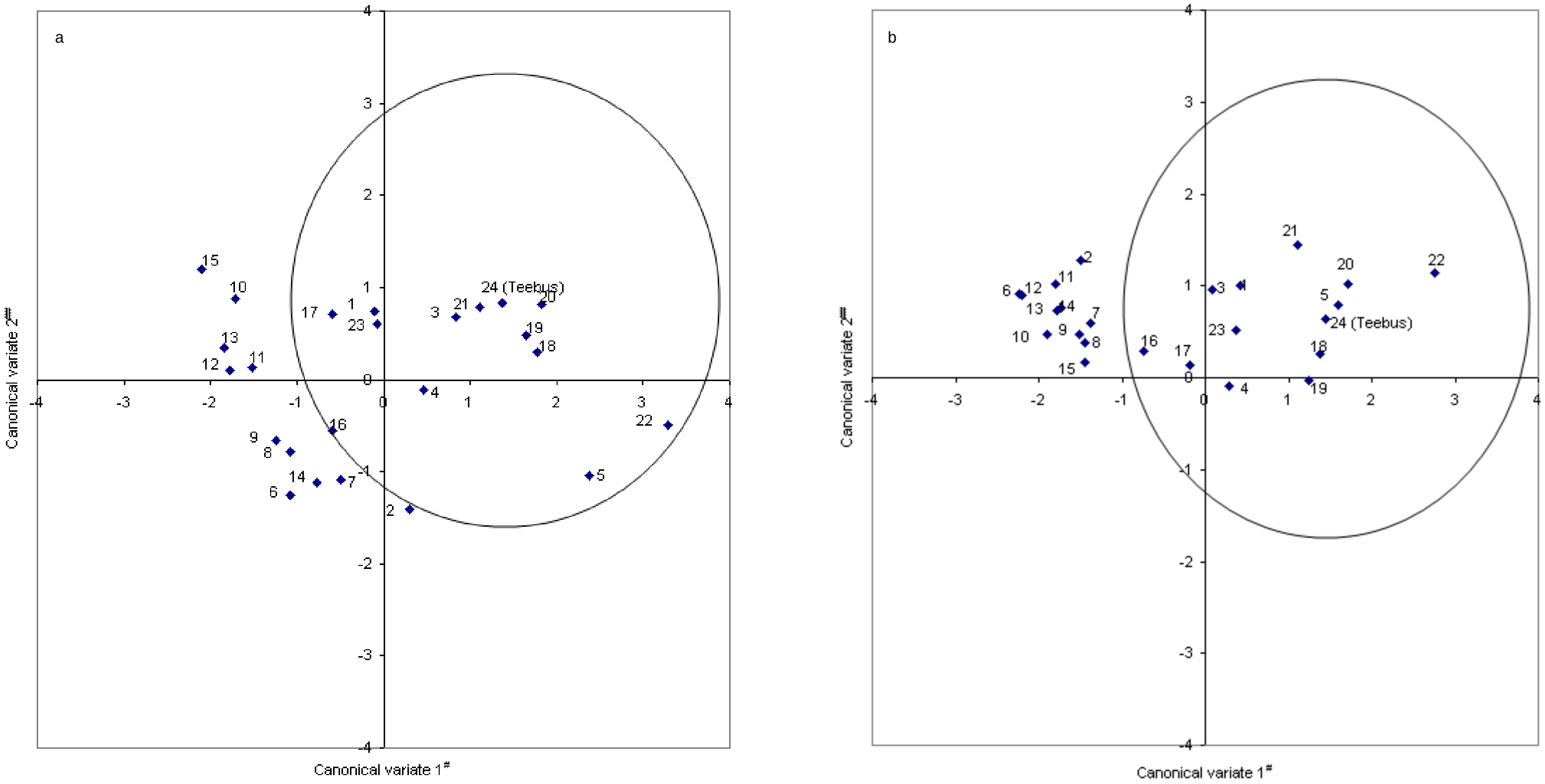
Table 5.14 Correlation matrix of canonical variates 1 and 2 with canning quality parameters of 24 small white bean entries from the pilot breeding trials from three localities

	Texture	Clumping	L-value	a_L-value	Hydration coefficient
Canonical variate 1	0.52	0.22	-0.80	0.75	-0.88
Canonical variate 2	0.04	0.84	0.03	-0.12	-0.31

Figure 5.2b provides the positioning of entries on a plot with respect to the scores of CV 1 and CV 2 as calculated with the prediction model. The latent roots for CV 1 and CV 2 were only > 1 in the case of CV 1 (4.3.2.1.9). The discriminating equations used for CV 1 and CV 2 were (4.3.2.1.9) according to equations 1 & 2 (5.3.1).

Teebus served as the reference standard for choice grade cultivars and the 95 % confidence circle on the plot of the scores for CV 1 vs. CV 2 (Figure 5.2b) identified entries that belonged to the choice grade class for canning.

Canonical variate 1 discriminated between entries based on HC and size values and CV 2 on VA and split values (Table 4.23). The high CV 1 score for Teebus was the result of the high size and low HC values of Teebus. The slightly positive score of CV 2 of Teebus was the result of lower VA and splits values found during this season (equation 1). All entries, except of 4 and 19 had lower VA and splits values due to the seasonal effect. The low HC values of Teebus found with the model are in agreement with those of the CVA (Figure 5.2a). Entries (1, 3, 4, 5, 16, 17, 18, 19, 20, 21, 22 and 23) found within the 95 % confidence circle of Teebus (Figure 5.2b) were the same as for the CVA (Figure 5.2a). This indicates that the model was successful in determining the entries with similar canning quality as Teebus (reference standard). Therefore the model can be successfully applied to determine the canning quality of entries over a number of localities. This is important, since breeders always test new cultivars and lines over a number of localities before making decisions, since canning quality varies significantly over localities (Chapter 4, Tables 4.18 & 4.19; Table 5.11). When CVA is used to select lines for breeding purposes, all canning parameters need to be determined at first, but when the model is used, only VA, HC, splits and size have to be determined. No expensive equipment is necessary to determine these parameters, which offers a low cost alternative to canning quality evaluation procedures.



#Canonical variate 1 = (-) L-value; a_L-value; (-) Hydration coefficient

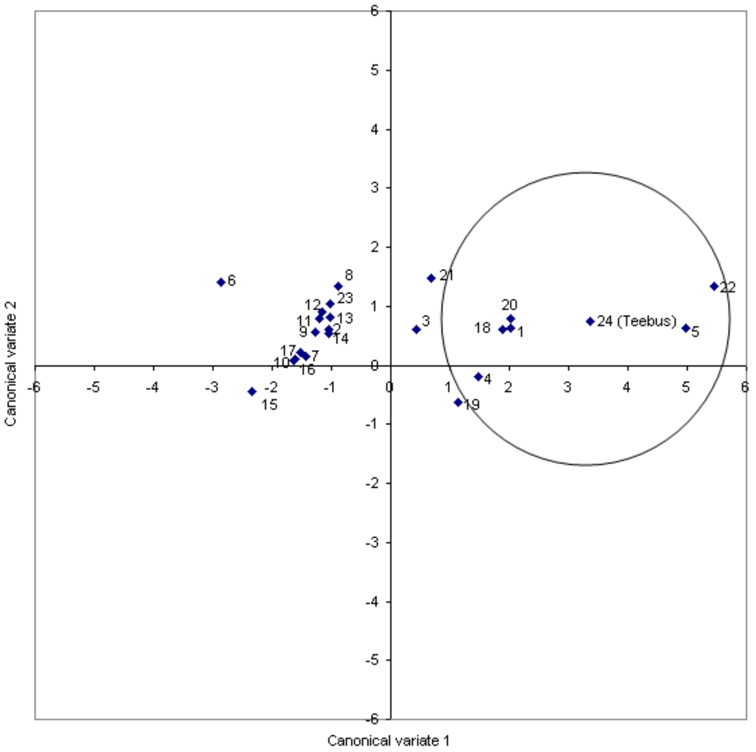
##Canonical variate 2 = Clumping

#Canonical variate 1 = (-) Hydration coefficient; Size

##Canonical variate 2 (-) Visual appearance; (-) Splits

Figure 5.2 Plot of canonical variates 1 vs. 2 for 24 small white bean entries from three localities as a) determined by CVA in Genstat and b) predicted by the CVA model (95 % confidence circle indicates entries not significantly different from Teebus).

The positioning of cultivars at different localities (Bethlehem, Delmas and Potchefstroom) was also determined using CVA to determine important entry x locality interactions. Figure 5.3 provides the plot of entries at Bethlehem for CV 1 against CV 2 according to their coordinates derived from the model (discriminative equations 1& 2). Teebus was indicated to be in the region with high size, but low HC values (Figure 5.3) (equation 1). The CV 2 score of Teebus was also slightly positive, due to lower VA and splits values (equation 2). Entries 1, 4, 5, 18, 20 and 22 were found not to be significantly different from Teebus (*P* > 0.05).

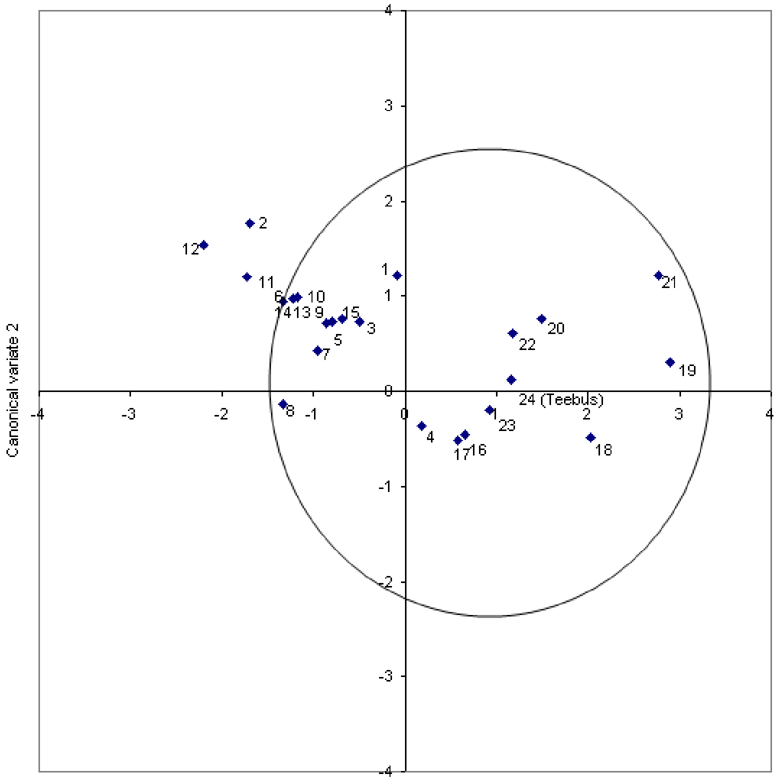


#Canonical variate 1 = (-) Hydration coefficient; Size

##Canonical variate 2 (-) Visual appearance; (-) Splits

Figure 5.3 Plot of canonical variates 1 vs. 2 for 24 small white bean entries from Bethlehem as predicted by the CVA model (95 % confidence circle indicates entries not significantly different from Teebus).

Figure 5.4 provides the plot for entries at Delmas for CV 1 against CV 2 according to their coordinates derived from the model (discriminative equations 1 & 2). Teebus was again found to be in the region with high size, but low HC values (equation 1). The CV 2 score slightly positive due to lower VA and split values (equation 2), but was closer to the gridline than in Figures 5.2b & 5.3. Entries within the 95 % confidence circle of Teebus were no. 1, 3 to 10 and 13 to 23.

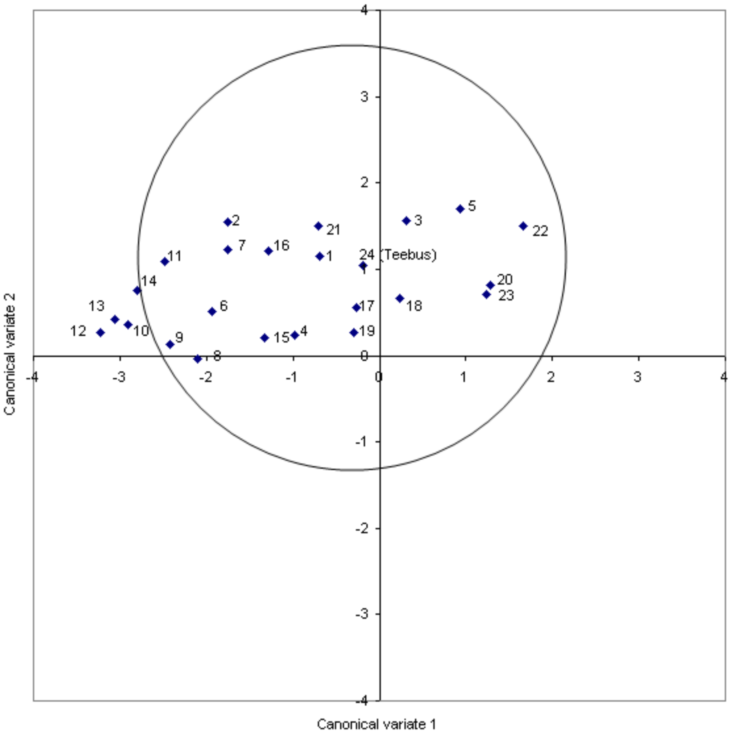


#Canonical variate 1 = (-) Hydration coefficient; Size

##Canonical variate 2 = (-) Visual appearance; (-) Splits

Figure 5.4 Plot of canonical variates 1 vs. 2 for 24 small white bean entries from Delmas as predicted by the CVA model (95 % confidence circle indicates entries not significantly different from Teebus).

Figure 5.5 provides the plot of entries at Potchefstroom for CV 1 against CV 2 according to their coordinates derived from the model (discriminative equations 1 & 2). Teebus was again shown to be in the region with high size, but low HC values (equation 1) and lower VA values (equation 2). From Figure 5.5 it was shown that entries 1 to 9, 11 and 15 to 23 were within the 95 % confidence circle of Teebus.



#Canonical variate 1 = (-) Hydration coefficient; Size

##Canonical variate 2 = (-) Visual appearance; (-) Splits

Figure 5.5 Plot of canonical variates 1 vs. 2 for 24 small white bean entries from Potchefstroom as predicted by the CVA model (95 % confidence circle indicates entries not significantly different from Teebus).

The differences between the entries within the 95 % confidence circle of Teebus at different localities were due to significant entry x locality interactions found for all canning parameters, except for splits (Table 5.11). The relative effect of locality on canning quality was also identified to be more than that of entry for all canning parameters, except for HC (Table 5.13). Results from Figures 5.2 to 5.5 are summarized in Table 5.15 to indicate which entries were similar to Teebus over localities and at specific localities to determine entry x locality interactions.

Table 5.15 Summary of entries predicted within the 95 % confidence circles of Teebus for canning quality over localities and at specific localities

Entry	Locality where similar to Teebus			Similar to Teebus
no.	Bethlehem	Delmas	Potchefstroom	over localities
1	x	x	x	x
2			x	
3		x	x	x
4	x	x	x	
5	x	x	x	x
6		x	x	
7		x	x	
8		x	x	
9		x	x	
10		x		
11			x	
12				
13		x		
14		x		
15		x	x	
16		x	x	x
17		x	x	x
18	x	x	x	x
19		x	x	x
20	x	x	x	x
21		x	x	x
22	x	x	x	x
23		x	x	x

x = indicates entry predicted within the 95 % confidence circle of Teebus

Fewer entries were similar to Teebus at Bethlehem than other localities, indicating that strong cultivar x locality interactions was found at this locality (Table 5.15). Entries no. 1, 5, 18, 20 and 22 were identified to be similar to Teebus within al localities, as well as over localities. These are the best entries recommended for canning purposes, since entry x locality interactions was weaker than for other entries. Even at Bethlehem with strong entry x locality interactions they were above the other entries in canning quality. Differences in canning quality of these beans from different localities were lower.

As second choice, it is recommended that entries no. 3, 16, 17, 19, 21 and 23 may also be used for canning, since their quality parameters were similar to Teebus over localities and at Delmas and Potchefstroom. These entries should however not be grown at Bethlehem (Table 5.15).

The use of entries no. 2 and 11 is not recommended, unless specifically obtained from Potchefstroom, since its canning quality stability over different localities is low (Table 5.15). For the same reason, entries no. 13 and 14 are not suitable for canning, unless obtained from Delmas and entries no. 6 to 9 and 15 should only be used when obtained from Delmas or Potchefstroom. Entry no. 10 displayed a strong entry x locality interaction at Bethlehem and should only be used when obtained from this locality. Entry no. 4 was only similar to Teebus in canning quality at individual localities (Bethlehem, Delmas and Potchefstroom), but its canning quality over localities was unacceptable.

The model could therefore be used to select entries with canning stability over localities or at a specific locality. Breeders would use their own discretion and would sometimes select lines just outside the 95 % confidence circle to ensure that all potential good entries are entered into the next phase of their breeding program. Selection of these entries could be important, since the positioning of entries over seasons could change.

5.4 CONCLUSIONS

The model to predict canning quality of small white beans in tomato sauce was specifically developed to identify suitable breeding lines. Application of the model in the evaluation of cultivar trials proved not to be specific enough to classify cultivars as choice or standard grade cultivars. The model could serve however as a rapid test to indicate groupings of cultivars without the use of specific 95 % confidence circles, since only VA, size, splits and HC need to be determined.

Significant differences between entries, localities and entry x locality interactions were found for most canning quality parameters, which indicates that sufficient variation in data from the pilot breeding trials were present to enable the testing of the model. All R^2-values were significant and RMSE and CV values were low, which indicated that data from these trials were valid to be used for the testing of the model. F-values indicated that locality effects were predominantly responsibly for the variation in canning quality. Most of the variation in canning quality was affected by environmental effects, except for HC, which was mostly affected by genotype.

Both the CVA for entries from Bethlehem, Delmas and Potchefstroom, as well as the model, identified entries 1, 3, 4, 5, 16, 17, 18, 19, 20, 21, 22 and 23 not to be significantly different from Teebus in canning quality. With the model it was therefore able to predict the average canning quality of dry beans over localities. The model could also be applied to determine the positioning of entries relative to Teebus at specific localities and to identify important entry x locality interactions to indicate to the breeder which entries are stable in canning quality over different localities. Entries no. 1, 5, 18, 20 and 22 were indicated to be the most stable when grown at different localities. Bethlehem displayed the most entry x locality interactions and only entries specifically adapted to this environment should be considered for canning.

The model for the prediction of the canning quality of dry beans would therefore be applicable under normal conditions where new cultivars or lines selected for breeding are tested over more than one locality. With the assistance of the MCT, the model could therefore be used to determine the canning quality of entries with respect to each other over localities. With this model it is not necessary to use CVA and the only canning parameters that need to be determined is HC, size, VA and size. This offers a rapid and low cost alternative to canning quality evaluation procedures.

CHAPTER 6

GENERAL DISCUSSION AND CONCLUSION

Eighty percent of South African small white beans are canned in tomato sauce and sold as baked beans. The canning characteristics of dry beans largely determine consumer acceptability (Hosfield & Uebersax, 1980; Balasubramanian *et al*., 2000). Consumers are especially aware of the texture, wholeness, colour (Faris & Smith, 1964; Hosfield *et al*., 1984b), appearance and digestibility (Hosfield *et al*., 1984b) of beans. Processors of beans are constrained by consumer preferences, but they also require beans to be easy to cook, be processed efficiently (Hosfield *et al*., 1984b; Walters *et al*., 1997) and deliver high processor yields (Walters *et al*., 1997).

Various laboratory canning protocols for dry beans are available in the literature (Hosfield & Uebersax, 1980; Balasubramanian *et al*., 1999; De Lange & Labuschagne, 2000), however, they are not all directly applicable to small white beans canned in tomato sauce. Both the techniques of Hosfield & Uebersax (1980) and Balasubramanian *et al*. (2000) were developed for beans other than small white beans, and canning in brine, instead of tomato sauce. The use of tomato sauce instead of brine as a canning medium could have significantly different effects on canning quality (Davis, 1976; Nordstrom & Sistrunk, 1977; Priestly, 1978; Anzaldua-Morales & Brennan, 1982). Can sizes used in the literature techniques (Hosfield & Uebersax, 1980; Balasubramanian *et al*., 1999) also differ from South African cans (De Lange & Labuschagne, 2000), but the main differences between industrial and laboratory canning of beans are related to soaking and blanching procedures (Balasubramanian *et al*., 2000).

The first objective of the present study was to develop or identify suitable laboratory canning and evaluation procedures for small white beans canned in tomato sauce. During this process, standard values for choice and standard grade beans for laboratory evaluation of the canning quality were also defined. Four small white bean cultivars submitted for testing in the National Dry Bean Cultivar Trials of the ARC-GCI during the 2000/01 season were used. These cultivars were obtained from nine localities. Canning of these beans was done according to the LCT, ICT and MCT and, evaluation with the LCEP and MCEP. Teebus served as the reference standard for "choice grade" beans, as was indicated by both De Lange & Labuschagne (2000) and industry. When Teebus (reference standard) was canned with the MCT, TXT1 values similar to that of the USA standard values of 72 kg.100 g^{-1} (Hosfield & Uebersax, 1980) were obtained, while splits and VA were significantly better with this canning technique than with the LCT and ICT. The PWDWT for Teebus canned with the MCT was in agreement with Canadian regulations of 60 % (Balasubramanian *et al*., 1999). Teebus canned with the LCT and ICT resulted in beans of lower quality, indicating the MCT to be the most suitable technique for laboratory canning. The most important canning quality evaluation parameters were identified from the LCEP and MCEP. Hydration coefficient would be the preferred canning quality parameter over WU, since HC is most frequently used in literature for laboratory canning evaluation, and RMSE and CV values were lower than for WU. R^2-values were higher and RMSE and CV lower for VA1 than for VA2. The CV was lower for SPLT1 than SPLT2. Visual appearance (VA1) and SPLT1 would therefore be the preferred parameters. Due to the high CV of TXT2, TXT1 would be the parameter of choice. Size (R^2 = 0.91), PWDWT (R^2 = 1.00) and clumping (R^2 = 1.00) were significant in their use as canning quality parameters. L-values for the colour of canned beans were found to be important, as canning would mostly influence the darkness in colour of small white beans. The a_L-values were important, since this colour parameter was the only indicator identified to be sensitive for changes in bean MC, while b_L-values were identified as sensitive to splits.

Laboratory canning and evaluation of dry beans are common practices for the testing of dry bean cultivars before commercial release to industry for canning purposes. Laboratory canning and evaluation procedures could be useful for evaluation of cultivars and lines selected for breeding, but is of no use unless equivalent results to that of canning industries can be achieved. Commercial canners use cultivar recommendations made on laboratory-based canning results. The second objective of the present study was to compare results obtained with the MCT to those of industrially canned beans. Evaluation of the canning quality of industrially canned beans, which were obtained from retailers, indicated that standard evaluation values for South African canning companies were not set, as is the case for the canning industries of Canada and the USA. It was furthermore shown that SA also needs its own set of standards for bean quality. Beans canned with the MCT were therefore also canned and evaluated industrially and met the required 80 % WU set by the USA standards for canned beans. This is due to the provision in soaking times that the industry makes for different bean cultivars. Grouping of laboratory and industrially canned bean cultivars according to choice and standard grade categories by using CVA identified HC, size, b_L- and a_L-values to be the most important parameters to discriminate between cultivars for CV 1 and CV 2 when laboratory techniques were used. Percentage washed drained weight after 7 days (PWDWT1), size, WU, splits and PWDWT2 were identified to distinguish better between cultivars for CV 1 and CV 2 when industrial techniques were used. Discrimination between groups of cultivars in terms of canning quality was the same for laboratory and industrially canned beans. Teebus was identified as choice grade and Helderberg, OPS-KW1 and PAN 185 as standard grade cultivars.

Comparison of laboratory and industrial canned beans in terms of regions by the use of CVA identified b_L- and L-values, splits and texture to be the most important parameters to discriminate between regions for CV 1 and CV 2 when laboratory techniques were used. Size, WU, splits and PWDWT1 were identified to distinguish better between localities for CV 1 and CV 2, when industrial techniques were used. The CVA for laboratory canned beans indicated beans from NW / NC to have significantly better canning qualities than the other regions. The CVA for regions of industrially canned and evaluated beans indicated no significant differences between regions in terms of canning quality. Experimental evaluation of canning quality was therefore more specific in discrimination between regions, due to the different ways of determining regional values. Laboratory techniques for canning and evaluation could be used successfully in the evaluation of the canning quality of bean cultivars intended for industrial canning.

Since laboratory canning is able to simulate the product that would be obtained by industrial canning, seed companies could use laboratory evaluation to test breeding lines and cultivars before commercial release. This could save themselves, as well as the commercial canner and dry been producer, the cost of losses experienced when a cultivar of unacceptable canning quality is commercially released. The commercial canner is mostly interested in obtaining cultivars with acceptable canning quality, but other factors, such as the yield of cultivars is also considered before agreeing to buy a certain cultivar. Cultivars with acceptable canning quality, but lower yields, could result in lower production of that cultivar, especially during poor crop years. This would explain the acceptance of standard grade cultivars, OPS-KW1 and PAN 185 by industry, as suitable for canning, since these cultivars are able to obtain high yields. Optimizing the industrial canning procedures for these cultivars could deliver a more acceptable product.

Canonical variate analysis was used in literature to discriminate between quality types in wheat breeding material (Osborne *et al*., 1993) and between yield, chemical and canning quality properties of dry beans (De Lange & Labuschagne, 2000). The third objective of the current study was to employ the laboratory canning method as a parameter together with other physical properties in the determination of the canning quality of seven small white dry bean cultivars from 33 localities and over two seasons. Canning quality data were interpreted by the use of CVA. Seed size of dry beans affected canning quality directly, since it affects HC, PWDWT, splits and size values. According to the CVA for cultivars, Teebus, Teebus RR1, PAN 120, PAN 123 and PAN 121 were classified as choice grade beans. OPS-KW1 and PAN 185 were classified as the only standard grade cultivars according to the CVA. The poor size values of these cultivars could lead to consumer rejection. The CVA resulted in a model in the form of two discriminating equations for the coordinates of CV 1 and CV 2, which could possibly be used with the modified canning techniques to predict the canning quality of dry bean samples not included in the specific trial, but grown under similar conditions:

$\text{CV 1} = -7.296\,(\text{HC}) - 0.107\,(\text{splits}) + 1.497\,(\text{size}) - 0.314\,(\text{VA}) + 7.02$

$\text{CV 2} = -1.809\,(\text{HC}) - 0.336\,(\text{splits}) - 0.678\,(\text{size}) - 0.448\,(\text{VA}) + 13.97$

The CVA for locality x season indicated only beans from Lichtenburg and Greytown (2002/03) to be significantly different from other localities. As the CVA of locality x season was unable to provide clear distinctions between the canning quality of beans from different environments, a CVA for canning regions x season was used. From this CVA, beans of 2002/03 were identified to have significantly lower canning quality than those of 2001/02. Beans from the KZN region was not significantly different from those of the most important dry bean production areas (GP / MP and FS) during both seasons. The canning quality of beans from NW / NC was significantly different from other regions. The canning quality of dry bean cultivars from different environments can therefore be successfully determined using CVA. Although the canning quality of beans from different regions could be determined with laboratory canning techniques and CVA, the commercial canner is constraint by the availability of beans from different regions. Most of the beans obtained for canning are from GP / MP and FS, but knowing the canning quality of different regions, could prepare the canner to optimize his canning process to deliver the best possible product from a specific region.

Van Lill & Smith (1997) made use of discriminating equations obtained from CVA to contrast the milling, mixing and fermentation quality of wheat genotypes. De Lange & Labuschagne (2000) obtained similar equations for canning quality, chemical analysis and yield, but the model was not validated. The model determined in the present study for the prediction of the canning quality of beans based on the discriminative equations for the coordinates of CV 1 and CV 2 also needed to be validated. The fourth objective of the present study was to validate the model equations for the prediction of the canning quality of small white beans by testing it on four cultivar samples of known canning quality (2000/01 season) and 24 breeding samples from three localities (2002/03 season), not included in the development of the model. The model was unable to make accurate predictions on the classification of cultivars as choice or standard grade. Standard and choice grade cultivars were however grouped separately, although the standard grade cultivars were not outside the 95 % confidence circle of Teebus. The model was therefore not sensitive enough to classify cultivars into canning grades, since its purpose was to select breeding lines. The model could however serve as a rapid way to identify cultivar groupings without the use of 95 % confidence circles. The model was therefore tested on breeding samples. Significant differences in entries, localities and entry x locality interactions were found for most canning quality parameters, indicating that sufficient variation in data from the pilot breeding trials were present to enable the testing of the model. All R^2-values were significant and RMSE and CV values were low, which indicated that data from these trials were valid to be used for the testing of the model. F-values indicated that locality was predominantly responsible for the variation in canning quality.

The CVA and the model identified the same entries over localities (Bethlehem, Delmas and Potchefstroom) not to be significantly different from Teebus ($P > 0.05$) in canning quality. The model was therefore able to predict the average canning quality of dry bean entries not included in the original model over localities. The model was also successfully applied to indicate the entry x locality interactions, thus enabling the identification of entries with stability over localities. Entries with a strong entry x locality interaction at a specific locality were also identified, thereby making recommendations for the use of certain entries at specific localities possible. The model for the prediction of the canning quality of dry beans would therefore be applicable under normal conditions where new cultivars or breeding material are tested over more than one locality. The model eliminates the need for performing CVA, while it is only necessary to evaluate canned beans for VA, HC, splits and size. Since no expensive equipment is necessary to evaluate breeding lines for these parameters, the model offers a rapid and cost-effective way of determining the canning quality.

The canning quality prediction model was developed over two seasons, including 16 and 17 localities for the respective seasons. Further research would include the expansion and stabilization of the model by including data from more seasons to ensure that all variation caused by seasons are included in the model. Secondly the genetic variability of cultivars included in the model could be enlarged by the addition of canning quality data of lines selected from various phases of a breeding program. Additional data could be added to the model, until variation caused by the addition becomes minimal. Further testing of the model could be done by using more breeding samples from another season.

The relative effects of genotype and environment on canning quality parameters, obtained from Chapters 3, 4 and 5, are summarized in Table 6.1. Different effects were obtained for different traits, mostly due to the number of genotypes and environments used in each trial, as well as the variation in genotypes or environments. During 2000/01, variation in most canning quality parameters was caused by environments due to the variation in the nine localities the regions were composed of. Environments were also predominantly responsible for the variation in canning quality of breeding samples from the pilot trials during 2002/03. Once again, more variation was found between localities than entries. This was caused by the limited variation that occurs in breeding material at such a late phase of a breeding program, since most of the outlying entries were already removed during previous phases. During 2001/03 and 2002/03, where more variation in both cultivars and localities in terms of canning quality were found, some canning properties were mostly affected by genotype and others by environment.

Table 6.1 The relative effects of genotype and environment on canning quality parameters of small white beans from different trials and seasons

Canning quality	Predominantly affected by G or E				% Affected by G and E	
	2000/01 (Cultivars) df (G) = 3 df (E) = 3	2001/02 (Cultivars) df (G) = 3 df (E) = 15	2002/03 (Cultivars) df (G) = 5 df (E) = 16	2002/03 (Breeding) df (G) = 23 df (E) = 2	G	E
Hydration coefficient	E	G	G	G	75	25
Washed drained weight (%)	G	E	E	E	25	75
Visual appearance (scale 1 to 10)	E	G	G	E	50	50
Splits (scale 1 tot 10)	E	G	G	E	50	50
Size (scale 1 to 7)	G	G	G	E	75	25
Clumping (scale 1 to 3)	E	-	E	E	0	100
Texture (kg 100 g^{-1} 12 s^{-1})	E	E	E	E	0	100
L-value	E	E	G	E	25	75
a_L-value	G	G	G	E	75	25
b_L-value	E	E	E	E	25	75

G = Genotype

E = Environment

Values > 1 attributed to E; Values < 1 attributed to G

From Table 6.1 it is shown that variation HC, size and a_L-values were caused by genotypic effects in 75 % of the cases. These results are in agreement with those of Walters *et al*. (1995) who indicated HC to be highly heritable. As was found in 2000/01 for HC, Hosfield (1991) found low H^2 values for HC and indicated that this property is frequently affected by other factors. The different combination of localities used to determine HC during 2000/01 could have caused the higher E/G values, due to the sensitivity of this property to environmental factors. Environmental difference caused variation in texture and clumping values in 100 % of the cases and in 75 % of the cases with L-, b_L- and PWDWT values. Ghaderi *et al*. (1984) also found clumping to be more significantly influenced by environment than cultivar. Colour of beans was also indicated to be strongly affected by environment (Ghaderi *et al*., 1984), despite being expressed by specific genes (Moh, 1971). The a_L-values were found to be less sensitive to environment (Table 6.1). In 50 % of the cases environmental differences caused most of the variation in VA and splits values. Walters *et al*. (1995) found the use of subjective measurements, as done in the case of splits, clumping and VA, to lower the H^2 of these traits, while the different localities and the number of localities could have added to the sensitivity of these traits to environmental effects. Contrasting to results from the present study Walter *et al*. (1995) found texture and PWDWT to be highly heritable. As mentioned, results are dependent on the variety and types of localities used. A wide range of localities from different production areas was used in the present study.

These results could serve as guidelines to breeders when evaluating breeding lines at different stages of the breeding program for canning quality. At the early stages of the breeding program, where differences in genotype are of more importance, samples could only be evaluated for canning properties mostly affected by genotype, i.e. HC, size and a_L-values. At this stage it would also be important to determine VA and splits, since these two properties displayed equal number of cases to be affected mostly by genotype and environment. Only determining these five canning properties early in the program where many samples are often included, could have time and cost-saving advantages. During the intermediate and later stages of a breeding program, environmental effects become more important, since genotypes selected at the early stages, should be tested over more environments. During these stages PWDWT, clumping, texture, L- and a_L-values should also be added to those properties predominantly determined by genotype to be tested. Together with statistical approach of the model, developed for the selection of breeding lines, the breeding program, which is usually very expensive, could be made more cost-effective.

The modified canning and evaluation procedures together with CVA could therefore be successfully employed to classify cultivars according to choice or standard grade classes. These canning procedures could also be used with the assistance of the model to select lines from a breeding program according to acceptable canning quality.

To conclude, this research showed that, although South African small white beans are mostly canned in tomato sauce, the reference standard (Teebus) for choice grade beans was mostly able to meet the regulations standards set by bean canners in the

USA and Canada. The parameters and standard being texture (72 kg.100 g^{-1}) (Hosfield & Uebersax, 1980), HC (1.80) (Hosfield *et al*., 1984a; Hosfield, 1991) and PWDWT (60 %) (Balasubramania *et al*., 2000). This indicates that these regulations could serve as guidelines for canning quality, irrespective of the canning technique or medium used.

It was furthermore shown that for each canned bean product, a small-scale technique for canning would have to be developed if the canning quality is to be evaluated. The MCT of this research, as well as the other techniques (Balasubramanian *et al*., 2000 and Bolles *et al*., 1990) could only act as guidelines. Values for the most important canning parameters also needed redefining, since tomato sauce affects the colour (Heinen & Van Twisk, 1976), splits (Davis, 1976), texture (Nordstrom & Sistrunk, 1977) and PWDWT (Nordstrom & Sistrunk, 1977; Priestly, 1978) differently than brine. The values would then also have to be redefined for other canned bean products.

Lastly, the work of De Lange & Labuschagne (2000), who made use CVA for the interpretation of yield, chemical and canning quality data, was expanded to develop a prediction model for the canning quality of dry beans. The use of prediction models was previously applied in wheat (Van Lill & Smith, 1997), but since it was now shown that it could be applied to dry beans, it is also advised that its application in other crops should be investigated.

SUMMARY

Laboratory canning and evaluation of dry beans are common practices for testing canning quality of cultivars before commercial release to canning industries. Suitable laboratory canning and evaluation procedures for small white beans in tomato sauce were identified. Standard values for choice and standard grade beans for laboratory evaluation of canning quality were defined, using four small white bean cultivars from nine localities during the 2000/01 season. The cultivar Teebus was used as reference standard for choice grade beans and its canning quality complied with international guidelines when the modified canning technique (MCT) was used. From the laboratory and modified canning evaluation procedures hydration coefficient, percentage washed drained weight, visual appearance (scale 1 to 10), splits (scale 1 to 10), texture (kg.100 g^{-1}.12 s^{-1}), size, clumping, L-values, a_L-values and b_L-values were identified as suitable canning parameters for small scale evaluation of beans.

Beans canned with the MCT were also canned and evaluated industrially and results compared. The interpretation of the different canning parameters with laboratory and industrial canning were simplified by the use of canonical variate analysis (CVA). Canonical variate analysis indicated the same groupings for cultivars according to choice and standard grade canning quality for laboratory and industrial canned beans. Laboratory canning and evaluation could be used in the evaluation of the canning quality of beans intended for industrial canning.

Canning quality of seven small white bean cultivars from 33 localities and two seasons was determined with the MCT and CVA. Cultivars with acceptable and unacceptable canning quality were identified using laboratory evaluation and CVA. The CVA resulted in a prediction model for canonical variates 1 and 2 (CV 1 and CV 2) by identifying two discriminative equations for CV 1 and CV 2 scores. The CVA for environments identified differences in the canning quality of beans from different regions, while also indicating seasonal differences. The canning quality of dry bean cultivars from different environments can be determined using CVA.

The model equations for the prediction of the canning quality of small white beans were validated on four cultivar samples from four regions (2000/01 season) and 24

breeding samples from three localities (2002/03 season) that were not included in the development of the model. The CVA and the model identified the same entries from breeding trials over localities not to be significantly different from Teebus ($P > 0.05$) in canning quality, but were unable to group cultivars statistically correct according to choice grade. The model was however capable of grouping standard and choice grade cultivars separately. The model could be applied to identify breeding trial entries as choice grade and to identify entry x locality interactions.

The use of small-scale canning and evaluation procedures in combination with CVA could be employed to classify cultivar canning quality as either choice- or standard grade and to determine environmental canning quality. These techniques could be used, with the assistance of the prediction model to compare samples from a breeding program with a reference standard.

OPSOMMING

Droëbone word meestal in die laboratorium ingemaak en geëvalueer vir inmaakkwaliteit voor kommersiële vrystelling aan inmaakindustrieë. Geskikte laboratorium inmaak- en evalueringstegnieke vir kleinwitbone in tamatiesous, is geïdentifiseer en standaardwaardes vir keur- en standaardgraad bone vir laboratoriumevaluering gedefinieer. Vier kleinwit boonkultivars vanaf nege lokaliteite is hiervoor gebruik gedurende die 2000/01 seisoen. Die kultivar Teebus is gebruik as verwysingstandaard vir keurgraad bone en sy inmaakkwaliteit het voldoen aan internasionale riglyne toe die gewysigde inmaaktegniek (MCT) gebruik is. Die laboratorium en gewysigde evalueringsprosedures is gebruik. Die hidrasiekoëffisiënt, persentasie dreineringsmassa, visuele voorkoms (skaal 1 to 10), brekasie (skaal 1 to 10), tekstuur (kg.100 g^{-1}.12 s^{-1}), grootte, klontvorming, L-, a_L- en b_L-waardes is geïdentifiseer om geskik te wees as inmaakparameters vir die kleinskaalse evaluering van bone.

Die resultate van bone wat met die MCT asook industrieel ingemaak is, is vergelyk. Die interpretasie van die verskillende inmaakparameters wat tydens laboratorium en industriële inmaak gebruik word, is vergemaklik deur van kanoniese variansie analises gebruik te maak (CVA). Kanoniese variansieanalises het dielfde groeperings vir cultivars ten opsigte van keur- en standaardgraad inmaakkwaliteit met beide die bone wat met laboratorium en industriële tegnieke ingemaak is, aangedui. Die laboratorium inmaak – en evalueringstegnieke kan dus gebruik word vir die evaluering van die inmaakkwaliteit van bone wat vir industriële inmaak bedoel is.

Die inmaakkwaliteit van sewe kleinwit droëboonkultivars vanaf 33 lokaliteite en oor twee seisoene is bepaal met die MCT en CVA. Kultivars met aanvaarbare en onaanvaarbare inmaakkwaliteit is geïdentifiseer deur van die laboratorium evalueringsprosedure en CVA gebruik te maak. Uit die CVA is ‘n model vir die eerste en tweede kanoniese variante (CV 1 and CV2) verkry deurdat twee onderskeidende vergelykings vir CV 1 en CV 2 tellings aangedui is. Die CVA vir omgewingsverskille het die inmaakkwaliteit van bone vanuit verskillende streke aangedui, asook dié vanaf verskillende seisoene. Die inmaakkwaliteit van droëbone uit verskillende omgewings kan dus met behulp van ‘n CVA bepaal word.

Die modelvergelykings, verkry met die CVA, vir die voorspelling van die inmaakkwaliteit van kleinwit bone is geverifieer op vier kultivars vanaf vier streke (2000/01 seisoen) en 24 teelmonsters vanaf drie lokaliteite (2002/03 seisoen) wat nie tydens die ontwikkeling van die model ingesluit was nie. Die CVA en die model het dieselfde inskrywings oor verskillende omgewings aangedui as nie betekenisvol verskillend van Teebus ten opsigte van inmaakkwaliteit nie ($P > 0.05$). Die model kon egter nie kultivars statisties korrek voorspel volgens inmaakgraad nie. Standaard- en keurgraad kultivars is wel korrek saamgegroepeer. Die model kan suksesvol aangewend word om teelmonsters te identifiseer as keurgraad oor lokaliteite en kan inskrywing x lokaliteit interaksies aandui.

Die gebruik van kleinskaalse inmaak- en evalueringsprosedures, tesame met CVA kan suksesvol gebruik word om kultivars te klassifiseer as keur- of standaardgraad en om die inmaakkwaliteit van omgewings te bepaal. Hierdie inmaaktegnieke kan ook tesame met die voorspellingsmodel gebruik word om die inmaakkwaliteit van kleinwit bone vanaf ‘n teelprogram met ‘n verwysingstandaard te vergelyk.

APPENDIX A

Table 1 Monthly rainfall, irrigation and average maximum temperatures of 16 small white bean localities during the 2001/02 season (Liebenberg *et al*., 2002)

Locality	#Monthly rainfall (mm)						Irrigation (mm)	#Average maximum temperature (°C)				
	November	December	January	February	March	Total		November	December	January	February	March
Arnot	180	110	96	101	12	499	0	24.9	26.6	29.2	27.3	29.2
Bergville	136	118	110	62	93	519	100	-	-	-	-	-
Clocolan	90	193	114	28	53	478	0	23.7	25.8	26.7	27.4	27.1
Coligny	126	129	68	83	45	451	0	-	-	-	-	-
Delmas	128	94	132	79	43	476	0	24.6	26.7	28.4	26.1	27.0
Ermelo	158	158	31	46	36	429	0	-	-	-	-	-
Harrismith	86	78	121	48	34	367	0	22.5	24.5	25.9	24.9	25.4
Koedoeskop	176	77	12	32	13	310	400	-	-	-	-	-
Kroonstad	99	107	74	15	12	307	0	25.1	27.5	29.4	28.6	28.9
Lichtenburg	87	113	90	74	63	427	0	-	-	-	-	-
Maseru	-	-	-	-	-	-	-	-	-	-	-	-
Potchefstroom	155	147	61	92	47	502	26	25.5	27.7	39.8	28.1	28.3
Reitz	125	103	129	80	10	447	0	21.3	23.2	25.4	24.9	26.5
Syferbult	-	-	-	-	-	-	-	-	-	-	-	-
Ukulingo	-	-	-	-	-	-	-	-	-	-	-	-
Wildebeesfontein	-	-	-	-	-	-	-	-	-	-	-	-
Mean	129	119	87	62	38	434	44	23.9	26.0	29.3	26.8	27.5
Min	86	77	12	15	10	307	0	21.3	23.2	25.4	24.9	25.4
Max	176	147	129	92	63	502	400	25.5	27.7	39.8	28.6	28.9
Range	90	70	117	77	53	195	400	4.2	4.5	14.4	3.7	3.5

#where available

Table 2 Monthly rainfall, irrigation and average maximum temperatures of 17 small white bean localities during the 2002/03 season(Liebenberg *et al*., 2003)

Locality	#Monthly rainfall (mm)						Irrigation (mm)	#Average maximum temperature (°C)				
	November	December	January	February	March	Total		November	December	January	February	March
Bergville	-	-	-	-	-	-	-	-	-	-	-	-
Bethlehem	10	122	69	104	65	370	0	24.9	24.9	26.9	26.8	25.2
Bethal	0	40	95	85	0	220	0					
Cedara	57	109	67	115	84	432	0	23.6	25.3	26.3	27.1	27.1
Chrissiesmeer	0	69	85	33	54	241	0	-	-	-	-	-
Clocolan	17	120	88	82	130	437	0	-	-	-	-	-
Coligny	-	-	-	-	-	-	-	-	-	-	-	-
Cradock	22	60	16	37	37	172	375	27.7	29.5	31.6	31.9	28.9
Delmas	4	124	0	0	0	128	26	26.3	26.9	27.6	28.7	27.9
Ermelo	0	161	100	62	24	347	0	-	-	-	-	-
Ficksburg	17	120	86	83	134	440	0	-	-	-	-	-
Greytown	62	111	94	59	39	365	0	25.0	26.9	28.0	28.7	28.2
Harrismith	28	122	73	110	58	391	0	24.7	25.1	26.9	26.5	25.6
Kokstad	61	144	109	75	120	509	25	24.2	25.0	26.5	27.7	25.7
Lichtenburg	18	115	112	97	27	369	0	-	-	-	-	-
Reitz	0	80	60	26	0	166	0	-	-	-	-	-
Vryheid	0	0	80	60	30	170	0	-	-	-	-	-
Mean	20	100	76	69	53	317	28	25.2	26.2	27.7	28.2	26.9
Min	0	0	0	0	0	128	0	24.2	25.0	26.5	26.5	25.6
Max	62	161	112	110	134	509	375	27.7	29.5	31.6	31.9	28.9
Range	62	161	112	110	134	381	375	3.5	4.5	5.1	5.4	3.3

#where available

Table 3 Soil type, soil analysis and fertilisation of 16 small white bean localities during the 2001/02 season (Liebenberg *et al*., 2002)

Locality	#Type of soil		#Soil analysis			#Fertilisation	
		pH (H_2O)	Phosporous (ppm)	Nitrogen (ppm)	Nitrogen	Phosphorous	Potassium
Arnot	Avalon	5.3	16	102	43	14	7
Bergville	Avalon	4.3	23	201	55	20	10
Clocolan	Avalon	6.6	6	114	62	20	27
Coligny	Bainsvlei	6.0	28	30	17	13	17
Delmas	Hutton	5.4	70	83	23	14	18
Ermelo	Hutton	4.4	41	65	42	14	7
Harrismith	Avalon	4.3	26	192	70	15	-
Koedoeskop	Clay loam	-	-	-	45	-	-
Kroonstad	Avalon	4.2	54	185	91	12	6
Lichtenburg	Hutton	6.2	23	94	7	10	13
Maseru	-	-	-	-	-	-	-
Potchefstroom	-	-	-	-	-	-	-
Reitz	-	-	-	-	54	18	27
Syferbult	-	6.2	12	4	52	35	17
Ukulingo	-	-	-	-	-	-	-
Wildebeesfontein	Hutton	-	-	-	-	-	-
Mean		5.3	31	108	47	17	16
Min		4.2	6	4	7	10	6
Max		6.6	70	201	91	35	27
Range		2.4	64	197	84	25	21

#where available

Table 4 Soil type, soil analysis and fertilisation of 17 small white bean localities during the 2002/03 season (Liebenberg *et al*., 2003)

Locality	#Type of soil		#Soil analysis			Fertilisation	
		pH (H_2O)	Phosporous (ppm)	Nitrogen (ppm)	Nitrogen	Phosphorous	Potassium
Bergville	-	-	-	-	-	-	-
Bethlehem	-	-	0	0	50	13	13
Bethal	Hutton	5.2	23	120	45	18	24
Cedara	Hutton	4.5	7	184	80	30	0
Chrissiesmeer	Vaalgrond	5.2	27	68	40	18	24
Clocolan	Avalon	-	0	0	36	19	28
Coligny	Bainsvlei	-	0	0	0	0	0
Cradock	-	6.9	60	292	80	40	20
Delmas	Hutton	5.4	54	113	16	24	16
Ermelo	Hutton	5.0	14	187	45	18	24
Ficksburg	Avalon	6.2	31	113	30	23	30
Greytown	Hutton	-	0	0	26	40	53
Harrismith	Avalon	5.0	15	82	70	15	0
Kokstad	Clovelly	4.3	16	169	80	20	0
Lichtenburg	Bainsvlei	7.3	6	240	9	6	3
Reitz	Avalon	5.0	29	46	52	17	26
Vryheid	Hutton	4.3	7	99	30	23	30
Mean		5.4	19	114	43	21	19
Min		4.3	0	0	0	0	0
Max		7.3	60	292	80	40	53
Range		3.0	60	292	80	40	53

#where available

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