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**GENOTYPE x ENVIRONMENT INTERACTION FOR QUALITY
PARAMETERS OF IRRIGATED SPRING WHEAT**

BY

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List of abbreviations

Alv. P/L	- Alveograph P/L (configuration) ratio
Alv. stre	- Alveograph strength, which is equal to W/6.54 in joules
AMMI	- Additive main effect and multiplicative interaction
BFLY	- Breakflour yield
BU	- Brabender units
CV1,2	- Canonical variate axis 1 or 2
CVA	- Canonical variate analysis
Env. (E)	- Environment
FABS	- Farinograph water absorption
FCL	- Flour colour
FLN	- falling number
FLY	- Flour yield
FPC-LECO	- Flour protein content LECO - method
FPC-NIR	- Flour protein content near infrared reflectance-method
Gen. (G)	- Genotype
GPC-FL	- Grain protein content FL - method
GPC-LECO	- Grain protein content LECO - method
GPC-WH	- Grain protein content WH - method
HLM	- Hectoliter mass
HMW-GS	- High molecular weight glutenin subunits
LFV12%	- Loaf volume at 12% protein content
LFVPT	- Loaf volume point score
LMW-GS	- Low molecular weight glutenin subunits
MDT	- Mixograph development time
Min	- Minutes
Moist	- Moisture content
MPT	- Mixograph point score
PCAN	- Principal component analysis
SDSS	- Sodium dodecyl sulphate sedimentation
SEAS x GEN	- Season x genotype (interaction)
SKCS-diam.	- Single kernel characterisation system - diameter
SKCS-HI	- Single kernel characterisation system - hardness index
SKCS-W	- Single kernel characterisation system - weight
TKM	- Thousand kernels mass
VK	- Vitreous kernels
W	- Area under the alveograph curve
WGC12%	- Wet gluten content at 12% protein content
WH	- Whole kernel protein

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CHAPTER 1

INTRODUCTION

Wheat is one of the most important cereal grains world wide, and is used mainly for bread-making. It is a staple food in many countries, including South Africa. However, the marketing of wheat is mostly dominated by the processing industries (millers and bakers), to whom quality is very important. Bread-making quality relates to the characteristics of wheat grains which result in the yielding of a high percentage of flour with the required colour, the development of flour and bread-making ingredients to doughs and baking of a palatable loaf with a fine texture (Finney *et al.*, 1987). There are more than 20 characteristics, which determine the quality of wheat for suitability for bread-making. Most of the quality characteristics are polygenically inherited, and will therefore be influenced by the environment to a large extent. According to Ciaffi *et al.* (1996), several studies have shown that environmental variations associated with quality traits often exceed genotypic variation. As a result, a cultivar which has good quality at one location will therefore not necessarily perform well at another locality.

The main importance of wheat as compared to other cereals is the fact that the major storage compounds are starch and protein. Starch constitutes the main part of the endosperm and thus the expected yields. On the other hand, although protein constitutes a small part of the whole endosperm, its content and composition plays a major role in wheat quality. An excess amount of starch or protein will not result in an optimum starch-protein interaction, which is very important to most of the quality parameters particularly grain hardness. According to Bechtel *et al.* (1996), grain hardness is an important characteristic that plays a significant role in the marketing and processing of wheat both nationally and internationally. Pomeranz *et al.* (1985) observed that genotype had a larger influence on variability of wheat hardness than did location. Huebner and Gaines (1992) noted that the hardness of individual wheat kernels was influenced by genotype, harvest date, and location of the kernels on the head spike. According to Van Lill (1992) the quality requirements designed by the bread-making industries represent one side of the wheat scenario, with farmers' requirements on the other side. Higher grain mass per area at the lowest possible cost is the primary objective of farmers (producers). Unfortunately, a negative relationship exists between grain yield and protein content (Johnson *et al.*, 1985). The tendency is ascribed to the wheat plant's growth pattern, where nitrogen (N) is first utilised to realise maximum yield potential, and then additional N availability could increase the grain N percentage (Deckard *et al.*,

1984). Although the relationship between yield and protein content is influenced by the genetic potential for protein content (Stoddard and Marshall, 1990), environmental factors such as soil fertility and adequate soil moisture have been reported to be important variables in the determination of final crop quality (Smika and Greb, 1973).

Under irrigation, moisture is not a limiting factor but soil fertility may be one of the factors influencing quality. Therefore there is a need to ensure that soil nitrogen is sufficient particularly in higher yielding environments. Wheat, as one of the cereal grains grown in temperate climates, seems to be more adapted in cooler environments than hot ones. According to Gaines *et al.* (1996), climatic conditions during growth apparently have greater influence on most quality traits than does genotype. Ciaffi *et al.* (1996), reported that the optimum temperature range for reaching maximum kernel weight is 16 – 21°C. With further increase to 30°C, the extent of both protein and starch synthesis seem to be reduced, with starch being more affected than protein. Thus, it seems that the increase in grain protein content as a result of high temperature is due to suppression of starch synthesis rather than to a change in the quantity of nitrogen. The same authors reported that a unique variation in the composition of polymeric proteins, related to a loss of dough strength, was observed in the presence of frequent episodes of daily maximum temperatures above 35°C during grain filling. As a result gliadin synthesis continues at a greater rate than glutenin synthesis during a period of heat stress. Consequently the mature grain has a higher ratio of gliadin/glutenin and produces a weaker dough. Therefore higher temperature seemed to affect the composition of the polymeric fraction (soluble/insoluble polymers protein ratio) without influencing their synthesis.

The interaction of genotype with environment is a situation whereby certain genotypes may show better performance at some locations than other. According to Crossa (1990) the variation in characteristics among certain agricultural production alternatives (including genotypes) when evaluated in different environments, is known in the classical sense as interaction. The interaction is part of the behaviour of the genotype or agronomic treatment and confounds its observed mean performance with its true value. Therefore there is a need to identify genotypes, which show positive environment interactions with particular locations to maximise the values.

According to Van Lill (1992) the contrasting needs of the producing and processing industries burden the breeder. The breeder may be accused of neglecting either the yield or quality aspects in their breeding programmes. However, wheat breeding comprehends the integration of many disciplines such as genetics, entomology, pathology, biochemistry, cereal chemistry, agronomy, and statistics. A new wheat cultivar therefore represents all these objectives (Van Niekerk and Van Lill, 1990). Therefore it takes time to breed a cultivar which will fulfil all the requirements. Above all,

due to environment interaction the cultivar may deviate from the expected performance. Therefore close cooperation between researchers, producers and processors is very important for the well being of the wheat industry. The statistical analysis, additive main effect and multiplicative interaction (AMMI) method (Gauch, 1988) has shown to be excellent in analysis of genotype x environment interactions. This is from the fact that the method summarises patterns and relationships of genotypes and environments as well as offering a valuable prediction assessment (Purchase, 1997).

The aim of this study was to determine milling and baking quality of irrigated spring wheat genotypes grown in different environments in different years, to see the effect of genotype, environment and their interaction on quality parameters, and also to determine the relative association of these parameters. The aim was also to propose strategies to be taken by breeders, producers and processing industries to develop genotypes with good quality and maintain the quality of existing cultivars.

CHAPTER 2

LITERATURE REVIEW

Wheat quality, like grain yield is a complex trait that results from an interaction of several characteristics. This includes genetic (Baenziger *et al.*, 1985), environmental (Benzian and Lane, 1986; Mailhot and Patton, 1988) and their interaction. Both the unique genetics of wheat cultivars and their environment during growth have independent and interactive influences on all physical and biochemical quality attributes of wheat (Gaines *et al.*, 1996). Despite of genetic improvement being accelerated using modern techniques like molecular markers, unfortunately environments interact with genotypes to prevent them from fulfilling their genetic potential (Van Deventer, 1986; Peterson *et al.*, 1992; Graybosch *et al.*, 1995). A study examining tall statured, hard red spring wheat lines with similar genetic backgrounds grown in Western Canada, indicated that both cultivar and environment had large, but varying effects on all quality parameters measured (Baker and Kosmolak, 1977). Environmental factors include biotic and abiotic stresses and breeders face a big challenge in developing genotypes, which could resist these stresses, and at the same time have a good quality.

Cultivar screening by breeders for inherent good dough quality and physiological adaptation to environments, may improve and reduce variability of bread-baking quality (Van Lill, 1992). Moreover the use of recommended varieties and proper management by producers will reduce the spectrum of environmental effects to those, which cannot be controlled, like climate. Different parameters have been established for evaluating wheat quality and are used by breeders and processing industries for cultivar screening and evaluation of farmer's products respectively.

2.1 Quality parameters

As already mentioned wheat quality is influenced by various physical and biochemical characteristics of the grain apart from general field performance of the whole plant. It is through laboratory evaluation together with agronomic performance that a certain genotype can be regarded as being superior in quality. Some of the basic quality analysis done on wheat grain and flour before cultivar releases will be discussed in the following paragraphs.

All tests were done following the approved methods of the American Association of Cereal Chemists (AACC), although there may be some modifications depending on experience.

2.1.1 Wheat hardness, 1000 kernel mass and test weight

The above three parameters are used from the early breeding stage in screening wheat lines, up to the marketing of wheat to ensure that farmer's products will meet the milling and baking quality needs. Hardness is highly heritable and wheat cultivars are specified either to be hard or soft. The other two parameters are more influenced by environmental conditions and tend to vary from one place to another even within the same cultivar. In South Africa 1000 kernel mass of more than 40 g and test weight more than 76 kg.hl⁻¹ is preferable. Some researchers like Charles *et al.* (1996) have also indicated that higher test weight is an indication of higher protein content, which is one of the quality parameters. For endosperm it is the strength of starch-protein interactions that causes endosperm hardness (Barlow *et al.*, 1973). Van Lill and Smith (1997) reported that grains containing higher protein content were inclined to be harder, which in turn increased flour yield.

Flour extraction yield (%) refers to the process whereby the endosperm is separated from the bran by means of sets of fast moving rollers through which the wheat is fed. Extraction is a function of hardness, and endosperm of hard, firm wheat grains tend to separate more easily from the bran during the milling process. In addition, more starch granules are damaged when hard wheat is milled, thereby improving water absorption. Flour extraction, therefore, provides a useful measure of milling efficiency (Bass, 1988; Gibson *et al.*, 1998).

According to Finney *et al.* (1987) the mean differences in the ranges of kernel texture (breakflour yield) that resulted from environmental influences were 1.5 times greater than genotypical differences. Huebner and Gaines (1992) reported the hardness of individual wheat kernels to be influenced by genotype, harvest date and location of the kernels on the head spike.

According to Yamazaki and Donelson (1983) and Day *et al.* (1985) hardness appears to be controlled by two major and several minor genes and is not significantly influenced by growing conditions. Charles *et al.* (1996) reported that wheat grown in more humid environments were softer, producing more break - and patent flours and probably lower levels of damaged starch than those grown in drier environment.

Since flour is derived from wheat endosperm, the size, density and shape of the grain determines flour yield potential (Eggitt and Hartley, 1975). Marshall *et al.* (1986) found that grain size, measured by either grain weight or volume, was correlated with flour yield when seed was stratified for grain size within hard wheat cultivars but not among cultivars. Baker and Golumbic (1970) found seed size to be related to milling yield in hard red spring wheat, but found no relationship for

the other wheat classes. It appears that endosperm content (revealed by kernel plumpness), which is favoured by high photosynthetic rates and/or long grain filling periods is strongly influenced by environmental conditions (Planchon, 1969; Jenner *et al.*, 1991). Poor growing conditions (hot and dry) increase the degree and amount of kernel shrivelling and decrease flour yield due to a reduced proportion of endosperm to bran (Pinthus, 1973; Yamazaki, 1976; Pumphrey and Rubenthaler, 1983; Simmonds, 1989).

Test weight (hectolitre mass) is also an economically important parameter, because it may predict potential flour yield (Finney *et al.*, 1987; Nel *et al.*, 1998a). Higher test weight is indicative of grain plumpness (McDonald, 1994) following favourable growth conditions during grain filling (Evans *et al.*, 1975). During grain filling, growth conditions, which affect test weight, are moisture stress, high temperature, nitrogen supply and diseases.

According to Van Deventer (1986) the contribution made by South African winter wheat cultivars to the variation in hectolitre mass was significant at 38.2%. Contrary to this in the study of spring wheats, Nel *et al.* (1998a) found the contribution by cultivars to the total variation was only 0.8% and thus nonsignificant. However, cultivar x environment interaction was responsible for 12.5% of the variation in hectolitre mass, and as a source of variation had a more pronounced effect when compared to that of grain yield or protein content.

According to Park *et al.* (1997), though relatively higher test weight and 1000-kernel weight provided for high total flour yield and good milling attributes, growing location significantly ($p < 0.05$) affected these two parameters including others in both hard white and hard red samples.

In an attempt to establish an indirect predictive model to flour yield, Steve *et al.* (1995) found a positive and negative relation to flour yield for kernel width and 1000 kernel weight, respectively. Kernel width was also correlated with kernel volume ($r = 0.90$, $p = 0.0001$). However, the model explained only a small part of the total variability in flour yield ($R^2 = 0.22$). In their conclusion, higher test weight should not always be regarded as an indication of higher flour yield.

2.1.2 Endosperm starch content determination – falling number

In wheat like other cereal grains, carbohydrate compounds in the form of starch are the major storage compounds. It is due to an added advantage of having proteins as the second largest storage compound which makes it unique (in terms of physical and biochemical properties) and have multiple uses, including bread-making. When flour, water and all the other ingredients required for bread-making are being mixed, the storage proteins hydrate and yield a continuous

film like matrix in which the starch granules are embedded (Hoseney, 1985). This characteristic together with higher water absorption enhanced by damaged starch granules, such as when hard wheat is milled, causes unsprouted wheat flour to have a higher falling number.

Under rainy conditions prior to harvesting wheat grain may begin to germinate, a phenomenon known as preharvest sprouting (Derera *et al.*, 1977). The alpha-amylase in sprouted wheat results in degradation of starch into simple sugars. Consequently sprouted wheat will have a higher sugar content that is unacceptable to the baking industries. Falling number is a method based on the unique ability of α -amylase to liquefy a starch gel. The strength of the enzyme is measured by falling number (FN) apparatus, defined as time in seconds (sec) required to stir and allow the stirrer to fall a measured distance through a hot aqueous flour or meal gel undergoing liquefaction.

The alpha-amylase concentration gives an indication of the starch to sugar conversion in the wheat grain (Hagberg, 1960; Lukow and Bushuk, 1984). Higher falling number implies no or less conversion of starch into sugar. Therefore unsprouted grains will have more starch which will absorb water and thus higher FN values, whereas for sprouted grains the starch content is less and more sugar is present and this results to low FN values. The parameter is associated with baking quality (loaf volume and texture). Flour with higher FN, results in higher loaf volume and good (fine) texture, whereas lower FN flours result in lower loaf volumes and poor (coarse) texture. In South Africa a FN value of more than 250s is required.

Fleming *et al.* (1960) observed a larger effect of genotype than environment, with a significant genotype x environment interaction, on the alpha-amylase and protease produced among malted hard wheats. Nel *et al.* (1998b) in the study of spring wheat reported insignificant differences in falling number among cultivars and the environments. The variation due to environment was slightly higher, but in agreement with Baker and Kosmolak (1977) who found that the variation was due to cultivar x environment interaction.

Fenn *et al.* (1994) also showed significant genotype x environment interaction for falling number in their study with 1BL/1RS – translocation wheats. But in contrast to this Nel *et al.* (1998b) believed genotype to be more important than environment. This is also supported by the results from winter wheat, where genotypic variation appeared to be dominant (Van Lill and Purchase, 1995; Barnard *et al.*, 1997; Van Lill and Smith, 1997).

2.1.3 Sodium dodecyl sulphate – sedimentation (SDSS) test

The gluten proteins of wheat are chiefly responsible for the visco-elastic structure of the dough. The differences in the functional properties of gluten are due to the differences in the properties of gluten protein groups, their interactions with each other and with other constituents of wheat flour. The SDSS test is used for measuring relative gluten strength as it indicates differences in the quantities of the polymeric glutenins (gel protein).

According to János (1998) the SDSS volumes of different cultivars are considered to be a relatively stable quality feature, not very sensitive to environmental effects. Their study showed SDSS volume of whole meal or flour made from cultivars with different quality is hereditary relatively stable. This signifies its suitability for quality selection of the early generations. However, as observed by Dhaliwal *et al.* (1987) and Carver and Rayburn (1995) the presence of the 1BL/1RS translocation causes a decrease in the SDSS volume.

In a study by Sontag–Strohm *et al.* (1996) on the high molecular weight (HMW) glutenin subunits, the cultivar Ulla was observed to contain two biotypes which differed from each other at two loci: Glu-A1 and Glu-A3/Gli-A1. One of them, Ulla-1, contained subunit 2* (Glu-A1b) and Glu-A3o/Gli-A1o, and Ulla-2 contained the null allele (Glu-A1c) and Glu-A3a/Gli-A1b. The two biotypes were crossed; random lines produced by single seed descent and about 95 F₆ lines from four bulked Ulla progeny lines were analyzed. Significant interaction between the allelic variants of HMW glutenins and low molecular weight (LMW) gluten proteins affected the SDS – sedimentation volume. At the mean flour protein level of 13.1% (dry mass basis – dmb); the effect of LMW gluten variants was larger in the lines deficient of a HMW glutenin subunit than in lines having a HMW glutenin subunit (2*). At the higher flour protein levels (mean = 15%, dmb) the effect on SDSS volumes was additive; progeny carrying allele b (subunit 2*) and o/o at Glu-A1 and Glu-A3/Gli-A1 had significant greater sedimentation volumes than the progeny carrying alleles c (no subunit) and a/c, respectively. These results agree with previous studies (Payne *et al.*, 1987; Gupta *et al.*, 1989; Benedettelli *et al.*, 1992).

In another study by Krattiger *et al.* (1996) the group 1 and 6 inter-varietal chromosome substitution lines of Cappelle-Desprez (Bezostaya 1) were intercrossed along with the donor and recipient varieties, Cappelle-Desprez and Bezostaya 1, to give 36 genetically different families. The analysis of the means of these families showed that variation in SDSS volume fitted a predominantly additive model. They also noted that hardness; due to the gene *ha* for hardness located on chromosome 5D was also the most likely explanation for increased SDSS values. This is because

grain hardness gives rise, on milling, to increased starch damage, resulting in more SDS absorption, leading to swollen starch grains and to larger SDS volumes.

Glutenins rather than gliadins has been shown to have more effect on SDSS. The study on the effect of fusarium head blight (scab) caused by *F. graminearum* Schwebe, by Dexter *et al.* (1996) found gliadins not to be much affected, but the proportion of glutenin in damaged kernel flour was less compared to flour from clean kernels. Similar results were reported for American hard red spring wheat infected by *F. graminearum* by Boyacioglu and Hettiarachchy (1995). An additional effect of *Fusarium* spp. infection on gluten properties is immaturity, brought on by incomplete development of the seeds by premature death of infected spikelets.

SDSS values can range from 20 or less for low protein wheat of inferior bread-baking strength to as high as 70 or more for high protein wheat of superior bread-baking strength. The high protein (and gluten content) helps to retain gas by forming a continuous film together with starch granules during fermentation and this results to higher loaf volumes (F.P. Koekemoer – personal communication).

2.1.4 Protein content, moisture content and protein quality

The higher the protein percentage the better the expected quality will be for a given sample, because the proportion of important components like gluten will also be high. Flour moisture content as such is only used as guide on the correct amount of water to be added when performing various tests. However, when wheat grains are harvested at higher moisture content, there is a risk of temperature build up during storage. The consequence of this is a phenomenon known as heat damaged wheat, whereby most of the biochemical properties, particularly of protein, are destroyed. This has been realized in some of the wheat quality laboratories like Small Grain Institute, Bethlehem, South Africa (F.P. Koekemoer – personal communication).

Protein content

Grain protein content is a major contributor to nutritional quality and plays a major role in the functionality of wheat flour (Koekemoer *et al.*, 1999). Quality parameters such as rheological (mixograph, farinograph/consistograph, alveograph and extensograph), sedimentation and loaf volume are influenced by protein content. However, protein quality is a limiting factor, and the quality improves if gluten content is higher, especially HMW-glutenin subunits. A linear correlation between protein content and loaf volume generally exists, which indicates protein content to be a

measure of quality of wheat (Finney, 1945). Therefore in assessing wheats, higher protein content is an indication of superiority in quality. In South Africa wheat with protein content of about 12% and above is preferred.

Khan *et al.* (1989) studied hard red spring wheats and determined correlations between the quantity of protein fractions and the bread-making quality parameters. The results showed significant positive correlations between protein content and both loaf volume and wet gluten. Also Peter *et al.* (1998a) found a very high positive and statistically significant correlation of the total protein content with the wet gluten (+0.890c). The correlations between the total protein content and the sedimentation value and the loaf volume were good and moderately significant (+0.638b, +0.605b).

According to Noaman *et al.* (1990), grain protein content is the consequence of a complex physiological process and is controlled by numerous genes. In a study of winter wheat grown in the Free State of South Africa, Van Lill *et al.* (1995a) reported large variability among genotypes for bread-making characteristics such as protein content, mixograph dough development time and baking strength index.

Grana *et al.* (1988) reported that "high protein genes" incorporated from *Triticum dicoccoides*, increased protein content and produced between 61% to 72% of the yield of the highest yielding check cultivar. Johnson and Mattern (1980) evaluated 20 000 entries over 13 years and calculated that 5% of the variation in protein content was accounted for by genotypes. This study revealed that actual protein content is mainly determined by growing conditions. This is supported by South African cultivar evaluation programme results under irrigation whereby, for the cooler central areas, cultivar contribution to the total variance for protein content was 5% and 3% for earlier and late planting dates respectively. For the warmer northern areas cultivar contribution was 2% for both planting dates (Ybema *et al.*, 1998).

According to Laubscher (1980) the effect of cultivars on protein content and loaf volume was dominated by that of environment for spring wheat cultivars in the Western and Southern Cape in South Africa, this is also supported by Moss (1973) and Manley and Joubert (1989). Robert *et al.* (1996) reported that relative influences of genotype, environment and G x E on flour protein attributes were compared by calculating the ratios of variance components. The results showed that components associated with environmental factors exceeded genotypic variances for flour protein content, sodium dodecyl sulfate sedimentation volume and low molecular weight saline unextractable protein.

The wheat plant requires a basic amount of nitrogen (N) from the soil to accumulate dry mass and N content in the vegetative tissue to realise acceptable yield and protein content, (Deckard *et al.*, 1984). McMullan *et al.* (1988) reported that plant N content at anthesis (NRA) is significantly ($r = 0.61$) related to nitrogen harvest index (NHI). Consequently the amount of N translocated is significantly correlated with plant N content at anthesis ($r = 0.87$). They also reported that grain protein content was significantly correlated with total plant N content ($r = 0.95$). Therefore selection for cultivars, which show high, biological N, yields at anthesis (BA) and high remobilization values of this vegetative N will improve grain N concentration (Slafer *et al.*, 1990).

Higher temperature during grain filling, has less effect on nitrogen translocation and crude protein would subsequently be increased (Evans *et al.*, 1975). Also higher soil temperatures have shown to favour the mineralisation and uptake of nitrogen (Smika and Greb, 1973). Water can increase nitrogen availability to the crop as it increases root growth; the mass flow of water, and therefore nitrogen, towards the plant; Mineralisation of N from soil organic matter; and movement of N fertilisers into the root zone (Sander *et al.*, 1987).

According to Pawlson *et al.* (1992), rainfall prior to grain filling may accelerate nitrogen leaching and other forms of nitrogen loss. As a result they found a negative relationship between rainfall in the three weeks following nitrogen application and nitrogen availability to the crop. On the other hand rainfall later in the season may cause nitrogen dilution by extending leaf life and maintaining photosynthesis and therefore, carbohydrate assimilation (Taylor and Gilmour, 1971).

Nel *et al.* (1998a) reported that significant G x E interactions were found for grain protein content and hectolitre mass for spring wheat grown in the Western and Southern cape from 1992 – 1995. The lowest and highest grain protein contents were derived from high-yielding and low-yielding environments respectively. However, some of the cultivars showed considerable sensitivity to both high and low protein areas, indicating a lack in stability for this parameter. Similarly, cultivars with higher yield potentials tend to have lower protein contents than cultivars with low yield potentials at a given level of available N (Terman, 1979; Clarke *et al.*, 1990). This confirms the well-known negative relationship between grain yield and protein content (Johnson *et al.*, 1985; Simmonds, 1996; Koekemoer, 1997).

The relationship between yield and protein content is influenced by the genetic potential for protein content (Stoddard and Marshall, 1990). However, environmental factors such as soil fertility and adequate soil moisture have been reported to be important variables in the determination of final crop quality (Smika and Greb, 1973). According to Van Lill (1992) the diverse effect of agronomic

practices on the protein content of cultivars, signifies the importance of crop management to achieve both an acceptable yield and protein content.

Johnson *et al.* (1985) reported that although the amount of grain protein tends to be negatively correlated with yield, the correlation coefficients seldom exceed ($r = 0.60$) indicating that much of the variation in protein is independent of yield and that simultaneous breeding advances in yield and protein are possible. This is supported by a recent study on selection strategy for combining high grain yield and high protein content in South African wheat cultivars Koekemoer *et al.* (1999). They concluded that selection for grain protein yield would give the best solution towards a simultaneous improvement of both grain yield and protein content.

Protein quality

Protein quality relates to the compositional and quantitative aspects of the gluten storage proteins namely gliadins and glutenins (Wall, 1979). The water and salt soluble fractions (albumins and globulins) are not significantly related to loaf volume, but together with endogenous lipids are considered to enhance loaf volume. Therefore protein composition is primarily responsible for the differences in loaf volume for cultivars (genotypes) with the same protein content (Finney *et al.*, 1987; Panozzo *et al.*, 1990). Glutenins and gliadins together represent $\approx 80\%$ of the total protein in typical wheat flour (Hoseney *et al.*, 1969; Bietz and Wall, 1975; Pritchard and Brock, 1994; Tatham and Shewry, 1995).

The protein content can be affected by agronomic measures e.g. fertilisation, whereas the composition of the gluten proteins is genetically determined (Sabine *et al.*, 1997). According to Fowler and De la Roche (1975) genotype is instrumental in determining the quality parameters of wheat, and Payne (1986) who found that protein quality is primarily genetically determined in terms of differences in protein molecular properties supported this.

Harris and Sibbitt (1942) reported that when glutes, prepared from different cultivars, were tested in a standardized starch-gluten test system, loaf volumes were dependent on the source of gluten, that is, the properties of the wheat glutes were cultivar-dependent. Gluten proteins are therefore known as one component of the wheat kernel which influences bread-making quality to a large extent and are responsible for inherent differences in quality of different wheat cultivars (Finney, 1943; Sabine *et al.*, 1997). Since gluten content is associated with protein content, low gluten content was derived from high grain yielding environments and high gluten content from low grain yielding environments (Nell *et al.*, 1998b).

Robert *et al.* (1996) concluded that various components of flour protein differed in their response to environmental and genotypic factors. Flour protein concentration and the percentage of protein present as gliadin and non-gluten proteins was found to be most sensitive to environmental fluctuations. The percentage of protein present as glutenin was found to be nearly totally genotype dependent.

The contributions of gliadins and glutenins to dough properties have long been recognised, and it has been suggested that the gliadins generally contribute to dough extensibility and viscosity, whereas the glutenins are responsible for the dough elasticity (Khatkar and Schofield, 1997; Sabine *et al.*, 1997). It is the unique combination of dough viscosity and dough elasticity that comprises the functional properties of dough.

In addition to overall protein content (MacRitchie, 1992), other major effects on loaf quality have been demonstrated due to the glutenin-to-gliadin ratio (Doekes and Wennekes., 1982; MacRitchie, 1987; Gupta *et al.*, 1992; Blumenthal *et al.*, 1994; Pechanek *et al.*, 1997). This is supported by Uthayakumaran *et al.* (1999) who concluded that the protein content and glutenin-to-gliadin ratio (a measure of molecular weight distribution or protein size) have different roles in determining the various dough and bread quality parameters.

The variation in quality is also due to the high molecular weight glutenin subunits (HMW-GS) present (Payne and Lawrence, 1983). Payne *et al.* (1979, 1981) demonstrated first that the HMW glutenin subunits are affecting bread-making quality. According to Pomeranz (1988) although the HMW-glutenins make up only 10% of the total gluten and only 1% of the whole endosperm, they are nevertheless of fundamental significance in determining the rheological properties of the dough.

Considerable cytogenetic research has shown that genes for both gliadin and glutenin are located on chromosomes 1A, 1B, and 1D and 6A, 6B, and probably others (Heyne, 1987). According to Payne *et al.* (1987) and Payne *et al.* (1988) 11 complex loci containing the genes coding for the gluten proteins have been identified. These include loci such as Glu-A1, Glu-B1, Glu-D1 etc., on the group-1 chromosomes, which codes for HMW-GS. Allelic variation at all the loci exists and this results in subunits denoted by numbers like, 0 (null), 1 and 2* in Glu-A1; 6+8, 7, 7+8, 7+9, 13+16, 14+15 and 17+18 in Glu-B1; 5+10, 2+12 and 3+12 in Glu-D1.

Variations in the composition of glutenin subunits (especially HMW) express additively (due to subunits from different locis) on quality of wheat doughs. Consequently the extent to which

glutenins are affecting quality however, was found to be different in diverse countries (Payne *et al.*, 1987; Rogers *et al.*, 1989; Uhlen, 1990; Kolster *et al.*, 1991; Cerny *et al.*, 1992; Johansson, 1996). This may also be due to the effects of environment and G x E interactions.

According to Payne *et al.* (1987), the presence of high molecular weight subunit 1 or 2* in a hard wheat is usually an indication of a strong wheat for good bread making quality. Regarding Sontag-Strohm *et al.* (1996) the proportion of glutenin in protein had a stronger correlation with dough strength (extensograph, maximum resistance and mixograph, dough development peak time) in genetic lines varying in number of HMW than LMW glutenin subunits. Van Lill and Purchase (1995) reported that for winter wheat increased values for mixograph dough development time was also associated with favourable growth conditions during grain filling.

Sabine *et al.* (1997) reported that the Glu-B1 allele 7+9 and the Glu-D1 allele 5+10 were more frequent in the cultivars with better bread-making quality, and no cultivar with good quality contained the subunits 6+8 and 2+12. Lukow *et al.* (1989) having studied the HMW subunit composition of a great number of Canadian varieties, obtained data for the high positive effect of the allele 5+10 on the wheat quality. Their conclusion is that the best quality of a wheat variety is composed of 1A subunits 1 or 2*; or 1B subunits 7+8, 7+9 or 13+16, and 1D subunits 5+10 were invariably present.

In a study by Peter *et al.* (1998b) which showed that the allele 2* had better effect in comparison to allele 1 controlled by locus 1A, disagree with the data of Schepers *et al.* (1993), showing an advantage of allele 1 against allele 2* concerning their effect on sedimentation value. According to Gyula *et al.* (1998) the old Hungarian variety Bánkúti 1201 possesses excellent technological quality parameters despite the fact that it bears the HMW-subunits 2+12 on chromosome 1D. This signifies the important of breeders in different geographic areas to evaluate their genetic material so as to know which subunits has more influence on quality.

2.1.5 Flour colour

White bread is consumed more than both brown bread and cakes. Therefore both millers and bakers use degree of colour to produce a white bread as an important indication of flour quality. Generally the whiter the flour, the higher the grade within limits required for producing good quality bread. However, colour change may occur due to genetic, environment or G x E interaction effects, consequently affecting the quality of the final products. Changes in flour colour depends on several factors such as; the carotenoid pigments inherent in the wheat kernel, discoloration caused by microbial infestation, particles of bran, darker mill streams, the percent extraction of the flour etc.,

(Patton and Dishaw, 1968; Shuey and Skarsaune, 1973). Colour from carotenoid pigments normally does not present a problem to the baker and is usually bleached away by the miller.

According to Knott (1980) when breeding for rust resistance, through incorporation of chromosomes from *Agropyron species*, a yellow pigmentation caused by xanthophyll pigments may be incorporated into bread wheat.

Polyphenol oxidase (PPO), an enzyme that is widely distributed in cultivated crops, including wheat (Marsh and Galliard, 1986), may be related to an undesirable brown discoloration of wheat-based end products during processing or storage (Faridi, 1988; Kruger *et al.*, 1994). Park *et al.* (1997) reported that growing location and population for the hard white wheat samples influenced the variability in grain and flour PPO activities. Also there was a significant influence of GxE interactions on PPO activity in both grain and flour. Among the hard red samples, genotype and growing location both contributed to variability in flour PPO activity. The variation due to growing locations appeared to be larger than variation produced by genotypes. Grain colour is among the quality parameters, which showed significant correlation with grain and flour PPO activities.

Different equipment has been developed and are used by different laboratories, but they all aim at the same target of determining flour brightness. According to user's experience using flour colour grader series III (Wheat quality Lab. Small Grain Institute), the flour categories are:

Cake flour = -2.5 to 1.0

White bread = 1.5 to 4.5

Brown bread = 9 to 14

Grain and flour colour are measured with a Minolta Chroma Meter 300, using the CIE 1976 Chromameter *L*, *a*, *b* colour scale equipped with a standard C illuminant (Park *et al.*, 1997). *L* value expressed the whiteness of the sample with 100 as perfect white and 0 as black. A higher *L* value indicated a brighter or whiter sample. Values of *a* and *b* indicated the red-green and yellow-blue chromaticity, respectively. Positive *a* and *b* values expressed increased redness and yellowness, respectively. A value of 0 in *a* and *b* indicated gray.

Agtron (available in different models) is a reflectance spectrophotometer designed to measure relative reflectance of the sample at four monochromatic spectral frequencies. The apparatus is set for 0 – 100% reflectance with specific standards. The lower and higher reflectance readings, implies less bright or brighter flour, respectively. In a study on flour blends, Patton and Dishaw

(1968) using agtron F2-61, found that the agtron reading decreased when the percentages of powdered bran or clear flour were increased in the short patent bread flour. Shuey and Skarsaune (1973) using the M-500-A agtron noted that, the agtron readings were low with percentage increase in flour mineral (ash) contents.

2.1.6 Experimental milling test

The experimental milling is performed with either Brabender Junior Quadrumat mills for smaller samples from as little as 5g (Finney *et al.*, 1987), to flour extraction with a Bühler mill for samples larger than 500g (Lukow, 1991). The Bühler mill is a simplified representation of commercial mills. Kernel plumpness (an indication of higher test weight), which is favoured by high photosynthetic rates and/or long grain filling periods, may influence flour extraction yield (Planchon, 1969). For winter wheats grown in the Free State Van Lill and Smith (1997) found that both cultivar and environment contributed significantly to the variation in the milling characteristics.

According to Steve *et al.* (1995) flour yield is a complex trait, the sum of many minor effects. Factors that affect removal of the endosperm (kernel texture, endosperm adherence to the bran) as well as the amount of endosperm present (kernel volume, endosperm/bran ratio) impact on flour yield. In their study variable selection and regression analysis indicated that the best predictive model for flour yield to be:

$$\text{Flour yield (\%)} = 40.27 + (14.75)(\text{kernel width}) - (0.35)(\text{thousand kernel weight}).$$

However, the model, although statistically significant ($p = 0.025$), explains only a small part of the total variability in flour yield ($R^2 = 0.22$) and illustrates the difficulty in predicting flour yield indirectly.

Marshall *et al.* (1986) reported the importance of kernel volume in determining flour yield. Ghaderi *et al.* (1971) reported that kernel width showed a higher correlation with kernel volume than did kernel length. Altaf Ali *et al.* (1969) found that kernel width was correlated with milling yield for samples of grain not graded by seed size.

Conditioning of wheat before milling is done by adding a specific amount of water (ml/kg) to wheat grains. This is necessary so as to limit bran contamination during flour extraction, as it causes larger bran particles and this simplifies the sieving process. It also helps to soften the endosperm,

consequently the milling process is shortened, power consumption is reduced and the reduction rollers take longer to wear out.

2.1.7 The Mixograph

Mixograph measures and records dough development behavior and its resistance to mixing. The mixing curve (mixogram) indicates optimum development time (point of minimum mobility); tolerance to over-mixing, descending graph width, other dough characteristics (such as being weak or strong) and estimates bake absorption. The mixograph has been used to study dough rheology, blending, quality control and for evaluation of hard, soft and durum wheats.

During dough mixing, the resistance of the system to extension increases progressively until the point of minimum mobility is reached. This is referred to as the dough development time and is considered as the point where dough is optimally mixed (Finney *et al.*, 1987). The mixing time of the mixograph (in minutes) indicates the rate at which the flour and water are blended together into a quasi-homogeneous mixture in order to develop a gluten matrix and to incorporate air (Spies, 1990). This method proved to be a valuable criterion for the selection of wheat cultivars with superior quality (Van Lill and Purchase, 1995).

Mixograph mixing time, peak height and bandwidth are dependent on both protein quality and quantity (Khathar *et al.*, 1994). This in turn, is strongly influenced by the amount of nitrogen fertiliser (Kilian *et al.*, 1990) as well as water stress (Neales *et al.*, 1963) and high temperatures (Campbell and Read, 1968) during kernel filling.

In the study of the effects of cropping systems, Van Lill (1992) observed that dough development time was principally genetically determined when compared to the effects of cropping systems or planting date, especially under climatically favourable weather conditions. However, under unfavourable conditions, the dough weakening response induced by stress after flowering differed amongst cultivars. It was shown that this stress related response was influenced by cropping systems, probably through contributions to soil water conservation or improvement of soil fertility.

In the study of the effect of environment Van Lill (1992) noted that mixograph mixing requirement was largely genetically determined. This signifies its importance as a selection criterion in the assessment of bread baking quality in early generation wheat lines. Low flour protein content appeared to increase mixograph mixing requirement, indicating environmental effects associated with low flour protein, which should be avoided in the evaluation of breeding material. Within cultivars, gliadin and glutenin content appeared to play a subordinate role in variation of mixograph mixing requirement, when compared to flour protein content. However, since gluten (gliadin and

glutenin) represents \approx 80% of the total protein (Pritchard and Brock, 1994; Tatham and Shewry, 1995), gluten effects at low protein content may be affected, nevertheless it has a major effect on wheat flour quality.

Lukow *et al.* (1999) evaluated the effect of genetic variation in the glutenin and gliadin protein alleles of Alpha 16 (Canadian Prairie spring wheat), on the dough mixing, bread and noodle quality properties. The presence of a gliadin component (BGGL) and the low molecular weight glutenin subunit (LMW – GS) 45 found in the selection Biggar BSR were associated with significant increases in dough strength characteristics. The results showed that gliadins, LMW–GS, and HMW–GS can influence bread and noodle making properties of wheat flour. Due to non-significant genotype by environment interactions, the differences observed in quality characteristics were mainly caused by the effect of genotype.

Interpretation of the mixograph

Measurements available from a mixogram that indicate various dough-mixing characteristics are:

1. **Time to maximum height (min)**, also called peak or point of minimum mobility: This is the time required to mix the dough to its optimum suggested mixing time (e.g. in South Africa) is 2 min to 3 min, (with 2.5 min as optimum). A shorter mixing time will result in sub-optimal dough development, whereas longer mixing time is not desirable due to spending more time and energy inputs and this implies financial loss to the baker. The optimum mixing time of 2.5 min is, however, strongly influenced by both the protein content and oxidation ability of the flour (Finney and Yamazaki, 1967). Mixing time decreases as flour protein content increases to about 12%, thereafter remaining approximately constant with increases in flour protein. Generally as mixing time increases, dough extensibility decreases and dough stability, elasticity and mixing tolerance increase (Hendriks, 1992).
2. **Maximum height of curve center** (or height of curve center at a specified time after start of mixing): Mixograph peak height is the maximum height of the mixograph curve (in millimeter).

This is a function of the protein content and water absorption capacity of the flour (Finney and Shogren, 1972). The optimum peak occurs when optimum mixing has taken place and all the protein and starch are hydrated (Spies, 1990). The height of the curve increases with increasing protein content (Hendriks, 1992).

3. **Angle between ascending and descending portions of curve at peak :**

Center of curve at the peak is taken as the apex of the angle, the sides of the angle are lines drawn along the center of curve for a specified number of minutes (1 min has been suggested). The lower gradient of the descending slope (wide angle), together with the width of the mixograph curve, in mm at two minutes past peak dough development is an indication of dough strength (resistance to breakdown or over-mixing) which is advantageous to bakers. It is also an indication of higher gluten in flour, which is associated with gas retention during fermentation and this results in higher loaf volumes and good texture.

4. **Area under the curve :** this is measured with a planimeter or personal computer having area integrator software.

5. **Mixogram point score :** the quality laboratory at Small Grain Institute, established a scale (1 – 5) for scoring the mixograms. The scale takes into consideration the mixing time, break-down process, easiness of determining the mixing time and the thickness of the breakdown band.

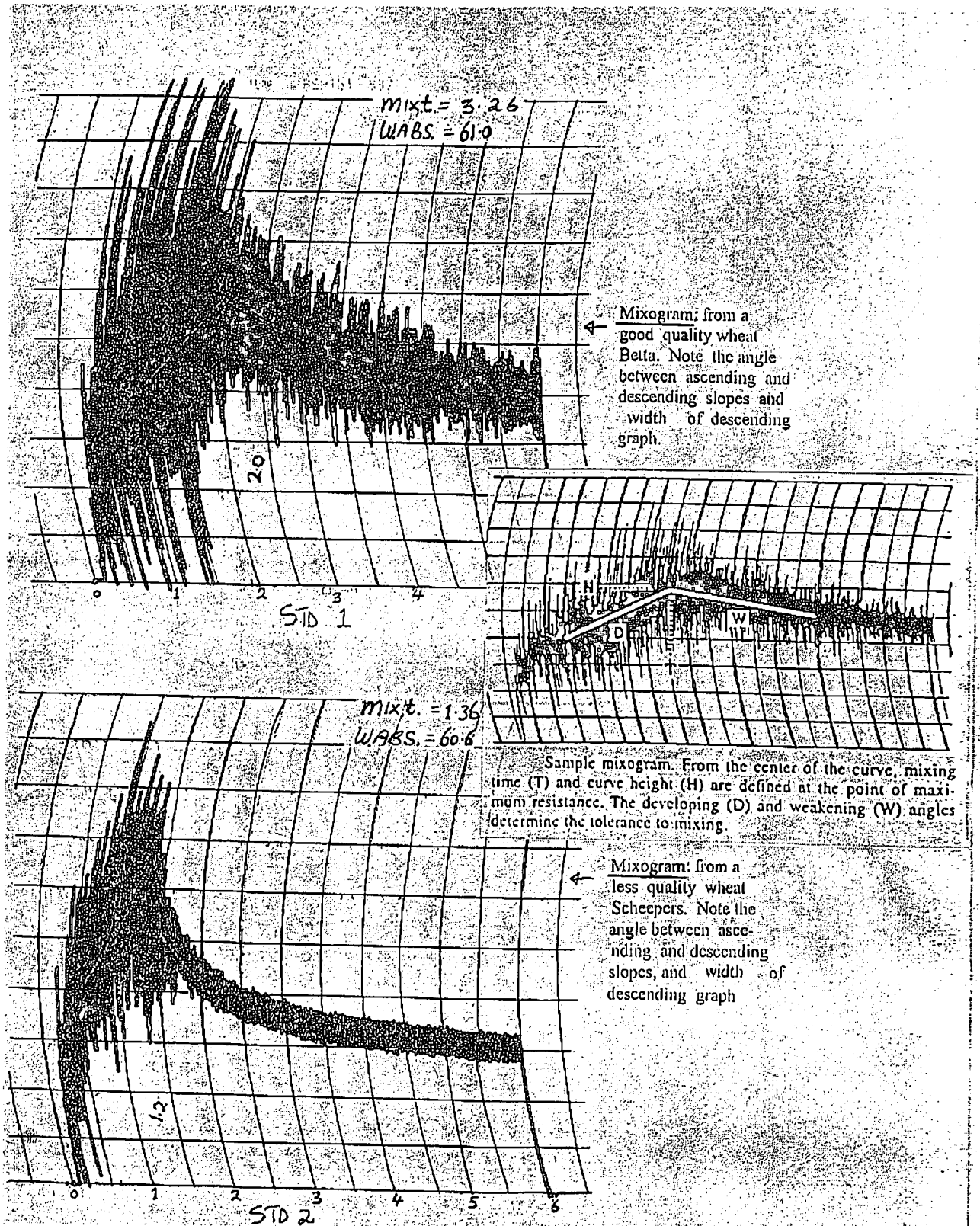


Figure 2.1 Mixograph results for a good quality wheat Betta and low quality Scheepers.

MIXOGRAM POINT SCORE SCALE

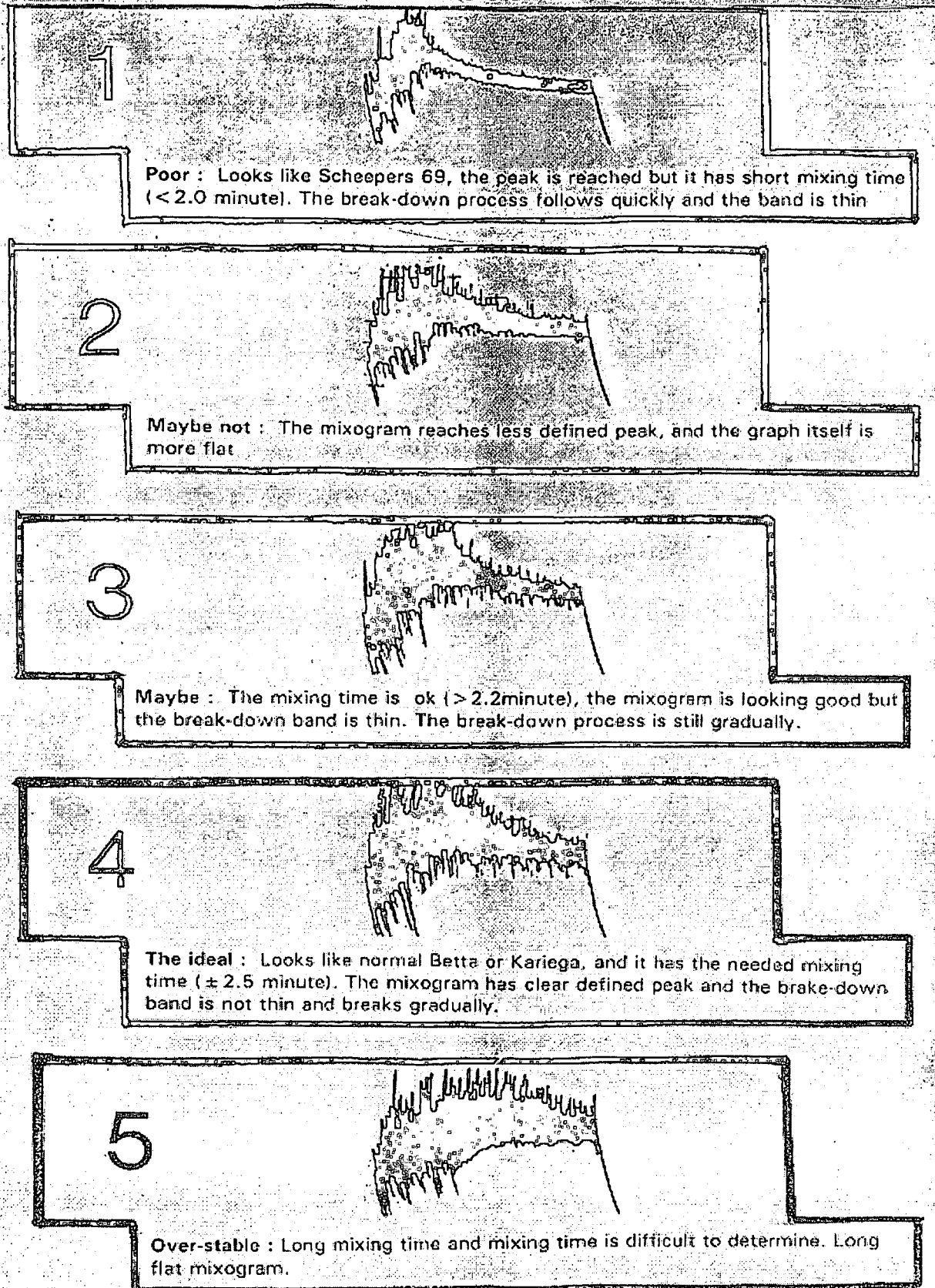


Figure 2.2 Mixogram point score showing different mixograms and their scores

2.1.8 The Farinograph

The farinograph measures and records the resistance of dough to mixing. It is used to evaluate water absorption of flours and to determine stability and other characteristics of doughs during mixing. Two basically different methods are in common use; constant flour weight procedure and constant dough weight procedure.

Water absorption is among the indicators of baking quality (Finney *et al.*, 1987; Van Lill *et al.*, 1995a). Water absorption gives an indication of the potential of the protein molecules to absorb moisture. In general higher protein content flour results in higher water absorption (Finney and Shogren, 1972). Van Lill and Smith (1997) who noted that grains containing higher protein were inclined to be harder support this. Ash content is liable to increase when hard wheat is milled, consequently improving the water absorption.

As it is with the mixograph, the farinograph evaluates dough development behavior and dough stability. Dough stability estimates the ability of dough to resist mechanical mixing (Brunori *et al.*, 1989).

Van Lill (1992) studied the correlation between quality characteristics and the different protein fractions. The albumin content showed weak positive correlations with flour protein content, dough development time, dough stability and water absorption whereas the globulin content positively correlated with dough development time. In contrast, the gliadin and glutenin content were both highly significantly ($p = 0.001$) correlated with flour protein, farinograph properties (dough development time, stability and water absorption) as well as to loaf volume.

Randall *et al.* (1993), reported that significant relationships were identified between rheological (farinograph inclusive) parameters and the high molecular weight glutenin subunit patterns. Band combinations 5 + 10, 13 + 16 and 7 + 9 were suggested to be predominant in conferring good rheological quality characteristics. The presence of subunit 9, coded by locus Glu-B1, shortened the dough development time and increased loaf volume, farinograph water absorption and gluten content (Khan *et al.*, 1989). Peter *et al.* (1998a) also noted that the HMW glutenin subunits very clearly control the main qualitative features of the gluten, namely sedimentation value, farinographic data and loaf volume. It is therefore clear that genotype has more influence on farinograph parameters, but still environment and genotype by environment interaction may contribute to the final expression of the parameters.

Interpretation of the farinograph

The farinograph has two scales; the horizontal, for time (in minutes) and the vertical in Brabender units (BU) from 0 to 1000. Low and higher BU for given flour implies less and higher water absorption respectively, with 500 – BU being optimum. The final amount of water added is the absorption capacity of the flour. **Absorption** is defined as the amount of water necessary or required to center the farinograph curve on the 500 – BU line for flour-water dough. Other values are derived from the farinogram curves and among those that have been proposed are:

1. **Arrival time** : this is the time required for the top of the curve to reach the 500-BU line after the mixer has been started and the water introduced. This value is a measurement of the rate at which the water is taken up by the flour. Generally, it is found on a given variety of wheat that, as the protein increases, the arrival time also increases.
2. **Dough development time (Peak or peak time)** : this is the interval to the nearest 0.5 min from the first addition of water to that point in maximum consistency (minimum mobility), immediately before first indication of weakening. For flours that have nearly flat curves for several minutes, peak time may be determined by taking mean between the midpoint of the flat portion on the top of the curve and highest point of arc at the bottom of the curve. Occasionally two peaks may be observed; the second should be taken for determination of dough development time.
3. **Stability** : this is defined as the time difference, closest to 0.5 min, between the point where the top of curve first intersects the 500-BU line (arrival time), and the point where the top of curve leaves the 500-BU line (departure time). If the curve is not centered exactly on the 500 line at maximum resistance but rather, for example, at 490 or 510 level, a line must be drawn at any point parallel to the 500 line. This new line is then used in place of the 500 line to determine arrival time, departure time, and stability. This value, in general, gives some indication of the tolerance to mixing a flour will have.
4. **Time to breakdown** : this is the reading most recently introduced, and it is the time from start of mixing until there has been a decrease of 30 units from the peak point. It is determined by drawing a horizontal line through the center of the curve at its highest point and then drawing another parallel line at the 30–units, lower level. The time elapsed from the start of mixing until the center of descending curve crosses this lower line is "time to breakdown".

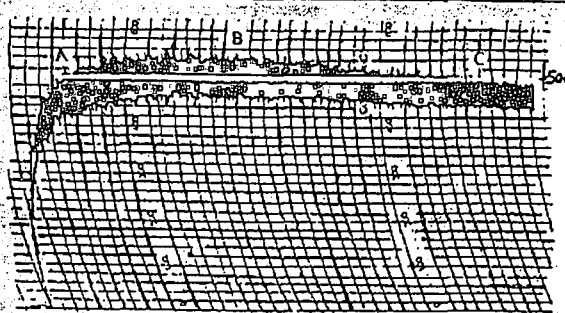
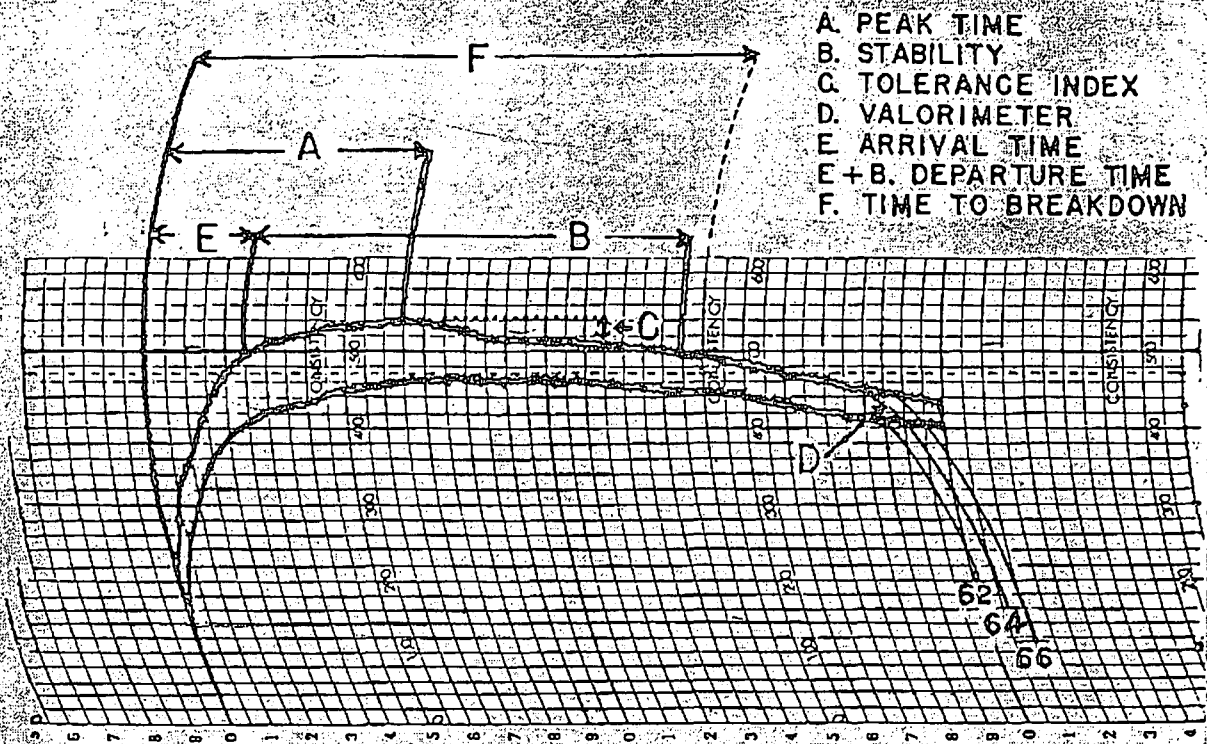
5. **Valorimeter value** : this is an empirical single-figure quality score based on dough development time and tolerance to mixing and is derived from the farinogram by means of a special template supplied by manufacturers of the farinograph equipment. This value is dependent upon two characteristics of the farinograph curve; the dough development time and the rate at which the dough breaks down after the peak time. To read the valorimeter value, the farinogram is first placed in the valorimeter so the zero time and the 500-BU line of the farinogram corresponds to the zero time and the 500-BU line of the dummy farinograph chart in the valorimeter. After placing in position, the left-hand edge of the movable slide is placed on the peak (dough development time), or in the case of a flat curve, the first indication of weakening. The valorimeter value is then read at the right-hand edge of the slide, 12 min past the peak, and is the value corresponding to the line of the stationary template that intersects the center of the farinogram at this point.
6. **Tolerance index** : this value represents the difference in BU from the top of the curve at peak time to the top of the curve measured 5 min after peak time is reached. Another related measurement called " Drop - off " refers to the difference in BU from 500-BU line to the center of the curve measured at 20 min from the addition of water.
7. **Departure time (DEP)** : this is the time to the nearest 0.5 min, from the first addition of the water until the top of the curve leaves the 500-BU line and equals the sum of the arrival time plus the stability. The longer the time the stronger the flour.

The most important characteristics for quality prediction are; farinograph absorption capacity, peak time and stability. In South Africa the ideal absorption value should reach approximately 60% as the optimum but it can go as high as 63%. Peak time of 4 – 4.5 min is desirable and it is better if the graph will remain for 4 min after peak at a higher level. Therefore the stability should be around 9 min and above.

Values for the parameters in Figure 3 are:

Arrival time	2.5 minutes
Peak time	6.5 minutes
Stability	11.0 minutes
Departure time	13.5 minutes
Time to breakdown	14.0 minutes
Tolerance index	30 BU
Valorimeter	64 units

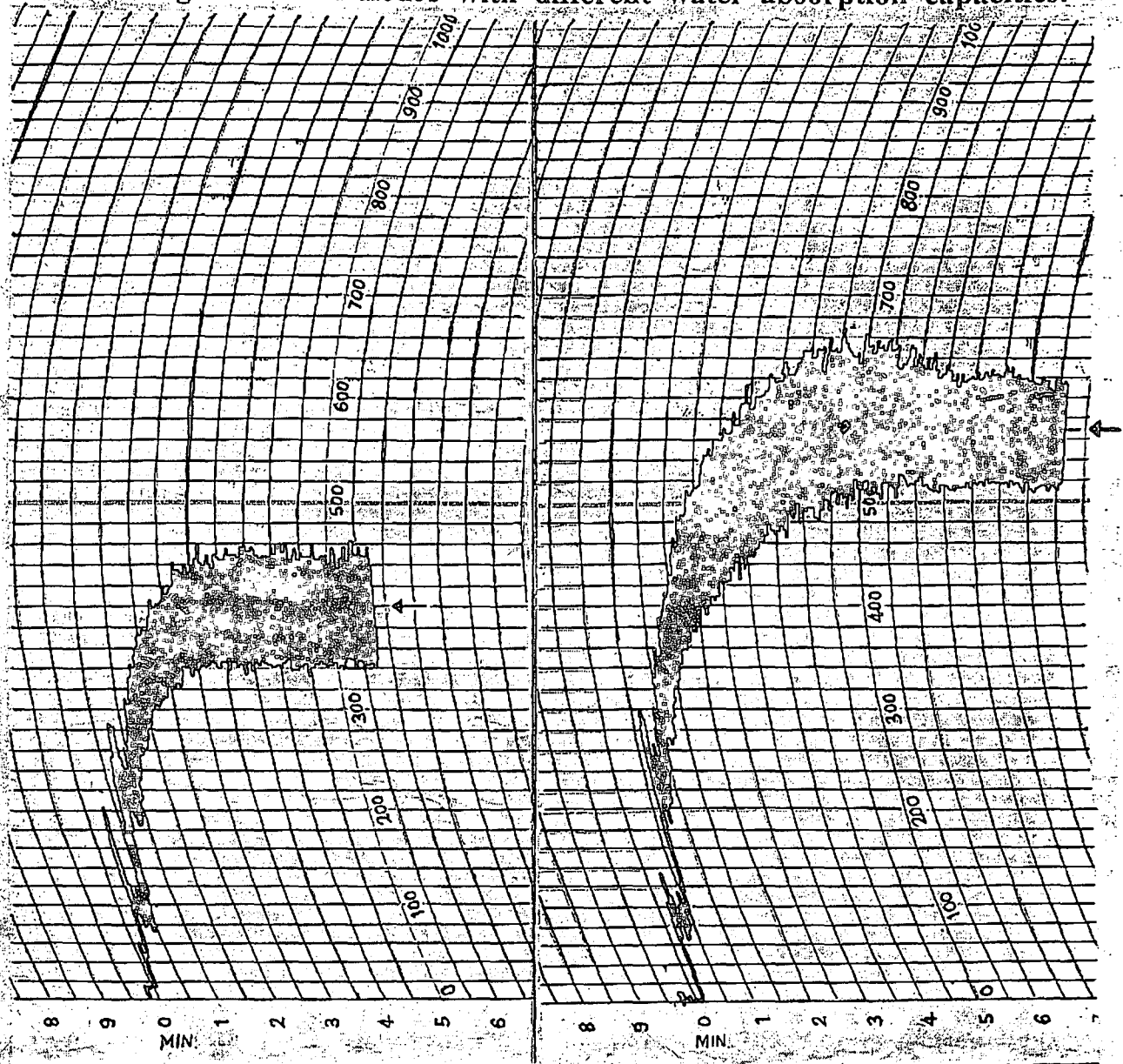
Readings Commonly used in Interpreting a Farinogram:



Sample farinogram. The curve is centered on the 500 line and reaches a maximum at point B, the mixing time. The arrival time (A) and departure time (C) refer to the curve envelope crossing the 500 line.

Figure 2.3 Interpretation of the results from a farinograph test

Farinogram from flours with different water absorption capacities:



Flour with less
Absorption capacity.
Number of blocks from
Center of graph (arrow)
to 500 BU = 5,
 $0.7 \times 5 = 3.5\text{ml.}$
Optimum absorption is
 $65 - 3.5 = 61.5\text{ml.}$

Flour with high
Absorption capacity.
Number of blocks from
center of graph to 500 BU
 $= 3.5, 0.7 \times 3.5 = 2.45\text{ml.}$
Optimum absorption will be
 $65 + 2.45 = 67.45\text{ml.}$

Figure 2.4 Determining the optimum water absorption with farinograph test.

2.1.9 The consistograph

This is one of the new modern rheological methods that has recently been designed to measure the water absorption capacity of flour and to follow the behavior of the doughs during mixing. The effect of additives on the consistograph curve can be seen very clearly, and a piece of dough can be taken from an industrial mixer and placed into the consistograph to determine an instantaneous consistency. Two types of tests may be performed, namely; constant hydration and adapted hydration.

When the consistograph is compared to other existing equipment (for example the farinograph), it is not a copy of these apparatuses. The main important point is that, the consistograph needs a cohesive dough to record pressure, and the more cohesive the dough, the more pressure will be recorded. It therefore shows that the consistograph always deals with easy to handle doughs. On the other hand the farinograph is based on the measurement of a torque between two arms. The tougher the dough which increases resistance between arms, the higher the recorded value. An important fact to note is that the arms of the farinograph are always in the product. Because of that, even if the product is not cohesive there will be a recording.

In a test on rye flour, for the farinograph it was possible to calculate some measurements, whereas on the consistograph under the same conditions, the measurements were nearly zero. The reason for this is the difficulty to form a protein network in the rye flour, (Lab World, per. Comm.). This clearly shows that the consistograph measurement needs a good cohesion of the dough. The consistograph seems to be more sensitive to the gluten content and properties than the farinograph.

There is a very good relationship between the two methods concerning water absorption determination as far as normal flours are concerned. For the flour having a high gluten content or damaged starch we can observe differences. In general tendencies, both devices show relationships concerning the dough behavior during mixing. But the consistograph is somehow more sensitive (and especially for the strong types of flour) and records differences whereas the farinograph gives very comparable results. This explains that a direct correlation between the two equipments cannot be given easily.

(A) Constant hydration

The best example of a device working at a constant hydration is the alveograph. The user needs to know the moisture content of the flour before testing the flour with the alveograph. It is very important because the flour will be hydrated according to its moisture content. Therefore the basis of the calculation on the alveograph (which remains the same as the consistograph at constant hydration) is to form dough which is hydrated at 50%, if the flour moisture content is 15%. It can also be calculated as 76.47% hydration on a dry basis. For example, 125 ml of salt water will be added to 250g of flour at 15% moisture content. One will add more water if the flour is drier, and less if the flour contains more water. In any case, the ratio of water to dry matter will always be the same. The advantage of this method is that it requires only the moisture content to be available.

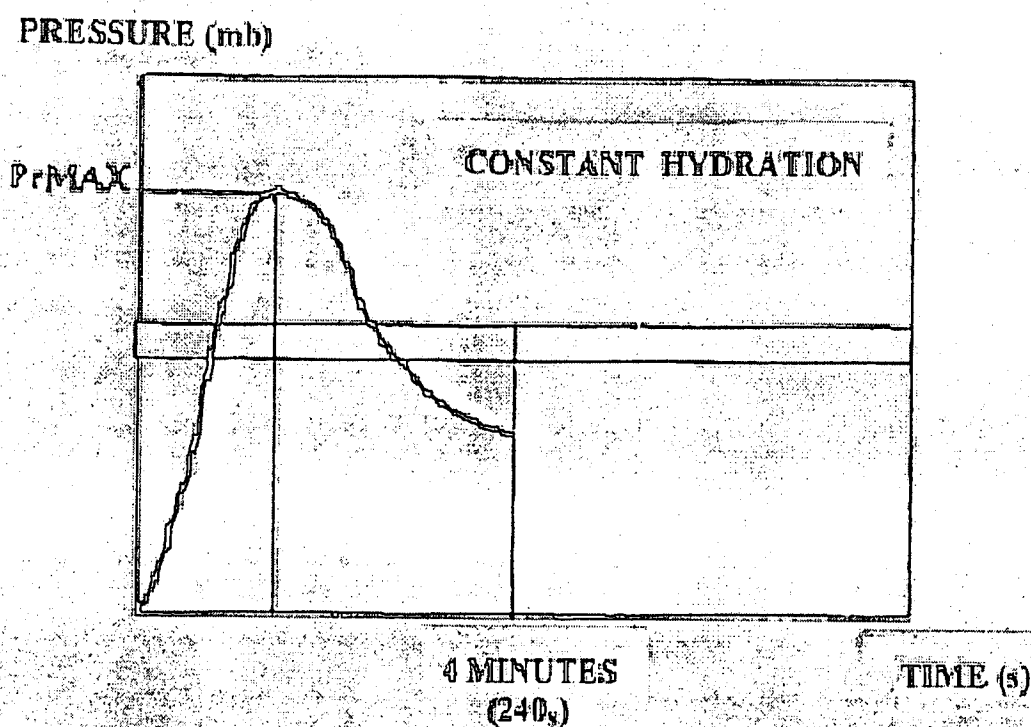


Figure 2.5 Results for a constant hydration test showing the importance of Primax for flour water absorption

- **PrMax** : equals the maximum measured value of the pressure, directly related to the water absorption capacity of the flour.

Several tests on different flours have shown a linear relationship between dough softening and increase in hydration. It permits the consideration that the softening of the dough is a function of its hydration.

This allows the determination of the absorption just by knowing the PrMAX at a certain hydration level for (example constant hydration). When a straight line sloping downward is followed from a certain PrMAX value until where this line crosses a horizontal line corresponding to a given PrMax TARGET. The value on the x-axis corresponding to this point is the hydration (on dry basis) for such flour.

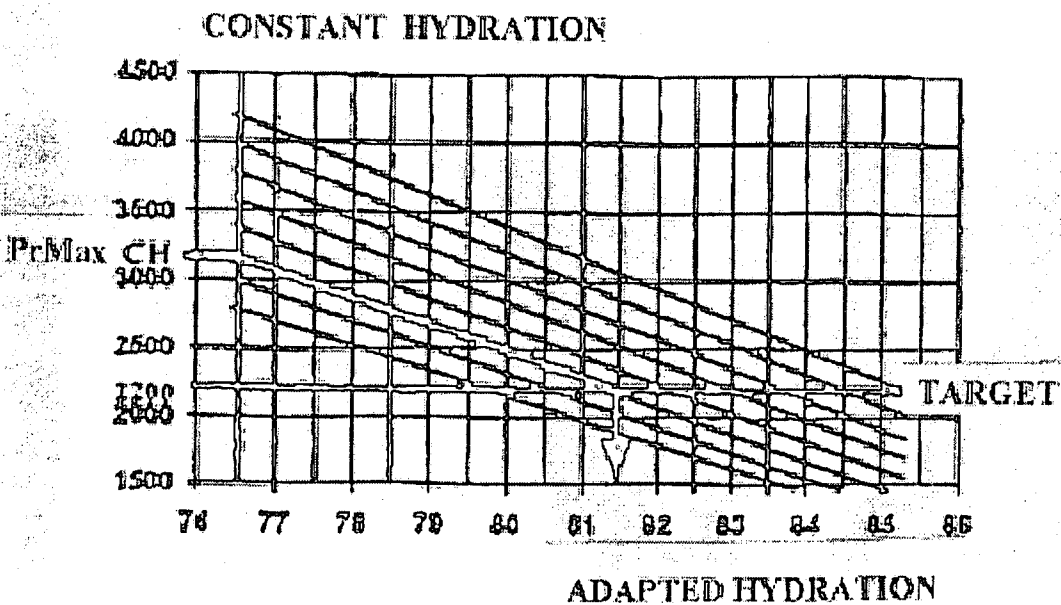


Figure 2.6

Linear relation between hydration increase and softening of the dough. The y-axis. Values starts at 1500 with 500 unit increments, and x-axis start at 76 with 1 unit increments.

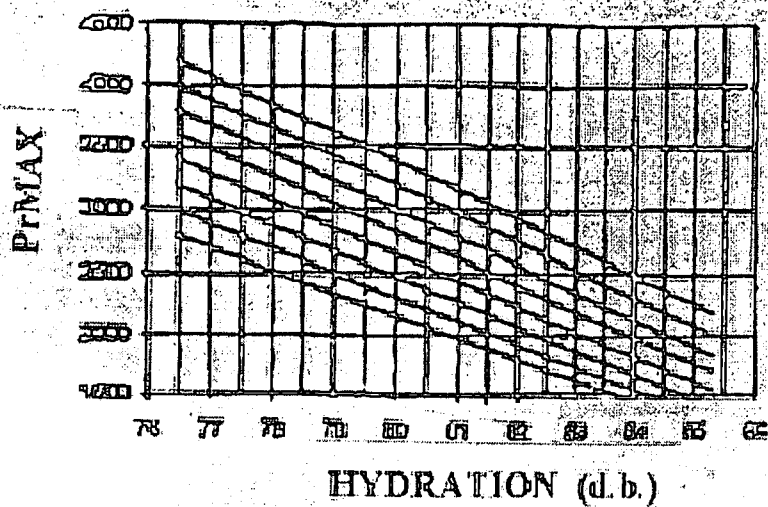


Figure 2.7 Determining hydration capacity of the flour by using its PrMax. The y-axis values start at 1500 with 500 unit increments and for x-axis start with 76 with 1-unit increments.

- **WA :** water absorption, the hydration necessary to reach 1700mb on the basis of 15% moisture content.
- **HYDHA :** the hydration necessary to reach 2200 mb on the basis of 15% moisture content (if CHOPIN protocol is used). This value is displayed when the PrMax of the curve is higher than the PrMax MINI of the protocol used. When you create your own protocol and increase the PrMax MINI, and use the PrMax TARGET such as those of CHOPIN (2200), HYDHA will not be displayed for the samples with lower PrMax, but their WA will be almost the same or close to that of the CHOPIN protocol.

(B) Adapted hydration

This test is performed according to the hydration capacity of the dough, and therefore is consecutive to a test with constant hydration. The test can be initialised either by selecting an abbreviation of adapted hydration with a question mark [AH?] in the previous screen of CH results, or by selecting AH CONSISTO in the test menu. In this test, the point to reach is a "constant maximum pressure point". This test is interesting for two reasons; the first one is to assure that the 2200 mb target (or others) is obtained. The second one is to evaluate the behavior of the dough during mixing.

- **Time to PrMax** : this is related to the ability of the flour to form a dough and to reach the desired consistency. This time tends to decrease when working on weak flour.
- **The stability** : is measured at the time during which the pressure is higher than PrMAX minus 20%. Weak and strong flours tend to have smaller and higher stabilities respectively.
- **The 250s and 450s drop** : These show the pressure decrease at the two times compared to PrMax, and therefore weakening of the dough at this time, which reflects the capacity of the dough to resist to mixing. These data are most of the time related, but we can sometimes observe curves having similar drops at 450s whereas the 250s drop is different. This gives a good indication of dough resistance to mixing. - The parameters related to the dough behavior are valid if the measured value of PrMax is in the range $\pm 7\%$ of the Target PrMax. If PrMax is not equal to 2200 mb (or the target PrMax), the alveolink calculates the correction of hydration (Δ HYDHA) which is necessary to be added to HYDHA in order that PrMax becomes 2200mb during the AH Consisto test. The corrected hydration value is displayed ($\text{HYDHA C} = \text{HYDHA} + \Delta \text{HYDHA}$) only if it is more than $\pm 5\%$ (absolute value) as compared to HYDHA. It is then possible to run a new AH Consisto test using the corrected value HYDHA C for improving the results.

PRESSURE (mb)

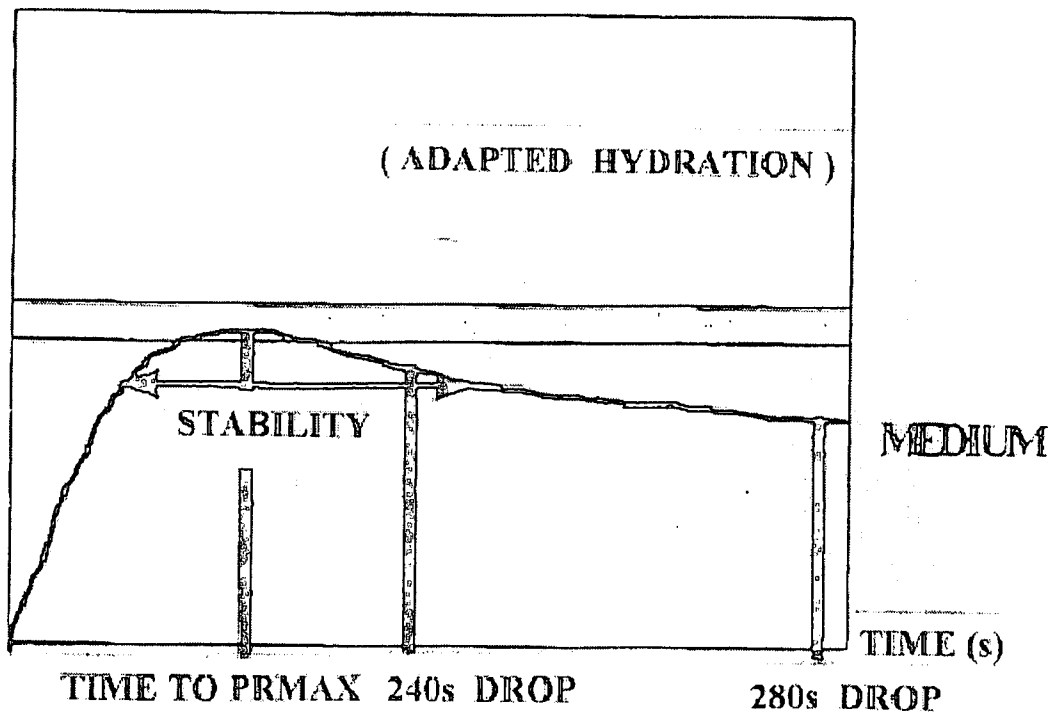


Figure 2.8 Results for an adapted hydration test with all the values showing the dough behaviour

PRESSURE (mb)

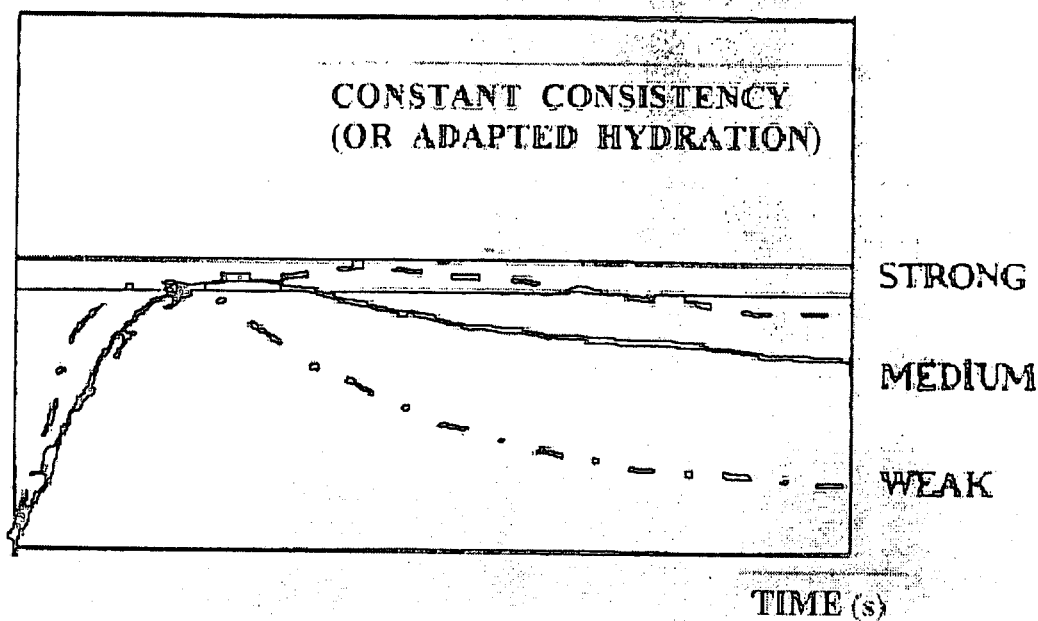


Figure 2.9 Adapted hydration test results showing flours with different strength.

2.1.10 Alveograph method for wheat flour (AACC 54 – 30A)

The alveograph preceded the other instruments and it first appeared in the early 1920s. It is designed to measure the resistance to bi-axial extension of a thin sheet of flour-water-salt dough (generally at a constant hydration level). A sheet of dough of definite thickness prepared under specific conditions is expanded by air pressure into a bubble until it is ruptured, and internal pressure in the bubble is graphically recorded. It is applicable to all wheat flour types, including very strong bread wheats, which are usually run at an adjusted hydration rate to allow for their higher degree of damaged starch (Walker and Hazelton, 1996).

According to Van Lill and Smith (1997) protein content influences alveographic measurements. They found that for winter wheats in the summer rainfall region, the measurements were more sensitive to environmental effects than genotypes (cultivars).

However, as it is for the other rheological characteristics, protein quality (especially certain glutenins) has more influence on alveograph parameters, and this signifies genetic control for the character. Hou *et al.* (1996) studied the relationships of quality of glutenin subunits of selected U.S. soft wheat flours to rheological and baking properties. They noted that the high molecular weight glutenin subunits (HMW-GS); 1 to be correlated positively with alveograph extensibility (L), subunit

2* with pressure inside the bubble (P) and P/L values and subunit pair 5+10 with P and strength (W) values.

These results are consistent with those of Branlard and Dardevet (1985) who found that subunits 2* and 1 were positively correlated with P and L values respectively. Payne *et al.* (1987) assigned the same quality score to subunits 1 and 2*, and the presence of these subunits in a hard wheat usually indicates a strong wheat for good bread making.

In their study Labuschagne and Van Deventer (1995) found that in the group (Dirkwin/Zaragosa, cross) the HMW-GS 17+18 contributed to the variation of alveograph strength, stability, distensibility and P/L ratio. In the other group (Waverley/Zaragosa cross) none of the alveograph parameters was influenced by these HMW-GS and their contribution to quality variation was very small.

Results interpretation

The results are measured or calculated from the obtained five curves, before or after deleting the isolated ones (on the manometer or the alveolink). The parameters of the alveographic measurements are:

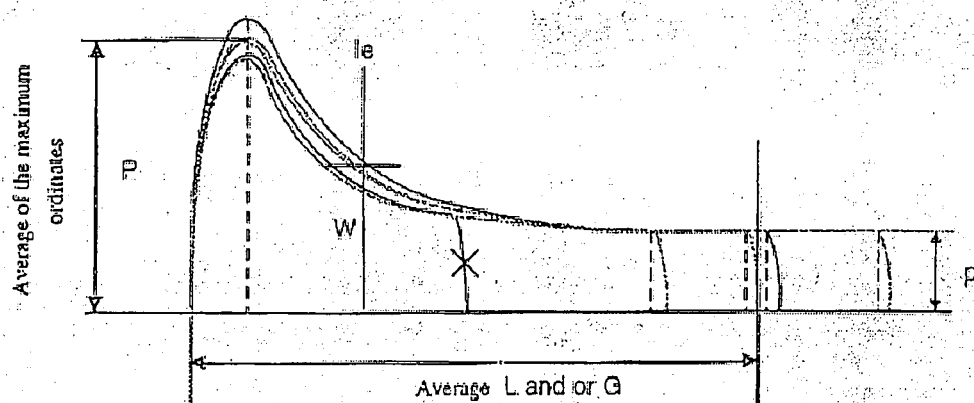


Figure 2.10 Results from an alveograph test.

P : **Tenacity** (*maximum pressure required for deformation of the sample*). This is the average of maximum ordinates, measured in millimeters and multiplied by 1.1. It is expressed to the nearest unit (without the decimal fraction of a millimeter). It relates

to the dough's tenacity and elastic resistance and is a predictor of the dough's ability to retain gas. Weak flours result in low **P**, whereas higher **P** suggest strong flours.

L (or G) : Extensibility (*length of the curve*), Extensibility is the average abscissa at rupture of each curve measured in millimeters on the zero line, from the origin of the curve to point corresponding vertically with the clear drop due to the rupture of the bubble. The dough's extensibility predicts its handling characteristics. Longer and short **L** values are an indication of weak and strong doughs respectively.

W : Baking strength (*surface area under the curve*), This is the deformation action of the dough, based on one gram of dough, evaluated in 10^{-4} joules. This is the amount of work required for the deformation of the dough and is related to the baking "strength" of the dough. Lower and higher **W** values indicate weak and strong flours respectively. Practical calculation; for flour having **G** indexes between 12 and 26

$$W = 6.54 \times s$$

where; s = surface of the curve in cm^2

G = index of swelling

P/L : This ratio is conventionally called the curve configuration ratio. The value serves as an index of protein quantity and quality. For example, a high **P** and short **L** values would denote a "bucky" or very elastic dough. It is possible to predict the **P**, **L**, and **W** values for blends by knowing the properties of the starting flours Walker and Hazelton, (1996).

p : Pressure at bubble breaking point.

le : Elasticity (le ; pressure at 4cm from the beginning of the curve).

Index of swelling (G) : this is an average of the swelling indexes on the calculation chart and corresponds with the rupture abscissas "**L**". Conversion table of "**L**" into "**G**" (where; $G = 2,226 \sqrt{L}$) and planimetric conversion charts are supplied with apparatus). In general an alveogram with higher **P** (tenacity) and more length, **L** (extensibility) is better than the one in which either of the two parameters is much more reduced. South African wheats should have a configuration **P/L** ratio close to 0.8. Also the surface area under the curve (**W**), should be around 250 as an optimum value, when divided by a constant of 6.54 will result in an alveograph strength of ± 35 in joules.

2.1.11 Glutomatic system (For determination of gluten)

Gluten, an insoluble protein in wheat flour is recognised as a basic quality factor of wheat. A gluten test gives in a few minutes a measurement of protein quantity and an indication of quality, allowing a rapid decision on how to use the wheat. The simplicity of a gluten determination provides important information and is a practical test for wheat and wheat flour classification at all handling and processing points, (silo/elevator, mill and baker). For a plant breeder, to develop wheats with high protein content and protein quality have always been a major goal. Therefore gluten tests are valuable in screening different cultivars for protein quality and quantity.

The glutomatic is an automatic apparatus, which develops the gluten from wheat flour. Dough mixing and subsequent separation of starch and other solubles from the dough takes place in the same test chamber under controlled standardized conditions. The gluten ball is centrifuged to remove excess water and weighed as wet gluten. This can be examined for elasticity as a protein quality factor. To obtain the dry gluten (protein) amount, the gluten is dried between two Teflon – coated hotplates.

The protein content can be affected by agronomic measures e.g. fertilisation, whereas the composition of the gluten proteins is genetically determined. The gluten consists mainly of aggregating glutenins and monomeric gliadins. The glutenins are responsible for the dough elasticity, while the extensibility and viscosity of the dough is determined by the gliadins (Colt , 1990; Shewry *et al.*, 1995).

A large portion of variation observed in flour quality may be attributed to variation in gluten protein content and composition (Bietz, 1988). Exhaustive experimentation has been conducted in attempts to explain wheat quality variation as a function of genetic variation in gluten protein subunit composition (Bietz, 1988 and MacRitchie *et al.*, 1990). However, such analyses can only hope to explain that portion of wheat quality variation that is genetically determined. Subunit composition is genetically fixed: hence it can't explain that portion of wheat quality variation that is dependent upon environmental factors or G x E interactions.

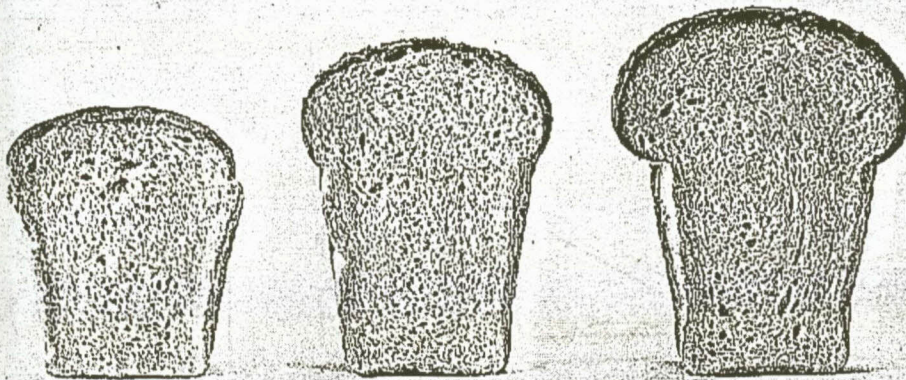
In their study, Robert *et al.* (1996) found that gluten protein fractions were positively correlated with quality parameters, whereas non-gluten fractions were negatively associated with quality. Glutenin was mostly highly positively correlated with loaf grain and texture and was independent of flour protein content. They also noted that flour protein concentration and the percentage of protein present as gliadin and non-gluten proteins were most sensitive to environmental fluctuations. The glutenin part was found to be almost totally genotype dependent.

Dough testing with blends of constant glutenin-to-gliadin ratio showed increases in the mixing time, mixograph peak resistance, maximum resistance to extension, extensibility and loaf volume as the protein content increased. On the other hand, at constant protein content, increases in glutenin-to-gliadin ratios were associated with increases in mixing time, mixograph peak resistance, and maximum resistance to extension, loaf volume and with decrease in extensibility. Thus total protein content and glutenin-to-gliadin ratio independently affected dough and baking properties (Uthayakumaran *et al.*, 1999).

Milovanovic *et al.* (1998) studied the influence of 1BL/1RS translocation on technological quality of winter wheat. They found that content of wet gluten had a more important role in determination of crumb value and loaf volume in cultivars with the translocation than in cultivars without translocation. This points out special attention to be paid to the content of wet gluten in materials that possess the mentioned translocation.

Interpretation of glutamatic results

The higher the percentage of gluten content the higher the expected loaf volume will be. According to Swedish Seed Association, Svalov, Sweden the correlation between Glutomatic values and Kjeldahl values is 0.983.



20% wet gluten content

30% wet gluten content

40% wet gluten content

The above three breadloaves were baked with the same quantity of flour and under same conditions, but with different gluten (protein) content.

Figure 2.11 Baking results showing the effect of percentage wet gluten content in the flour

2.1.12 Loaf volume

Loaf volume is obtained from a basic baking test for evaluating bread wheat flour quality by a straight dough process that employs long fermentation and in which all ingredients are incorporated in the initial mixing step. The method is a 180 min sugar based fermented dough system without shortening. It is intended primarily for laboratory assessment of bread wheat flour quality under vigorous fermentation conditions. Effects of ingredients and processing conditions, and particularly oxidation response, can also be assessed.

Baking is the final test of wheat flour as it indicates what the final product looks like. The desired higher loaf volume and good (fine) texture is a result of high protein content especially gluten in wheat grains. This also shows that there was no sprouting damage, as flour from sprouted wheat grains result in low loaf volumes and poor texture regardless of a cultivar being of good quality.

Bread is the principal food around the world and provides more nutrients to mankind than any other single food source (Pomeranz and Shellenberger, 1971). For example, in South Africa more than six million loaves of bread are consumed daily (Anonymous, 1995). Bread making is primarily based on protein concentration and quality (Finney *et al.*, 1987). A linear correlation between protein content and loaf volume generally exists, indicating protein content to be a measure of wheat quality (Finney, 1945).

Loaf volume and water absorption are among the indicators of baking quality (Finney *et al.*, 1987; Van Lill *et al.*, 1995a & b). Loaf volume gives an indication of the gas retention capacity of the dough during the fermentation process and indicates the volume of bread determined by rapeseed displacement (Shogren and Finney, 1984). Water absorption gives an indication of the potential of the proteins to absorb moisture. Generally higher protein content flour results in a higher water absorption (Finney and Shogren, 1972). The more water absorbed, the bigger the volume of dough per unit flour that can be produced.

The SDSS volumes (a measure of flour aggregative ability) have been found to be positively correlated with both protein content and bread volume of the cultivars (De Villiers and Laubscher, 1995). It therefore appears that SDSS values are good parameters for estimating (and predicting) the baking quality of wheat cultivars.

According to Lorenzo (1986) a high protein content is not necessarily a prerequisite for high loaf volume. Sandstedt and Ofelt (1940) who found a decrease in loaf volume, also support this in baking quality at higher protein content (above 13%). This is again the consequence of environment and genotype effects in terms of protein quality.

Ivanov *et al.* (1998) found that meteorological conditions influence the accumulation of some amino acids and protein fractions and are dependent on the genotype specificity, as well. They also found that some of the bread-making quality characteristics were significantly correlated with the glutenins, the gliadins and the total protein content. According to Uthayakumaran *et al.* (1999) the protein content and glutenin-to-gliadin ratio (a measure of molecular weight distribution or protein size) have different roles in determining the various dough and bread quality parameters. Differences in the quality observed from flour to flour are thus determined, in part, by a superimposition of the effects of protein content and glutenin-to-gliadin ratio.

2.2 Genotype x environment interaction and statistical analysis

The analysis of variance for genotype x environment interaction may be performed using additive main effect and multiplicative interaction (AMMI) method (Gauch, 1988). The results are provided in the form of simple ANOVA, means for environments and genotypes, biplots showing the extent of genotype and environment interaction. This method integrates analysis of variance (ANOVA) for the genotype and environment main effects with principal components analysis of the genotype-environment interaction into a unified approach and is especially useful in analysing multi-location trials (Gauch and Zobel, 1988). By the usual analysis of variance the AMMI analysis first fits the additive main effects of genotypes and environments and then describes the non-additive part, the genotype x environment interaction, by principal component analysis (PCA). The model can be described as the only multivariate analysis, due to integration of analysis of variance and principal components analysis into a unified approach. The most important approach of AMMI is particularly effective in clarifying genotype x environment interactions, and the results can be graphed in a very informative biplot that shows main and interaction effects for both genotypes and environments.

According to Purchase (1997), the AMMI model has clearly indicated that it can summarise patterns and relationships of genotypes and environments, as well as offer a valuable prediction assessment. While other multivariate analysis procedures (such as cluster analysis) may be difficult to interpret in relation to G x E interaction, the AMMI model offers very relevant biological information whereby principal component factors can be described according to environmental and/or biological factors and statistically is fairly simple. He recommended, that if a single method of describing G x E interaction and the stability of a genotype had to be selected, the AMMI model would be the most appropriate.

In using part of the AMMI analysis, PCA partitions G x E interaction into several orthogonal axes. Gauch and Zobel (1996) state that generally AMMI 1 and AMMI 2 models, with IPCA 1, and IPCA

2 respectively, are selected. However, for AMMI 3 and higher models, IPCA 3 and higher axes are generally dominated by noise, have little or no predictive value and no biological interpretability, and can thus be discarded. They also state that not only has extensive experience indicated the interpretability of a respectively large IPCA 1, but also that statistically, significant model parameters indicate that identifiable physical or biological causes are at work. This is supported by Nel *et al.* (1998a), whereby IPCA 1 had more contribution to interaction variation than IPCA 2. However, when determining stability both AMMI 1 and AMMI 2 are necessary as IPCA 1 scores can be plotted against IPCA 2 scores, Purchase (1997). From the AMMI biplot the more the genotype/environment approaches the mean and zero for the AMMI axis the more stable it is.

Canonical variate analysis (CVA) is a test used when it is of more interest to show differences between groups than between individuals. The differences between a large numbers of variables are firstly reduced to a smaller set of variables that account for most of the variability. This new set, called canonical variates, are linear combinations of the original measurements, and are thus given as vectors of loading for the original measurements. With this approach, a set of directions is obtained in such a way that the ratio of between-group variability to within-group variability in each direction is maximised (Digby *et al.* 1989; Van Lill *et al.*, 1995b). Osborne *et al.* (1993) employed canonical variate analysis for discriminating between quality types in breeding material, where differences between groups are of more significance than differences between individual breeding lines. Graybosch *et al.* (1993) used canonical correlation analysis to ascertain the extent to which a set of biochemical measurements was related to a set of quality measurements, and also, to determine the particular components that have been responsible for these correlations.

CHAPTER 3

MATERIALS AND METHODS

3.1 Materials

The wheat cultivars, analysed in this study, were obtained from trials conducted in irrigation areas by the Small Grain Institute (Breeding Department), during 1997 and 1998. The localities were; BullHill, Prieska, Hopetown, Douglas, Barkly West, Loskop and Koedoeskop (which was not included in 1997). BullHill, Prieska, Hopetown, Douglas and Barkly West comprised the cooler central areas, and Loskop and Koedoeskop the warmer northern irrigation areas. Genotypes common in both years were; Marico, Kariega, T4, Palmiet, SST825, SST822, SST876, SST57 and Inia. In 1997, SST55 and SST65 were included, whereas in 1998, SST38 was included making a total of 11 and 10 entries, respectively. Trials were conducted at experimental stations or farms of collaborators where the soil and climate are representative of a specific area.

The cultivars were planted according to a randomised block design with four replicates. Trial plots consisted of eight rows of six meter in length, which were later reduced to five-meter length. Inter-row spacing was maintained at 0.17 m. The planting rate of the different cultivars varied according to 1000 kernel mass of a specific seed lot. The seed used for each cultivar in the trials was made up in such a way that a uniform stand of plants m^{-2} could be achieved for each cultivar involved. Fertiliser applications on trial plots were done according to recommendations on the basis of individual soil analyses obtained from soil samples. Weed and pest control was performed when necessary. At harvesting the whole trial plot of six rows ($5.1m^{-2}$) was harvested where possible with a Wintersteiger trial harvester. When a trial harvester was not available the same plot size was harvested with sickles and threshed. The type, origin and year of release for the genotypes used in this study are indicated in Table 3.1.1.

Table 3.1.1 Entries of irrigation wheat cultivars included in the study

Entry	Type	Origin	Released
Palmiet	Pure line	Small Grain Institute	1985
T4	Pure line	Small Grain Institute	1965
Kariega	Pure line	Small Grain Institute	1993
Marico	Pure line	Small Grain Institute	1992
Inia	Pure line	Small Grain Institute	1966
SST38	Pure line	Sensako	1993
SST55	Pure line	Sensako	1992
SST57	Pure line	Sensako	1995
SST65	Pure line	Sensako	1987
SST876	Pure line	Sensako	1997
SST822	Pure line	Sensako	1993
SST825	Pure line	Sensako	1993

The samples were evaluated with the following tests and most of them using the indicated procedures of American Association of Cereal Chemistry (AACC).

3.2 Quality analysis

1 Thousand kernel mass and test weight

A Thousand kernel mass

The wheat samples were cleaned to get uniform grains at 12 to 13% moisture content. Unthreshed, highly shriveled, insect and mechanically damaged grains were avoided. The grains were placed in a numeral grain counter, after counting 1000 kernels the weight was taken. Three replications were used to determine 1000 kernel weight accurately.

B Test weight (hectoliter weight)

The apparatus include: Standard quart (qt) kettle, balance, hopper having round opening 3.21 cm (1.25 in) diameter, and stoker made of wood with smooth rounded edges. The samples were cleaned well with moisture content at 12 to 13%.

- Sufficient amount of grain was placed in a hopper until quart kettle overflows. The outlet of the hopper was positioned over the kettle, and grain allowed to flow into the kettle.
- Stoker was placed on kettle and excess grain removed lightly without jarring by stroking grain with three full – length zigzag motions. The grains were placed in weighing pan on the balance to record the weight.

2 Falling number determination (AACC 56 – 81B)

Falling number is a method based on the unique ability of α -amylase to liquefy a starch gel. The strength of the enzyme is measured by falling number (FN) apparatus, defined as time in seconds (sec) required to stir and allow the stirrer to fall a measured distance through a hot aqueous flour or meal gel undergoing liquefaction.

3 Sedimentation test (sodium dodecyl sulphate – SDS, AACC 56 – 70)

The SDS-sedimentation test is used for measuring relative gluten strength as it indicates differences in the quantities of the polymeric glutenins (gel protein). The method used is to that of AACC (Sodium Dodecyl Sulfate Sedimentation Test for Durum wheat).

4 Protein and moisture content

The method used is that of AACC method 39 – 11, applicable to wheat flour. An infrared reflectance spectrophotometer (Infra Alyser 360) was used which has been calibrated using Kjeldahl data.

5 Flour colour determination

A flour colour grader series III was used to determine the flour colour.

6 Bühler-mill method (AACC 26 – 21A)

The method is a simplified representation of commercial mills, applicable to production of bread and noodle flour. A Bühler 10' 084' 037 mill was used. Adding a specific amount of water on the basis of seed moisture content and percentage of vitreous (hard) kernels and left overnight (18 hrs) did tempering of seed. Recommended time is 12 to 18 hrs with the longer time being optimum. The clean-out method was used, without stopping the mill from warm-up or previous sample. Adjustment and modification of mill as directed in AACC method 26-21A, should be done to ensure anticipated flour yield. Flour yield should range between 70 and 75%, depending on wheat characteristics, cleaning, feed rate, ambient conditions, and maintenance of mill. Mill yield can be calculated on basis of total recovered products or on basis of wheat milled. All weights should be adjusted to 12% moisture, and yields expressed on constant moisture basis.

7 Junior quadrumat mill

The equipment is used to mill wheat grains into flour for various quality evaluations such as protein and moisture content, colour determination etc.

$$\% \text{ Flour extraction} = \frac{\text{Flour weight (g)}}{\text{Flour weight (g) + Bran weights (g)}} \times 100$$

8 Mixograph method (AACC 54 – 40A)

Applicable to wheat flour of hard, soft and durum wheats. Mixograph measures and records dough development behavior and its resistance to mixing. Since the equipment allows to use either of the two bowls depending on flour quantity (10 g and 35 g) in our tests we used the 35 g bowl.

9 Farinograph method (AACC 54 – 21A)

It is used to evaluate the water absorption capacity of wheat flours and other dough characteristics during mixing. A Brabender farinograph, with large (300 g flour) and small (50 g flour) mixing bowls is normally used. Further adjustments (as directed in AACC 54 – 21) needs to be done when changing from one bowl to another. For our tests the equipment was adjusted for 50 g flour (small bowl).

10 Consistograph method (Lab World (Pty.) Ltd.)

The consistograph is one of the new modern rheological method, which use two types of apparatus namely the mixer and the alveolink NG.

- A. The consistograph mixer, has a special "double arm kneader" to increase the intensity of mixing process. There is also a moveable side in the mixer with a static rod, which is between the two arms thus avoiding the balling of the dough and increases the efficiency of mixing.
- B. The alveolink NG records and processes the data from the pressure sensor in the mixer. It also manages the test time allowing an autonomous measurement and stopping the device automatically at the end of the test. It is also connected to the printer in order to print out hard copies.

11 Alveograph method for wheat flour (AACC 54 – 30A)

It is designed to measure the resistance to bi-axial extension of a thin sheet of flour-water-salt dough (generally at a constant hydration level). A sheet of dough of definite thickness prepared under specific conditions is expanded by air pressure into a bubble until it is ruptured, and internal pressure in the bubble is graphically recorded. The method uses the same apparatus as consistograph for mixing and recording. Nevertheless an additional apparatus for blowing the bubble is needed and in our case the Chopin alveograph (with circulating water bath, optional) was used.

12 Glutomatic system (For determination of gluten)

The glutomatic is an automatic apparatus, which develops the gluten of wheat flour. A 2% NaCl solution is used and dough mixing and subsequent separation of starch and other solubles from the dough takes place in the same test chamber under controlled standardised conditions. The gluten ball is centrifuged to remove excess water and weighed as wet gluten. This can be examined for elasticity as a protein quality factor. To obtain a dry gluten (protein) amount, the gluten is dried between two Teflon – coated hotplates.

13 Bread - baking method long fermentation basic straight- dough (AACC 10 – 09)

Intended primarily for laboratory assessment of bread-wheat flour quality under vigorous fermentation conditions. Dough mixing was done using a mixer, Swanson pin-type or equivalent, having a capacity for 100 – 500g dough.

14 Vitreous kernels

Kernels are cut with a blade and visually scored. The number of vitreous kernels is then expressed as a percentage.

15 Single kernel characterisation system

The SKCS 4100 single kernel characterisation system of Perten Instruments Co, Reno, NV (Martin *et al.* , 1993) was used to determine kernel diameter (the average diameter of 300 kernels), hardness index (the index as a percentage of the pressure of two rollers to crush 300 kernels), kernel weight (the average weight of 300 kernels expressed as mg).

3.3 Statistical analysis

Analysis of variance was performed using the additive main effect and multiplicative interaction (AMMI) method (Gauch, 1988). The data of 1997 and 1998 were analysed separately across localities, for each of the measured characteristics. A correlation matrix was compiled for all characteristics for each year to see their relative associations as influenced by environment, genotype and their interactions. In using part of the AMMI analysis, PCA partitions G x E interaction into several orthogonal axes, Gauch and Zobel (1996) reported that generally AMMI 1 and AMMI 2 models, with IPCA 1, and IPCA 2 respectively, are selected. Therefore in our analysis only AMMI 1 model plotted against means was used.

Canonical variate analysis (CVA) is used when it is of more interest to show differences between groups than between individuals. The analysis was therefore used to see which quality characteristics discriminated more among genotypes, environments and interaction effects for each year. The CVA test was also used for a combined analysis for both years particularly for genotypes to see their pattern of response to environments. With this test both IPCA 1, and IPCA 2 denoted as CV1 and CV2 respectively were used. This helps to see which characteristics are responsible for discrimination in either horizontal (x-axis) or vertical (y-axis). All analyses were done using the GENSTATS programme. The percentage contribution to the variation for environment, genotype and interaction was obtained by dividing their sum of squares with total sum of squares and multiplied by 100. For the IPCA, it is dividing the sum of squares for IPCA with sum of squares for interaction and multiplied by 100.

LSD was calculated as follows : $t_{(0.05) \text{ df}} \sqrt{\frac{2}{n} Ms_{\text{error}}}$

Where : t = students t distribution table
 n = number of observations
 Ms_{error} = mean square error

CHAPTER 4

RESULTS AND DISCUSSION FOR 1997 DATA

4.1 Quality parameters

Less optimal conditions were experienced in 1997 compared to 1998. The genotype and interaction effects were therefore lower in 1997.

Flour yield (Extraction)

Higher flour yield (extraction) is the primary objective for millers, and in South Africa, for example, an extraction of more or less 76% for white flour is used as a selection norm for new cultivars. The analysis of variance results for flour yield is summarised in Table 4.1.1. The highly significant F-value for treatment, main sources of variation, interaction and IPCA, indicates different genotype performance, varying growth conditions among the locations as well as presence of specific interactions between genotype and environment for this parameter. The residual was also significant at ($P < 0.01$) implying presence of noise. The results show high contribution of genotypes to the variation (33.1%), followed by environments (26.4%) and interaction (21.6%) and the IPCA captured 54.3% of the interaction sum of squares. This contrasts with the results by Nel *et al.* (1998b) whereby in rain-fed conditions in the Western and Southern Cape genotypes and environments contributed 2.5% and 68.7% respectively to the variation in flour extraction. However, this may be due to the fact that in our study moisture as an environmental factor was not a limiting factor. Temperature, edaphic conditions, diseases and pests were only limiting factors.

Considering the mean flour yields for the environments (Table 4.1.2), Barkly West had a value below the recommended value, with Loskop and Prieska slightly higher and the other localities close to the recommended value. SST65, SST822, Inia and Palmiet (Appendix 1), had a flour yield below the recommended value, with Marico, SST876 and Kariega slightly higher and others close to the recommended value. Taking into account other parameters like hectoliter and thousand kernel masses, which have an influence on, flour yield, these parameters were lower than the recommended values at Loskop (Tables 4.1.4 and 4.1.6) indicating presence of shrivelled kernels. Consequently the higher flour extraction observed in this location may be the result of bran contamination due to difficulties of endosperm separation from the bran.

Table 4.1.1 Analysis of variance results for flour yield in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	507.1	2.574			
Treatment	654	411	6.323	8.59	0.000	
Environment (E)	5	133.8	26.761	36.37	0.000	26.4
Block	12	7.8	0.652	0.89	0.562	
Genotype (G)	10	167.9	16.787	22.82	0.000	33.1
GxE	50	109.3	2.187	2.97	0.000	21.6
IPCA	14	59.3	4.235	5.76	0.000	54.3
Residual	36	50.1	1.39	1.89	0.006	
Error	120	88.3	0.74			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

From the AMMI biplot of genotype and environment means (Figure 4.1.1), large genotype x environment interaction are shown for SST57, SST55, Kariega and Marico. This indicates high sensitivity in flour yield for these genotypes due to variation in environmental conditions. The first two had flour yield values close to the mean but less than the recommended value, whereas the latter two had yield values higher than the recommendation. It seems SST57 and SST55 shows adaptation to low potential areas as they ranked higher only at Hopetown with Kariega ranking last, but Kariega and Marico ranked higher in most of the locations (Table 4.1.2). Other genotypes showed less interaction but they differed in genetic main effect, indicating to have different potentials. SST876 ranked second or third in most localities and is second to Marico for overall genotype yield. SST825, T4, SST65 and SST822 proved to be stable, however, only the first two gave flour yield in some locations higher than the recommended value. The other two had flour yield values lower than the mean and ranked lower in most of the locations, except Hopetown where SST65 ranked intermediate. Inia and Palmiet seem to have lower genetic potential for flour yield as they had the lowest values at most of the locations. Considering the environments (Figure 4.1.1), most of the locations had flour yield higher than the mean. Loskop and Prieska were higher and Hopetown, Douglas and BullHill slightly lower than the recommended value. However, Barkly West showed to be the outlier as non of the genotypes attained even the mean yield in this location (Table 4.1.2).

Table 4.1.2 Ranking of genotypes in each location for flour yield in percentage and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	Marico (77.86)	Marico (75.40)	Marico (78.64)	SST57 (77.68)	Marico(77.49)	Marico (78.38)
2	Kariega (77.14)	SST876 (75.22)	Kariega (78.35)	SST876 (77.67)	SST876 (77.27)	Kariega (77.27)
3	SST876 (77.13)	Kariega (74.35)	SST876 (77.17)	SST55 (77.23)	Kariega (76.47)	SST876 (77.47)
4	SST825 (76.20)	SST55 (74.18)	SST825 (76.61)	Marico (76.19)	SST55 (76.22)	SST825 (76.63)
5	T4 (76.04)	SST57 (74.18)	T4 (76.45)	SST65 (75.89)	SST57 (76.20)	T4 (76.47)
6	SST55 (75.90)	SST825 (74.01)	SST55 (75.67)	SST825 (75.62)	SST825 (76.08)	SST55 (76.17)
7	SST57 (75.74)	T4 (73.85)	SST65 (75.45)	T4 (75.47)	T4 (75.92)	SST57 (75.96)
8	SST65 (75.39)	SST65 (73.47)	SST57 (75.31)	SST822 (75.42)	SST65 (75.52)	SST65 (75.74)
9	SST822 (75.17)	SST822 (73.19)	SST822 (75.31)	Inia (75.40)	SST822 (75.24)	SST822 (75.53)
10	Inia (74.79)	Inia (72.90)	Inia (74.81)	Palmiet (74.69)	Inia (74.95)	Inia (75.12)
11	Palmiet (74.22)	Palmiet (72.29)	Palmiet (74.29)	Kariega (74.19)	Palmiet (74.34)	Palmiet (74.56)
Mean	75.96	73.91	76.19	75.95	75.97	76.35

Grand mean = 75.72 LSD (0.05) : treatment = 0.296 , environment = 0.981

Hopetown, Prieska and to a lesser extent Loskop showed interaction with certain genotypes and care should be taken in ranking these sites for flour yield. BullHill and Douglas show less or absence of interaction and thus flour yield rank in these sites may be reliable.

In summary, we can say that genotypes SST876 and Marico were very stable for flour yield at most of the sites although Marico showed an environment interaction at Hopetown. Kariega also performed well except at Hopetown where it had a negative interaction with the environment. However, SST57 and SST55 gave higher flour yields at Hopetown showing interaction with environment. Nevertheless the two genotypes together with SST825 and T4 ranked intermediate in most of the locations showing intermediate stability for flour yield (Table 4.1.2). For environments, BullHill, Douglas and probably Prieska may give reliable rank for flour yield. However, care is needed for genotypes showing interaction with environment at Hopetown. For Loskop and Barkly-West, timing of planting or selection of early maturing cultivars is necessary for optimum grain filling.

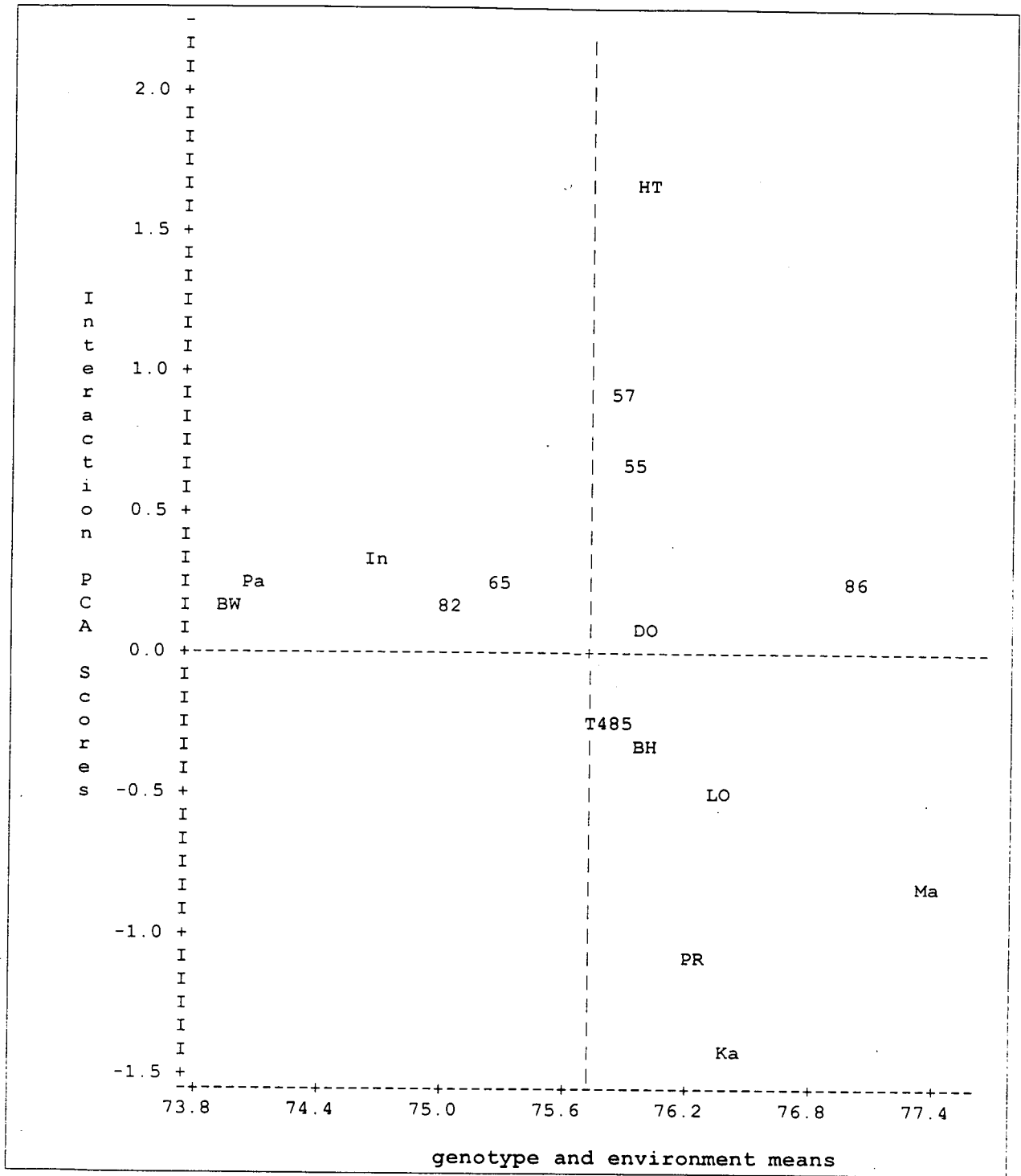


Figure 4.1.1 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57, at six localities BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for flour yield in 1997.

Hectoliter mass

Hectoliter mass is one of the parameters used to predict expected flour yield during milling. Taking South Africa as an example, a minimum hectoliter mass of 76 kg h⁻¹ is required for wheat to be graded as suitable for bread-making. The analysis of variance results for hectoliter mass are summarised in (Table 4.1.3). F-values were highly significant for treatment, main sources of variation, interaction and IPCA. This indicates different genotype performance, varying growth conditions among the locations as well as presence of specific interactions between genotypes and environments for this parameter. The significant block effect (p<0.01) indicates how sensitive the parameter is to environment and this shows there were variations for a given genotype even within a certain location. The residual was non-significant showing absence of noise and that is why the IPCA captured a larger percentage of the interaction effect. In this study, environment contributed up to 64.3% of the variation in hectoliter mass, which is less compared, to 86.7% found by Nel *et al.* (1998a). The contribution of genotypes to the variation in hectoliter mass was 10.3% which is higher than 0.8% found by Nel *et al.* (1998a), but it is less than the contribution of South African winter wheat cultivars which was 38.2% (Van Deventer, 1986). The interaction contributed 13.2% to the total variation and out of this 72.4% was captured by the IPCA.

Table 4.1.3 Analysis of variance results for hectoliter mass in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	1503.3	7.63			
Treatment	65	1328.6	20.44	18.04	0.000	
Environment (E)	5	967.0	193.41	170.67	0.000	64.3
Block	12	38.8	3.23	2.85	0.002	
Genotype (G)	10	155.5	15.55	13.72	0.000	10.3
G x E	50	206.0	4.12	3.64	0.000	13.7
IPCA	14	149.1	10.65	9.40	0.000	72.4
Residual	36	56.9	1.58	1.39	0.094	
Error	120	136.0	1.13			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

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Environment mean values varied between 74.28 kg h^{-1} at Loskop to 81.02 kg h^{-1} at Prieska (Table 4.1.4). Except for Loskop, other sites had means higher than the recommended value. This confirms the importance of this parameter in ensuring acceptable flour yield. However, despite Loskop having lower hectoliter mass, it had higher flour yield. This may be due to shrivelled kernels as revealed by lower kernel mass and this caused problem during milling, resulting in bran contamination with flour. The low genotype contribution as seen in this study and that of Nel *et al.* (1998a) suggests that for spring wheat, despite having enough supply of moisture, heat stress is one of the factors which limits grain filling. This is supported by the results from this study whereby genotype mean varied between 76.72 kg h^{-1} for Kariega to 80.36 kg h^{-1} for SST876 (Appendix 1), showing all genotypes giving higher than the recommended value. Nevertheless, due to environmental effects, especially temperature, in Loskop all genotypes had very low hectoliter mass and did not attain the recommended value (Table 4.1.4).

Table 4.1.4 Ranking of genotypes in each location for hectoliter mass (kg h^{-1}) and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	SST876 (80.52)	SST876 (79.21)	SST876 (82.88)	SST876 (81.23)	SST876 (82.85)	SST876 (75.44)
2	Palmiet (79.54)	Marico (78.43)	Palmiet (81.77)	SST825 (81.03)	SST825 (81.97)	Marico (74.79)
3	SST822 (79.27)	Palmiet (78.29)	SST822 (81.63)	SST55 (80.05)	Palmiet (81.64)	T4 (74.59)
4	T4 (79.27)	T4 (78.28)	SST825 (81.58)	SST822 (79.99)	SST822 (81.61)	Kariega (74.59)
5	Marico (79.22)	Kariega (78.12)	SST55 (81.44)	Palmiet (79.86)	SST55 (81.51)	Palmiet (74.53)
6	Inia (79.00)	SST822 (77.95)	Inia (80.99)	Inia (78.58)	Inia (80.67)	SST822 (74.18)
7	SST55 (78.96)	Inia (77.85)	T4 (80.93)	T4 (77.82)	T4 (80.34)	Inia (74.13)
8	SST825 (78.70)	SST55 (77.59)	Marico (80.47)	SST57 (77.45)	SST65 (79.83)	SST65 (73.89)
9	SST65 (78.61)	SST65 (77.59)	SST65 (80.36)	SST65 (77.42)	SST57 (79.82)	SST57 (73.82)
10	SST57 (78.56)	SST57 (77.52)	SST57 (80.33)	Marico (76.48)	Marico (79.54)	SST55 (73.81)
11	Kariega (78.50)	SST825 (77.14)	Kariega (78.87)	Kariega (73.02)	Kariega (77.21)	SST825 (73.31)
Mean	79.10	78.00	81.02	78.45	80.64	74.28

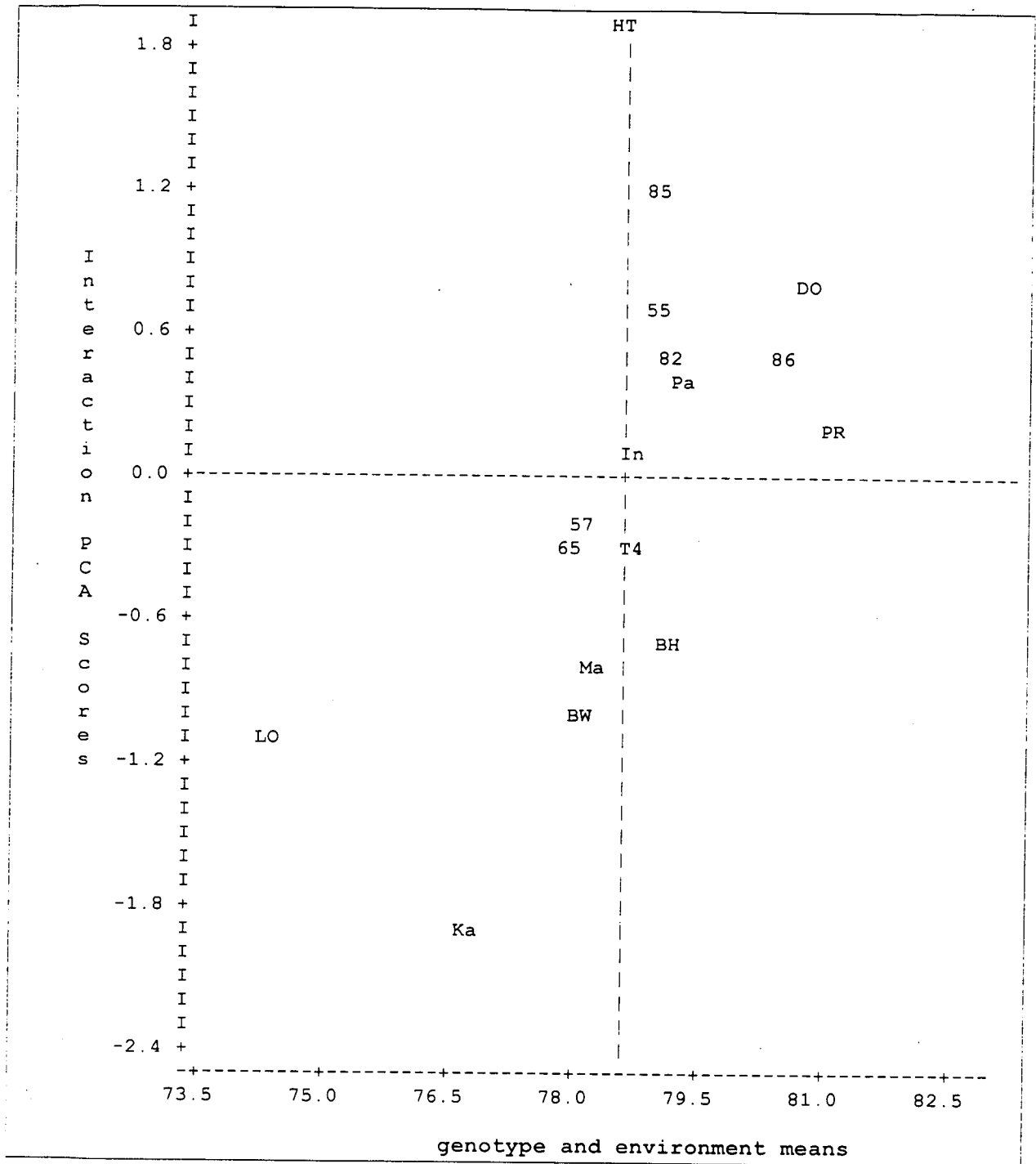
Grand mean = 78.58 LSD (0.05): treatment = 0.366 , environment = 1.215

The AMMI biplot for genotype and environment means (Figure 4.1.2) shows considerable genotype x environment interaction for Kariega, SST825 and to a lesser extent Marico and SST55. Kariega contrasts most with the other genotypes as it ranked last at BullHill, Prieska, Douglas and Hopetown. In the last site despite most of the genotypes showing higher hectolitre masses, it had the lowest value (Table 4.1.4). This shows high risks of specific genotype x environment interactions at Hopetown, such as disease effect, as the site is between western and eastern areas. SST825 and SST55 ranked higher at Hopetown, Prieska and Douglas with Marico ranking lower. However, Marico ranked second in Barkly West and Loskop where the former two ranked very low.

Before using these genotypes for planting, genotype x environment interaction should be taken into account. For other genotypes, SST876 ranked relatively high all locations, confirming it to have a wide adaptability for this parameter. SST822, Palmiet, Inia, T4, SST57 and SST65 proved to be stable and therefore ranking these genotypes for hectoliter mass may be reliable. Excluding the last two which were slightly lower than the mean and ranked lower in most locations, the other four may be included with SST876 as checks/reference genotypes for this parameter.

For the locations (Figure 4.1.2), Hopetown had high interaction with genotypes followed by Loskop, Barkly West and to a lesser extent Douglas. The interaction effects for Loskop and Barkly West were almost the same, as the genotypes SST876 and Marico ranked higher at these two sites. However, the difference is on main effect whereby Barkly West seems to be a more optimal environment than Loskop. This may be from the fact that the former site is more westward and thus heat stress may be less, compared to Loskop.

SST825 and SST55 ranked higher in Hopetown showing interaction with this site, as SST55 ranked middle to lower in other sites. SST825 also ranked second in Douglas, showing some interaction with this location (Table 4.1.4). Therefore ranking for hectoliter mass in these locations, especially Hopetown, Barkly West and Loskop may not be reliable. On the other hand Prieska had the highest mean and together with BullHill shows to be stable (no interactions). Consequently these two sites and probably Douglas may be reliable for hectoliter mass ranking.



NB: Kariega contrasts most with the other cultivars - lowest score

Figure 4.1.2 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST676 and 57 = SST57) at six localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for hectoliter mass in 1997.

Thousand kernel mass

Thousand kernel mass focuses more on the individual kernel mass and is also important in prediction of milling yield. For South Africa a thousand kernel mass of more than 40 g is recommended. The analysis of variance results are summarised in Table 4.1.5. The highly significant F-values for treatment, main sources of variation, block effect, interaction and IPCA, indicates different genotype performance, varying growth conditions among the locations as well as presence of specific interactions between genotypes and environments for this parameter. The significant block effect at ($p < 0.001$) signifies how sensitive the parameter is to environment and this shows still there were variations for a given genotype even within a certain location. However, the residual was significant at ($p < 0.01$) implying presence of slight noise effect. The study shows the environment to have higher contribution, about 51.3% to the total variation in kernel mass. The genotype contribution was 24.3%, slightly higher than that of hectoliter mass, implying more genotype influence for this parameter. The interaction effect was 13.2%, close to that of hectoliter mass, showing that main effects had more influence on this parameter and the IPCA captured 66.5% of variation.

Table 4.1.5 Analysis of variance results for thousand-kernel mass in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	5007	25.42			
Treatment	65	4449	68.45	21.32	0.000	
Environment (E)	5	2569	513.71	159.98	0.000	51.3
Block	12	173	14.42	4.49	0.000	
Genotype (G)	10	1217	121.70	37.90	0.000	24.3
G x E	50	663	13.27	4.13	0.000	13.2
IPCA	14	441	31.52	9.82	0.000	66.5
Residual	36	222	6.17	1.92	0.005	
Error	120	385	3.21			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = $(SS \text{ for Genotype, Environment or } G \times E / SS \text{ for total}) \times 100$

IPCA = $(SS \text{ for IPCA} / SS \text{ for } G \times E) \times 100$

The mean thousand-kernel mass for environment ranged between 34.86 g and 45.63 g for Loskop and Prieska respectively (Table 4.1.6). The difference between environments is shown clearly for this parameter, because only Prieska, BullHill and Douglas had means above and close to the recommended value and this is also true for most of the genotypes at these locations. For the

other locations except for some genotypes, which showed interaction, most of them had masses below the recommended value (Table 4.1.6). This reveals that the locations; Loskop, Barkly West and to a lesser extent Hopetown are of low potential. This is supported by the findings of Pinthus (1973), Yamazaki (1976), Pumphrey and Rubenthaler (1983) and Simmonds (1989) who reported that poor growing conditions (hot and dry) increase the degree and amount of kernel shrivelling resulting in reduced proportion of endosperm to bran ratio and this influences flour yield.

The genotype means (Appendix 1) ranged between 33.59 g to 42.91 g for SST57 and SST55 respectively, with only three genotypes namely SST55, Palmiet and SST825 being higher than the recommended value. Other genotypes, slightly closer to the recommended value, were SST822, Inia, SST65 and SST876, whereas others showed medium to low values. Compared to hectoliter mass this parameter revealed clearly the low potential of environments such as Loskop, Barkly-West and Hopetown, with Kariega ranking higher in the first location and SST55 in the rest, but only the Hopetown value was higher than the recommended value (Table 4.1.6).

Table 4.1.6 Ranking of genotypes in each location for thousand kernel mass (g) and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	SST55 (43.60)	SST55 (39.03)	SST55 (50.68)	SST55 (42.90)	SST55 (47.04)	Kariega (37.51)
2	Palmiet (41.90)	Palmiet (37.46)	Palmiet (48.19)	Palmiet (39.83)	SST825 (43.58)	Marico (36.87)
3	SST825 (41.65)	SST825 (37.19)	SST825 (48.07)	SST825 (39.80)	Palmiet (43.54)	SST65 (35.87)
4	SST822 (41.28)	SST822 (36.96)	SST822 (46.83)	SST822 (37.93)	SST822 (41.25)	Inia (35.41)
5	Inia (41.20)	Inia (36.91)	Inia (46.54)	Inia (37.49)	Inia (40.71)	SST822 (35.06)
6	SST65 (41.10)	SST65 (36.87)	SST876 (46.19)	SST876 (37.32)	SST876 (40.67)	T4 (34.33)
7	SST876 (40.59)	SST876 (36.27)	SST65 (46.18)	SST65 (36.94)	SST65 (40.01)	SST876 (34.29)
8	Marico (40.14)	Marico (36.05)	Marico (44.26)	Marico (34.32)	Marico (36.89)	SST55 (34.21)
9	Kariega (39.95)	Kariega (35.93)	Kariega (43.68)	Kariega (33.44)	Kariega (35.80)	Palmiet (34.16)
10	T4 (37.47)	T4 (33.39)	T4 (41.53)	T4 (31.54)	T4 (34.08)	SST825 (33.64)
11	SST57 (35.60)	SST57 (31.50)	SST57 (39.81)	SST57 (29.93)	SST57 (32.54)	SST57 (32.16)
Mean	40.41	36.14	45.63	36.49	39.64	34.86

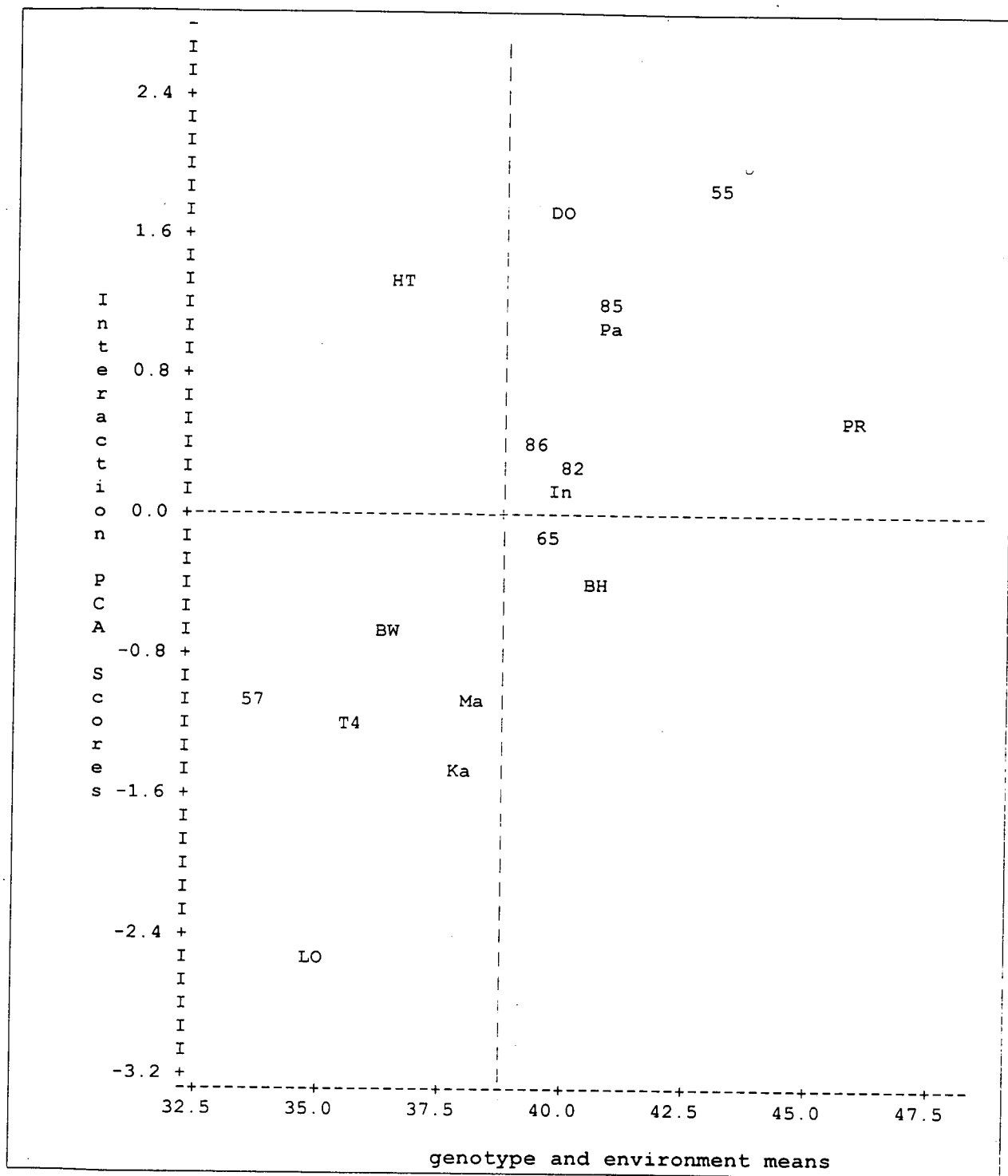
Grand mean = 38.86 LSD (0.05) : treatment = 0.617 , environment = 2.048

The AMMI biplot for genotype and environment means (Figure 4.1.3) shows a distinct grouping of genotypes. The genotypes SST55, SST825 and Palmiet shows high to slightly lower positive interaction and except at Loskop they were the top three ranking genotypes at other locations with SST55 ranking first. SST57, T4, Kariega and Marico showed a negative interaction, with SST57 ranking last at all locations. In five locations they appeared in the same order, SST57 being last and Marico a bit higher. It is only at Loskop where Kariega and Marico ranked higher, becoming closer to the mean and T4 ranked in the middle. SST822, Inia, SST65 and SST876 showed

stability and ranked in the middle in most locations with means slightly higher and closer to the overall mean and recommended value respectively.

For the locations (Figure 4.1.3), interaction effects were shown at Loskop and to a lesser extent Douglas and Hopetown. Interaction at Loskop is due to Kariega and Marico whereas SST55 is responsible at Douglas and Hopetown. The other three locations showed stability but they still differed in main effect (environmental potential). Prieska as such had the highest mean implying high potential, followed by BullHill, with values slightly higher than the recommended value and thus medium potential, which is comparable to Douglas. However, Barkly West had a mean lower than both the recommended value and overall mean, comparable to Loskop and Hopetown and this implies lower potential environments.

Therefore, in summary, genotype ranking for thousand-kernel mass may be reliable at all locations with those genotypes, which showed stability. However, taking into account the interaction, in other locations except Loskop, SST55, SST825 and Palmiet performed well whereas at Loskop it was Kariega and Marico which performed well. For the environments Prieska seems to be reliable for kernel mass ranking followed by BullHill and Douglas but care must be taken at the last location due to slight interaction observed.



NB: The genotypes form four distinct groups - TKM

Figure 4.1.3 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at six localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for thousand kernel mass in 1997.

Single kernel characterisation system – diameter

The kernel diameter tells how plump the wheat kernels are, and therefore is associated with both kernel and hectoliter mass and finally flour yield. However, since the endosperm of soft wheat tends to be less compact (loose), the kernels may have larger diameter but reduced mass. This is supported by Baker and Golubic (1970) who found seed size to be related with milling yield in hard red spring wheat but not for the other wheat classes. The analysis of variance results are summarised in Table 4.1.7. The highly significant F-values for treatment, main sources of variation, block effect, interaction and IPCA, indicates different genotype performance, varying growth conditions among the locations as well as presence of specific interactions between genotypes and environments for this parameter. The significant block effect at ($p < 0.001$) signifies how sensitive the parameter is to environment implying presence of variations for a given genotype even within a certain location. However, the residual was significant at ($p < 0.01$) implying presence of noise effect. In this study, environment contributed 45.7% to the variation in kernel diameter (Table 4.1.8). This is in agreement with findings by Planchon (1969) and Jenner (1991) who noted that endosperm content (revealed by kernel plumpness), which is a consequence of high photosynthetic rates and/or long grain filling periods, to be strongly influenced by environmental conditions. Genotype contribution to the variation was 28.2%, slightly higher than that of kernel mass, showing that genotype as the main effect also has influence on diameter. The interaction contributed 14.9% to the variation and out of this, IPCA captured 70.0%. This implies presence of interaction and as it was for kernel mass, four groupings of genotypes were observed.

Table 4.1.7 Analysis of variance results for SKCS – kernel diameter in 1997 (mm).

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	9.064	0.046			
Treatment	65	8.040	0.124	19.49	0.000	
Environment (E)	5	4.141	0.828	130.49	0.000	45.7
Block	12	0.262	0.022	3.44	0.001	
Genotype (G)	10	2.552	0.255	40.21	0.000	28.2
G x E	50	1.348	0.027	4.25	0.000	14.9
IPCA	14	0.903	0.065	10.17	0.000	70.0
Residual	36	0.445	0.012	1.95	0.004	
Error	120	0.762	0.006			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The location means ranged between 2.55 mm to 2.99 mm at Loskop and Prieska respectively and it showed three groupings in the environments; Prieska, followed by Douglas, Barkly West and BullHill together and then Hopetown and Loskop (Table 4.1.8). The genotype means (Appendix 1) ranged between 2.49 mm to 2.91 mm for SST57 and SST825 respectively. Genotype main effect also showed about three genotype groups. SST825 and Palmiet had higher means, far above the mean. SST55, SST876, SST822, Inia, Kariega and SST65 had means much closer to the grand mean with the former three being higher. Marico, T4 and SST57 had values much lower than the mean particularly SST57.

Table 4.1.8 Ranking of genotypes in each location for SKCS – diameter (mm) and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	SST825 (2.87)	SST825 (2.82)	SST825 (3.22)	SST825 (2.88)	SST825 (3.05)	Kariega (2.68)
2	Palmiet (2.77)	Kariega (2.76)	Palmiet (3.12)	Palmiet (2.78)	Palmiet (2.95)	SST825 (2.64)
3	SST876 (2.72)	Palmiet (2.72)	SST876 (3.06)	SST55 (2.71)	SST55 (2.87)	T4 (2.58)
4	SST822 (2.71)	SST876 (2.72)	SST822 (3.05)	SST822 (2.67)	SST822 (2.82)	SST876 (2.57)
5	SST55 (2.69)	SST822 (2.71)	SST55 (3.05)	SST876 (2.66)	SST876 (2.81)	Inia (2.56)
6	Inia (2.68)	Inia (2.70)	Inia (3.01)	Inia (2.61)	Inia (2.75)	SST822 (2.55)
7	Kariega (2.64)	T4 (2.66)	SST65 (2.96)	SST65 (2.55)	SST65 (2.70)	Palmiet (2.54)
8	SST65 (2.63)	SST65 (2.65)	Kariega (2.95)	Kariega (2.45)	Kariega (2.56)	Marico (2.53)
9	Marico (2.55)	SST55 (2.64)	Marico (2.87)	Marico (2.41)	Marico (2.53)	SST65 (2.51)
10	T4 (2.54)	Marico (2.63)	T4 (2.85)	T4 (2.35)	T4 (2.46)	SST55 (2.46)
11	SST57 (2.45)	SST57 (2.53)	SST57 (2.77)	SST57 (2.31)	SST57 (2.44)	SST57 (2.42)
Mean	2.66	2.68	2.99	2.58	2.72	2.55

Grand mean = 2.70 LSD (0.05) : treatment = 0.027 , environment = 0.091

In the AMMI biplot for genotype and environment means (Figure 4.1.4), large interaction was observed for SST825, Palmiet, SST55, Kariega, T4 and to a lesser extent Marico and SST57. The former three had values higher than the mean and showed positive interaction, whereas others had values below the mean with negative interactions. Therefore kernel diameter ranking for these genotypes may be unreliable in some locations. The other four, SST876, SST822, Inia and SST65 showed stability with SST65 being slightly lower than the mean. Therefore genotype ranking in kernel diameter for the first three may be reliable. SST825 ranked first and Palmiet second in five and four locations respectively, except at Loskop where SST825 ranked second and Palmiet slightly lower. This implies wide adaptability of SST825 for this parameter. SST55 ranked third at Hopetown and Douglas, but it was intermediate to low in other locations. However, its mean was comparable to SST876, SST822 and Inia and all were above the mean. Kariega ranked first and second in Loskop and Barkly West respectively but it was slightly below the mean, the same as SST65, due to poor performance in other locations. T4 ranked third in Loskop but lower in

other locations (Table 4.1.8) and together with Marico, SST57 shows low genetic potential for this parameter. The locations, (Figure 4.1.4) showed environmental interaction at Douglas, Hopetown, Loskop and Barkly West with Douglas and Hopetown having positive and Loskop and Barkly West negative interactions. BullHill and Prieska showed stability but they differed in main effect whereby Prieska seems to have more potential than BullHill for SKCS – diameter .

In conclusion we can say for the genotypes SST825, SST876, SST822, Inia and Palmiet may be taken as references in most of the locations, except Loskop where Kariega may substitute Palmiet. Kariega may also be included at Barkly West, whereas SST55 should be excluded in Loskop and Barkly West but included in other locations. Prieska and BullHill seem to give reliable ranking but Douglas and Barkly West may be included taking into account possible interaction.

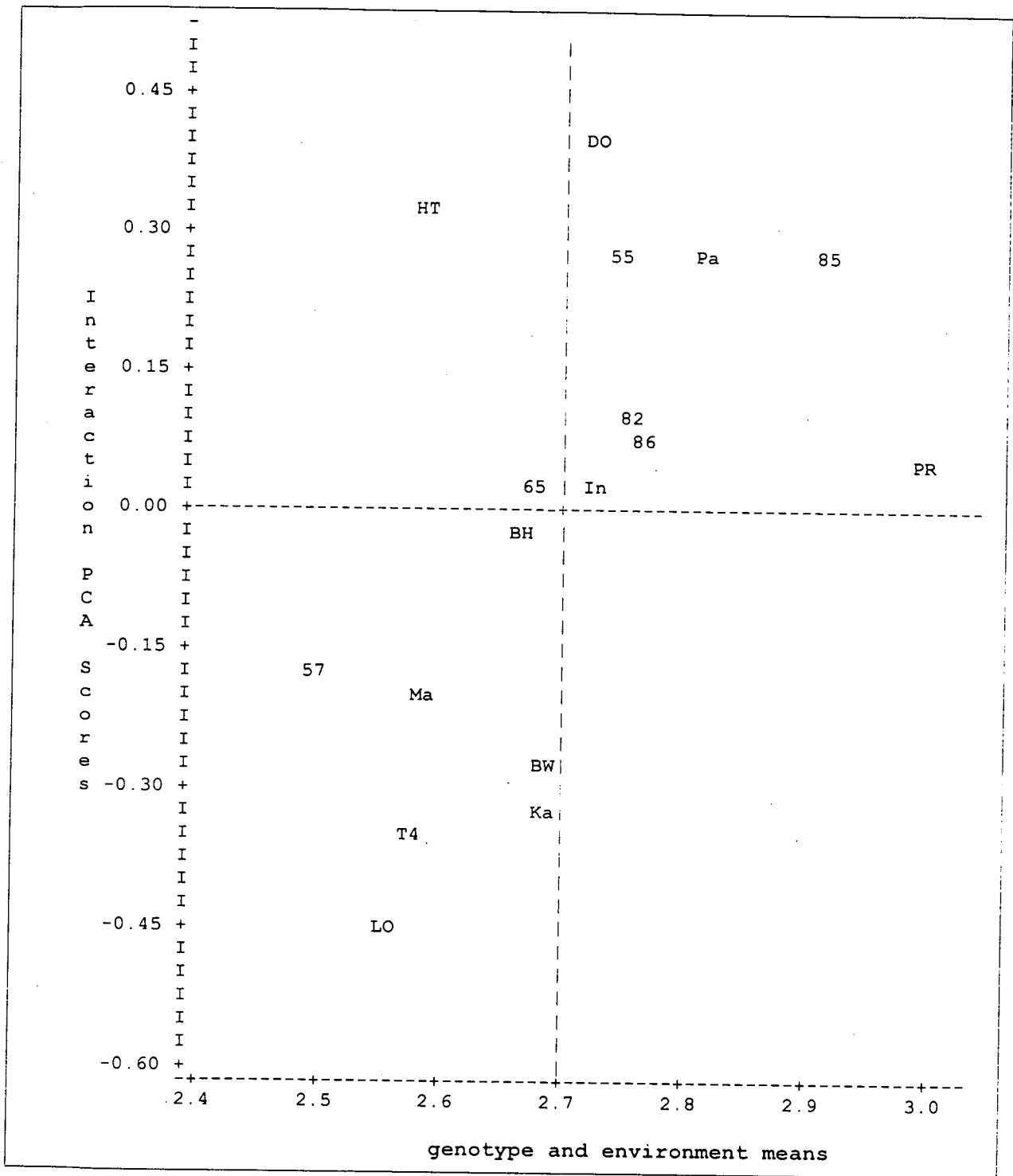


Figure 4.1.4 ANMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T₄ = T₄, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at six localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for SKCS-diameter in 1997.

Breakflour yield

Breakflour yield is an important characteristic in wheat flour as it increases the water absorption capacity of the flour. The ANOVA results are summarised in Table 4.1.9. All parameters showed high significance for treatment, environments, genotypes, interaction, IPCA and residual. The significant residual implies presence of noise effects and the non-significant block effect. This implies less variation for the parameter due to environment within the location rather than between locations. In this study, environments contributed 40.0% to the variation in this parameter but it is not so much different from the effect of genotypes, implying close effects for the main sources of variation to this parameter (Table 4.1.9). Genotype contribution to the variation was high at 38.2% and this is due to differences in hardness, which is genetically controlled, and diameter as mentioned previously. The interaction contributed 13.5% to the total variation and the IPCA captured 58.1% of this.

Table 4.1.9 Analysis of variance results for breakflour yields in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	1491.8	7.57			
Treatment	65	1368.5	21.05	22.47	0.000	
Environment (E)	5	596.4	119.29	127.30	0.000	40.0
Block	12	10.9	0.91	0.97	0.438	
Genotype (G)	10	570.0	57.00	60.83	0.000	38.2
G x E	50	202.1	4.04	4.31	0.000	13.5
IPCA	14	117.5	8.39	8.95	0.000	58.1
Residual	36	84.6	2.35	2.51	0.000	
Error	120	112.4	0.94			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The location means ranged between 20.61 at Barkly West to 25.96 at Loskop (Table 4.1.10). Since breakflour yield is a result of wheat hardness, according to Barlow *et al.* (1973), the strength of starch-protein interactions causes endosperm hardness. As mentioned earlier the higher flour yield at Loskop was due to bran contamination. The realised higher breakflour yields may be not proper also due to poor growth conditions in this location.

The highest flour break yields were realised in locations with slightly higher protein content and/or conducive growing conditions such as Hopetown, Prieska, BullHill and Douglas. Another observation is that, as kernel diameter increases, it causes an increase in starch which is the main

constituent of endosperm and this reduces the interaction with protein, especially if protein content is less, resulting in reduced endosperm hardness. Van Lill and Smith (1997) reported that grains containing higher protein content were inclined to be harder, which in turn increased breakflour yield. This is also observed in this study except for the genotype SST55. In most of the locations, genotypes with higher breakflour yield had medium to low kernel diameter and the reverse is true (Tables 4.1.9 and 4.1.10). This is due to the fact that medium to low diameter indicates compactness of the endosperm, increasing the hardness. The genotype mean values (Appendix 1) ranged between 19.69 to 25.35 for Palmiet and Kariega respectively. Due to significant influence of both main effects, three groups of genotypes were observed, although they still differ in interaction within the groups. The first group with higher means includes Kariega, SST55 and Marico, the second group with values slightly higher and close to the mean were T4, SST65, SST57, SST822 and Inia. The third group with medium to low values includes SST876, SST825 and Palmiet (Table 4.1.10).

The AMMI biplot for genotype and environment means (Figure 4.1.5) showed high interaction with environment for Inia and to a lesser extent SST57, SST876, Kariega, T4, Palmiet and SST822, with the first three being negative and others positive. Inia ranked first, followed by SST57 at Barkly West. SST876 ranked slightly higher. This shows Inia and SST57 to be genetically superior to SST876 for this parameter. However, they all ranked medium to low in other locations. Kariega ranked first in most locations except Barkly West where it ranked in the middle, showing slightly wider adaptability. At Loskop it had a high value indicating more interaction with this location.

T4 ranked second, SST822 at the middle and Palmiet slightly higher at Prieska showing interaction, but they differed in genetic potential, as in other locations the first two ranked middle to low and Palmiet was last in four locations. SST55, Marico and SST65 showed stability and they ranked middle to higher in most locations with values higher than the mean. However, they also showed different genetic potential compared to SST825, which ranked last in Loskop and second from last in other locations (Table 4.1.10).

For the locations (Figure 4.1.5), high genotype interaction was seen at Barkly West, Prieska and Loskop, indicating break flour yield ranking for these sites to be less reliable. Douglas and to a lesser extent BullHill and Hopetown shows stability and thus break flour yield ranking for these locations may be reliable.

In summary, the genotypes, Kariega, SST55, Marico, SST65 and SST822 may give reliable ranking at most of the locations. Hopetown, Douglas, BullHill and to a lesser extent Prieska may be

reliable for breakfleur yield rank. Although Loskop also showed higher values, due to its low potential, it may not give reliable rank and optimum breakfleur yield for most of the genotypes. Care must also be taken at Prieska where T4 showed environment interaction.

Table 4.1.10 Ranking of genotypes in each location for breakfleur yield and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hooetown	Douglas	Loskop
1	Kariega (24.34)	Inia (22.97)	Kariega (25.68)	Kariega (26.73)	Kariega (24.09)	Kariega (29.35)
2	SST55 (23.95)	SST57 (22.53)	T4 (23.75)	SST55 (25.49)	SST55 (23.41)	SST55 (27.67)
3	Marico (23.68)	SST55 (22.39)	Marico (23.64)	Marico (25.37)	Marico (23.19)	Marico (27.64)
4	SST57 (23.21)	Marico (21.95)	SST55 (23.60)	T4 (24.73)	SST57 (22.36)	T4 (27.39)
5	Inia (22.97)	Kariega (21.92)	SST822 (22.70)	SST65 (24.29)	SST65 (22.08)	SST65 (26.57)
6	SST65 (22.56)	SST65 (20.80)	SST65 (22.60)	SST822 (23.98)	T4 (22.04)	SST822 (26.48)
7	T4 (22.26)	SST876 (20.28)	SST57 (21.13)	SST57 (23.87)	Inia (21.89)	SST57 (25.60)
8	SST822 (21.82)	T4 (19.76)	Palmiet (20.02)	Inia (22.97)	SST822 (21.49)	Inia (24.34)
9	SST876 (20.99)	SST822 (19.64)	Inia (19.56)	SST876 (21.69)	SST876 (20.16)	Palmiet (23.70)
10	SST825 (19.75)	SST825 (18.23)	SST825 (19.32)	SST825 (21.25)	SST825 (19.19)	SST876 (23.43)
11	Palmiet (18.68)	Palmiet (16.26)	SST876 (18.97)	Palmiet (21.07)	Palmiet (18.43)	SST825 (23.41)
Mean	22.20	20.61	21.91	23.77	21.67	25.96

Grand mean = 22.69 LSD (0.05) : treatment = 0.334, environment = 1.108

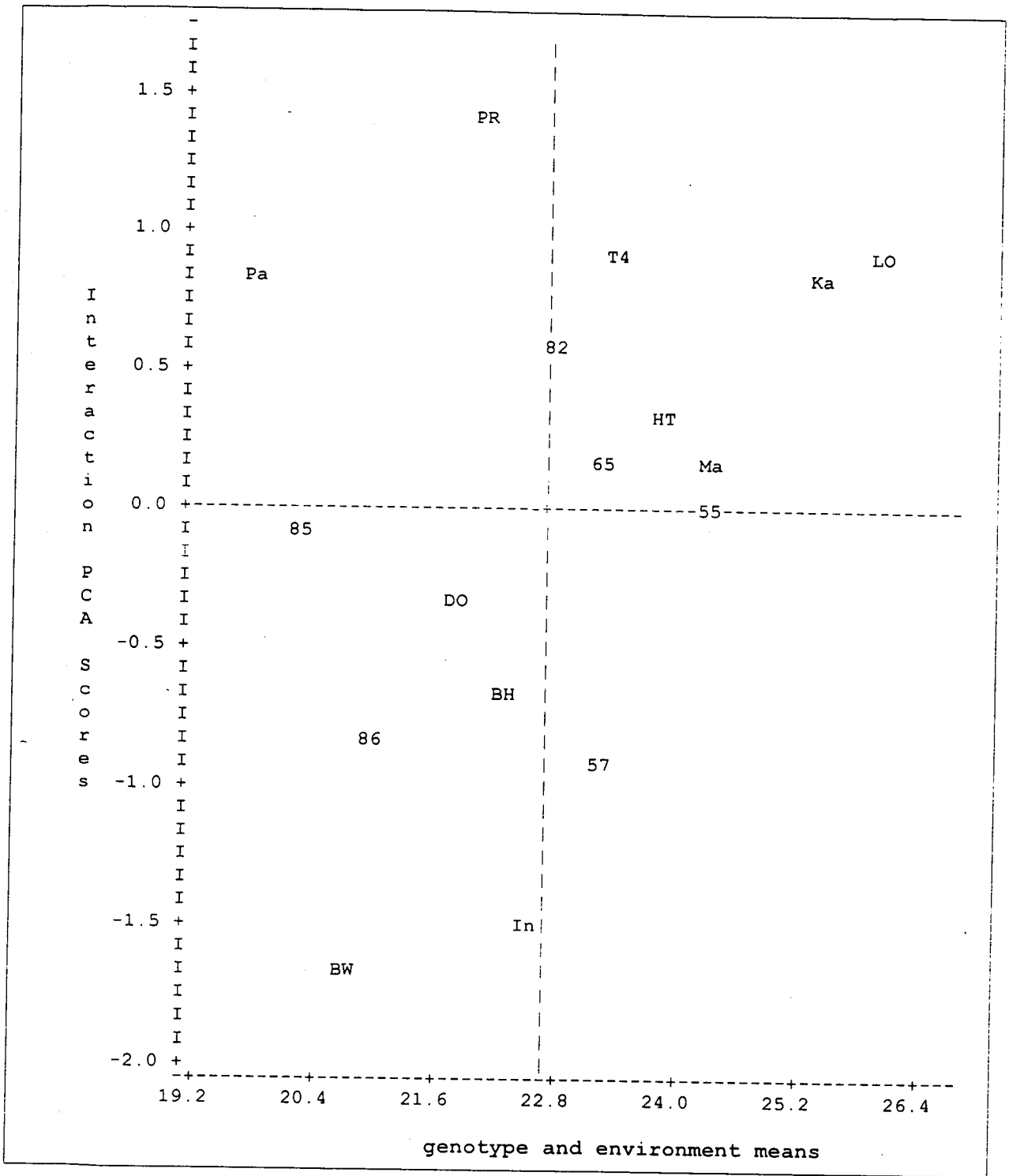


Figure 4.1.5 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at six localities BH = Bull Hill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop for breakflour yield in 1997.

Vitreous kernels

Hard and soft wheats are among the major groups of wheat. However, it is rare to find a genotype/cultivar which is hundred percent hard or soft and usually there is variation. Vitreous kernels therefore indicate the extent (percentage) to which a certain genotype appears to be hard. The ANOVA results for vitreous kernels are summarised in Table 4.1.11. Only treatment and main effects showed high significance and IPCA at ($p < 0.05$). However, blocks, interaction effect and residual were non-significant. This implies less variation for the parameter within a certain location, and less interaction effects as well as noise effect. In this study, environment had more influence on this parameter and contributed 63.3% to the total variation (Table 4.1.11). As mentioned in breakflour yield that hardness is a consequence of starch-protein interaction, kernel vitreousness may decrease in environments with poor grain filling conditions and less protein levels. The genotype contribution to the variation was 12.9%, less than that of environment and this implies that environmental conditions have more influence on this parameter. The main cause of smaller genotype effect is that grain filling and protein content, which are more influenced by environment than genotype, are responsible for kernel vitreousness. The interaction was responsible for only 7.0% of the variation, showing main effects, especially environment, being accountable for the variation in vitreous kernels.

The environmental means ranged between 54.67% to 86.67% at Loskop and BullHill respectively, indicating a big range (Table 4.1.12). Compared to other parameters discussed, large variability was observed, especially at Prieska and Loskop, indicating much deviation of individual genotypes from the mean value. Prieska as such had good grain filling conditions. Unfortunately protein content was lower compared to other sites. On the other hand the grain filling conditions at Loskop are generally poor and this made it to be more distinct compared to other locations. The genotype means (Appendix 1) ranged between 69.44 to 81.89 for SST57 and SST825 respectively and general observation shows two genotype groups of high and low mean values.

Table 4.1.11 Analysis of variance results for vitreous kernels in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	35030	177.8			
Treatment	65	29130	448.2	10.39	0.000	
Environment (E)	5	22171	4434.2	102.79	0.000	63.3
Block	12	723	60.3	1.40	0.177	
Genotype (G)	10	4506	450.6	10.45	0.000	12.9
G x E	50	2453	49.1	1.14	0.282	7.0
IPCA	14	1133	80.9	1.88	0.036	46.2
Residual	36	1320	36.7	0.85	0.707	
Error	120	5177	43.1			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

Table 4.1.12 Ranking of genotypes in each location for vitreous kernels (%) and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	SST822 (93.63)	SST822 (86.26)	SST822 (86.75)	SST822 (86.24)	SST822 (91.58)	Marico (62.30)
2	SST825 (90.44)	SST825 (82.59)	SST825 (86.14)	SST825 (82.99)	SST825 (87.95)	SST55 (61.53)
3	Marico (89.59)	SST65 (81.64)	Marico (86.10)	Marico (82.12)	Marico (86.97)	SST825 (61.22)
4	Inia (89.36)	Marico (81.59)	SST55 (85.16)	Inia (81.92)	SST65 (86.96)	Inia (59.33)
5	SST65 (89.06)	Inia (81.57)	Inia (84.73)	SST65 (81.66)	Inia (86.93)	Palmiet (59.30)
6	SST55 (88.53)	SST55 (80.51)	Palmiet (83.10)	SST55 (81.05)	SST55 (85.89)	SST822 (58.21)
7	Palmiet (86.59)	SST876 (79.03)	SST65 (82.43)	Palmiet (79.12)	SST876 (84.29)	SST65 (54.25)
8	SST876 (85.65)	Palmiet (78.59)	Kariega (76.72)	SST876 (78.37)	Palmiet (83.97)	SST57 (54.20)
9	Kariega (84.33)	Kariega (77.10)	SST57 (75.12)	Kariega (76.97)	Kariega (82.41)	Kariega (47.14)
10	T4 (79.59)	T4 (72.29)	SST876 (74.75)	T4 (72.22)	T4 (77.61)	T4 (43.29)
11	SST57 (76.56)	SST57 (68.18)	T4 (72.34)	SST57 (69.03)	SST57 (73.59)	SST876 (40.57)
Mean	86.67	79.03	81.21	79.24	84.38	54.67

Grand mean = 77.53 LSD (0.05): treatment = 2.26, environment = 7.505

The AMMI biplot for genotype and environment means (Figure 4.1.6) shows interaction for only SST876 and SST57 but all had low means especially SST57. SST876 ranked intermediate at Barkly West and Douglas but lower in other locations and last at Loskop. SST57 ranked last in four locations and only at Loskop and Prieska it ranked eighth and ninth respectively. Other genotypes showed more stability (less interaction), but genotype main effect may be observed whereby

Kariega and T4 had lower mean values than others. The genotype SST822 ranked first in most of the sites followed by SST825 and Marico, except Loskop where Marico ranked first followed by SST55 and SST822 at the middle. These four genotypes together with Inia, SST65 and Palmiet were above the mean showing to have higher genetic potential than others. On the other side Kariega, SST876, T4 and SST57, which ranked lower and had lower means, far below the mean, especially T4 and SST57, indicates low genetic potential for this parameter.

Figure 4.1.6 shows Loskop to be contrasting more with other locations, and it is the only one, which showed environment interaction with genotypes. Other locations proved to have no environment interaction and genotypes ranking higher were similar in most of the sites with Palmiet ranking a bit lower. However, at Loskop a different combination of genotypes, ranking higher, was observed (Table 4.1.12). This implies reliable and comparable ranking at all locations except Loskop for this parameter. For the genotypes SST822, SST825, Marico, SST55, Inia and SST65 may give reliable ranking at all locations.

Single kernel characterisation system – hardness index

Compared to the vitreous kernel parameter, which focuses on the amount of hard kernels, hardness index is more inclined on the extent of hardness for the individual kernels. Therefore the two parameters are influenced by similar environmental conditions, although for hardness index genotype main effect seems to be more pronounced. The analysis of variance (Table 4.1.13) shows highly significant variation ($p < 0.001$) for treatment, main effects, interaction as well as IPCA. The block effect and residual were significant at ($p < 0.05$), implying presence of variation within locations and noise effects to some extent. The environment contribution to the variation in hardness index was 57.3%, slightly lower than that of vitreous kernels. The genotype contribution to the variation in this parameter was 30.3%, which is more than twice that of vitreous kernels (Table 4.1.13). This implies varying genotype performance. Although the contribution of interaction to the variation was low (6.0%) it was highly significant, implying presence of interaction. Out of this the IPCA captured 49.2%.

Table 4.1.13 Analysis of variance results for SKCS – hardness index in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	17842	90.6			
Treatment	65	16705	257.0	33.62	0.000	
Environment (E)	5	10222	2044.4	267.43	0.000	57.3
Block	12	220	18.3	2.39	0.008	
Genotype (G)	10	5410	541.0	70.77	0.000	30.3
G x E	50	1072	21.4	2.81	0.000	6.0
IPCA	14	527	37.7	4.93	0.000	49.2
Residual	36	545	15.1	1.98	0.003	
Error	120	917	7.6			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

Environment mean values ranged between 56.38 at Loskop to 78.30 at Douglas. For this parameter the coefficient of variations were slightly higher but more similar to other locations with exception of Loskop. General observations shows four environmental groups which are; Douglas and Hopetown with higher values, Barkly West and Prieska with high to medium values, BullHill with medium to low values and Loskop with a number of intermediate and lower values (Table 4.1.14). This implies that for hardness index even a small difference between environments,

genotypes and interaction accounts more for variability compared to vitreousness. For vitreous kernels only main effects were significant and thus treatment, but for hardness index all sources of variations were significant.

The genotype means (Appendix 1) ranged between 60.23 to 76.78 for SST55 and SST825 respectively. For genotypes three groups were realised and these were; SST825, SST822, SST876 and Palmiet with higher values in most locations, T4, SST57, Marico and Inia with medium values and close to the mean, SST65, Kariega and SST55 with low values which ranked lower in most locations (Table 4.1.14).

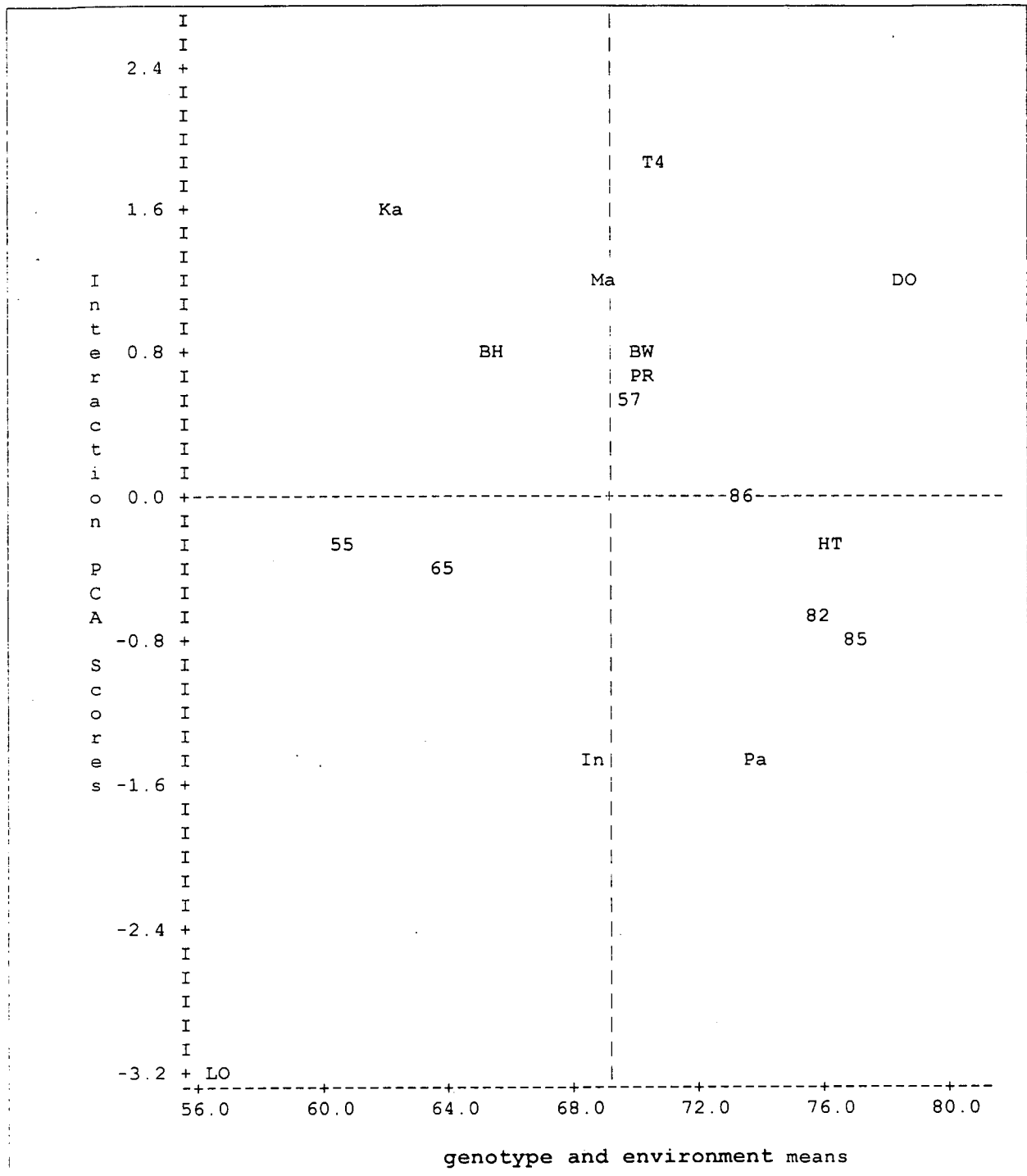
Table 4.1.14 Ranking of genotypes in each location for SKCS – hardness index (%) and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	SST825 (72.02)	SST825 (76.90)	SST825 (77.00)	SST825 (83.54)	SST825 (84.78)	SST825 (66.41)
2	SST822 (71.03)	SST822 (75.92)	SST822 (75.99)	SST822 (82.44)	SST822 (83.83)	Palmiet (65.20)
3	SST876 (69.30)	SST876 (74.23)	SST876 (74.12)	Palmiet (80.37)	SST876 (82.39)	SST822 (64.99)
4	Palmiet (68.18)	Palmiet (73.02)	Palmiet (73.27)	SST876 (79.97)	T4 (81.59)	SST876 (60.34)
5	T4 (67.83)	T4 (72.86)	T4 (72.33)	T4 (76.69)	Palmiet (80.69)	Inia (60.30)
6	SST57 (65.88)	SST57 (70.83)	SST57 (70.61)	SST57 (76.03)	Marico (79.29)	SST57 (54.92)
7	Marico (65.78)	Marico (70.77)	Marico (70.40)	Inia (75.43)	SST57 (79.15)	Marico (52.33)
8	Inia (63.23)	Inia (68.07)	Inia (68.33)	Marico (75.30)	Inia (75.73)	SST65 (51.95)
9	Kariega (59.23)	Kariega (64.24)	SST65 (64.01)	SST65 (70.23)	Kariega (72.91)	T4 (51.80)
10	SST65 (59.10)	SST65 (64.00)	Kariega (63.76)	Kariega (68.29)	SST65 (72.01)	SST55 (47.92)
11	SST55 (55.96)	SST55 (60.88)	SST55 (60.83)	SST55 (66.86)	SST55 (68.96)	Kariega (44.01)
Mean	65.23	70.16	70.06	75.92	78.30	56.38

Grand mean = 69.34 LSD (0.05): treatment = 0.95 , environment = 3.151

From the AMMI biplot for genotype and environment means (Figure 4.1.7) it shows some environment interaction for Palmiet, Inia, T4, and Kariega and to a lesser extent Marico. Both Palmiet and Inia had higher values at Loskop and Hopetown than in other locations. T4 ranked slightly higher in Douglas, lower in Loskop but intermediate in other locations. Kariega was second at Prieska, Hopetown and third at BullHill, Barkly West and Douglas whereas at Loskop it ranked last. Marico ranked intermediate at Douglas but slightly below the middle in other locations (Table 4.1.14). Other genotypes showed stability but genotype main effect made SST825, SST822 and SST876 to be far above and SST65 and SST55 far below the mean. Therefore as mentioned earlier only slight variation between locations was sufficient to reveal interaction. Genotype main effect in addition to environment seems to be primarily responsible for variation in this parameter.

Again, as it was for the vitreous kernels, Loskop contrasted more with other locations and it is the one with slightly stronger interactions, (Figure 4.1.7). This implies hardness index ranking in this location may be unreliable. Despite other locations showing stability, environmental main effects are still observed and thus Douglas, Hopetown, Prieska and Barkly West, which were above the mean, may be more reliable in ranking compared to BullHill which was below the mean. As genotype x environment interaction was not significant, rankings will be a reliable criterion of genotype performance.



NB: Loskop site contrasts with other sites from AMMI selections

Figure 4.1.7 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T₄ = T₄, Ma = Maitso, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST577 at six localities BH = Bull Hill, BW = Barkly West, PR = Prieska, HT = Hyper town, DO = Douglas and LO = Loskop) for SKCS - hardness index in 1997.

Single kernel characterisation system – weight

Moisture content, hardness index and weight are determined simultaneously by the single kernel characterisation system equipment. It seems the equipment takes the weight of thousand kernels as the values and results are close to those taken with a weighing balance. The analysis of variance results are summarised in Table 4.1.15. The F-values were highly significant for treatments, environments, genotypes, block effect, interactions and IPCA. This indicates different genotype performance, varying growth conditions among and within the locations as well as presence of specific interactions between genotypes and environments for this parameter. The significant block effect ($p < 0.001$) signifies how sensitive the parameter is to environment, implying presence of variations for a given genotype even within a certain location. However, the residual was significant at ($p < 0.05$) implying presence of some noise effect.

Table 4.1.15 Analysis of variance results for single kernel characterisation system – weight in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	4057	20.59			
Treatment	65	3595	55.30	19.96	0.000	
Environment (E)	5	1873	374.66	135.23	0.000	46.2
Block	12	129	10.75	3.89	0.000	
Genotype (G)	10	1170	16.99	42.23	0.000	28.8
G x E	50	552	11.03	3.98	0.000	13.6
IPCA	14	393	28.08	10.14	0.000	71.2
Residual	36	158	4.40	1.59	0.034	
Error	120	332	2.77			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The results show a large contribution by environment, 46.2% of the variation in this parameter. The location means ranged between 35.49 g to 45.38 g at Loskop and Prieska respectively. The environmental effect shows that Prieska had values above the mean, Douglas, BullHill and Barkly West had values very close to the mean and Hopetown slightly lower, whereas Loskop was much lower than the mean. This shows at least three grouping of the locations based on their mean values. The genotype contribution to the variation in weight was 28.8%, showing more influence of the genetic potential to this parameter. The mean values (Appendix 1) were between 33.92g to

42.65 g for SST57 and SST55 respectively. From mean values, three groupings of genotypes were observed which were; those with values above the mean in ascending order includes SST65, SST876, Inia, SST822, SST825, Palmiet and SST55. Genotypes with values slightly below the mean include Marico and Kariega, whereas T4 and SST57 had the lowest values, significantly lower than the mean. Based on the performance of genotypes in each location, as was the case for thousand-kernel mass, this parameter also shows Loskop to be a low potential, and Barkly West and Hopetown intermediate low potential environments. The interaction contributed 13.6% to the total variation in weight and out of this IPCA captured 71.2%. This implies more interaction effects in this parameter compared to vitreous kernels and hardness index.

Table 4.1.16 Ranking of genotypes in each location for single kernel characterisation system – weight (g) and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	SST55 (42.04)	SST55 (39.98)	SST55 (49.78)	SST55 (42.66)	SST55 (45.95)	Kariega (38.04)
2	Palmiet (40.82)	Kariega (39.91)	Palmiet (48.27)	Palmiet (40.95)	Palmiet (44.10)	Marico (37.50)
3	SST825 (40.42)	Marico (39.59)	SST825 (47.73)	SST825 (40.29)	SST825 (43.36)	Inia (36.09)
4	SST822 (39.98)	Inia (39.29)	SST822 (46.54)	SST822 (30.57)	SST822 (41.28)	SST65 (35.84)
5	Inia (39.96)	SST822 (39.12)	Inia (46.34)	SST876 (38.27)	SST876 (40.97)	SST822 (35.75)
6	SST876 (39.73)	Palmiet (39.05)	SST876 (46.27)	Inia (38.23)	Inia (40.85)	SST876 (35.55)
7	SST65 (39.49)	SST65 (38.93)	SST65 (45.76)	SST65 (37.57)	SST65 (40.14)	SST55 (35.50)
8	Kariega (39.15)	SST876 (38.90)	Marico (44.26)	Marico (35.28)	Marico (37.32)	Palmiet (34.84)
9	Marico (39.06)	SST825 (38.82)	Kariega (44.11)	Kariega (34.96)	Kariega (36.90)	SST825 (34.75)
10	T4 (35.64)	T4 (36.39)	T4 (40.62)	T4 (31.48)	T4 (33.42)	T4 (34.52)
11	SST57 (34.05)	SST57 (34.30)	SST57 (39.52)	SST57 (30.74)	SST57 (32.92)	SST57 (31.97)
Mean	39.12	38.57	45.38	37.18	39.75	35.49

Grand mean = 39.25 LSD (0.05): treatment = 0.574 , environment = 1.903

The AMMI biplot for genotype and environment means (Figure 4.1.8) shows high interaction for SST55, Palmiet, Kariega, Marico and T4 and to a lesser extent SST825 and SST57. This indicates that the environment influences ranking. SST55 ranked first in five locations except Loskop where it was below the middle. Palmiet also ranked second in four locations with Barkly West being in the middle and Loskop lower. SST825 ranked third in four locations except Barkly West and Loskop where it ranked lower. All three showed positive interactions. Kariega and Marico ranked higher at Loskop and Barkly West but lower at the other locations, whereas T4 and SST57 ranked last in all locations with slightly higher means at Prieska compared to other sites, and all four showed negative interactions. Other genotypes, SST822, Inia, SST876 and SST65 showed stability and therefore may give reliable rank in most of the locations (Table 4.1.16).

The locations (Figure 4.1.8) showed significant interaction at Loskop, Douglas and to a lesser extent Barkly West and Hopetown. SST55 and Palmiet showed higher values at Douglas with the

former also ranking higher in Hopetown, whereas Kariega and Marico were responsible for interaction at Loskop and Barkly West. To conclude we can say SST55, Palmiet, SST825, SST822, Inia, SST876 and SST65 may give reliable rankings in most of the locations. However, Kariega and Marico may also be included as references at Loskop and Barkly West where they showed positive environment interactions. For the locations, others except Loskop and Barkly West, may give reliable rankings to most of the genotypes and with higher mean values. However, the two sites contrast with others and to a lesser extent among themselves as Loskop had a lower mean value than Barkly West. Therefore genotype ranking in the two sites may not be reliable particularly at Loskop and care must be taken for those genotypes showing environment interactions.

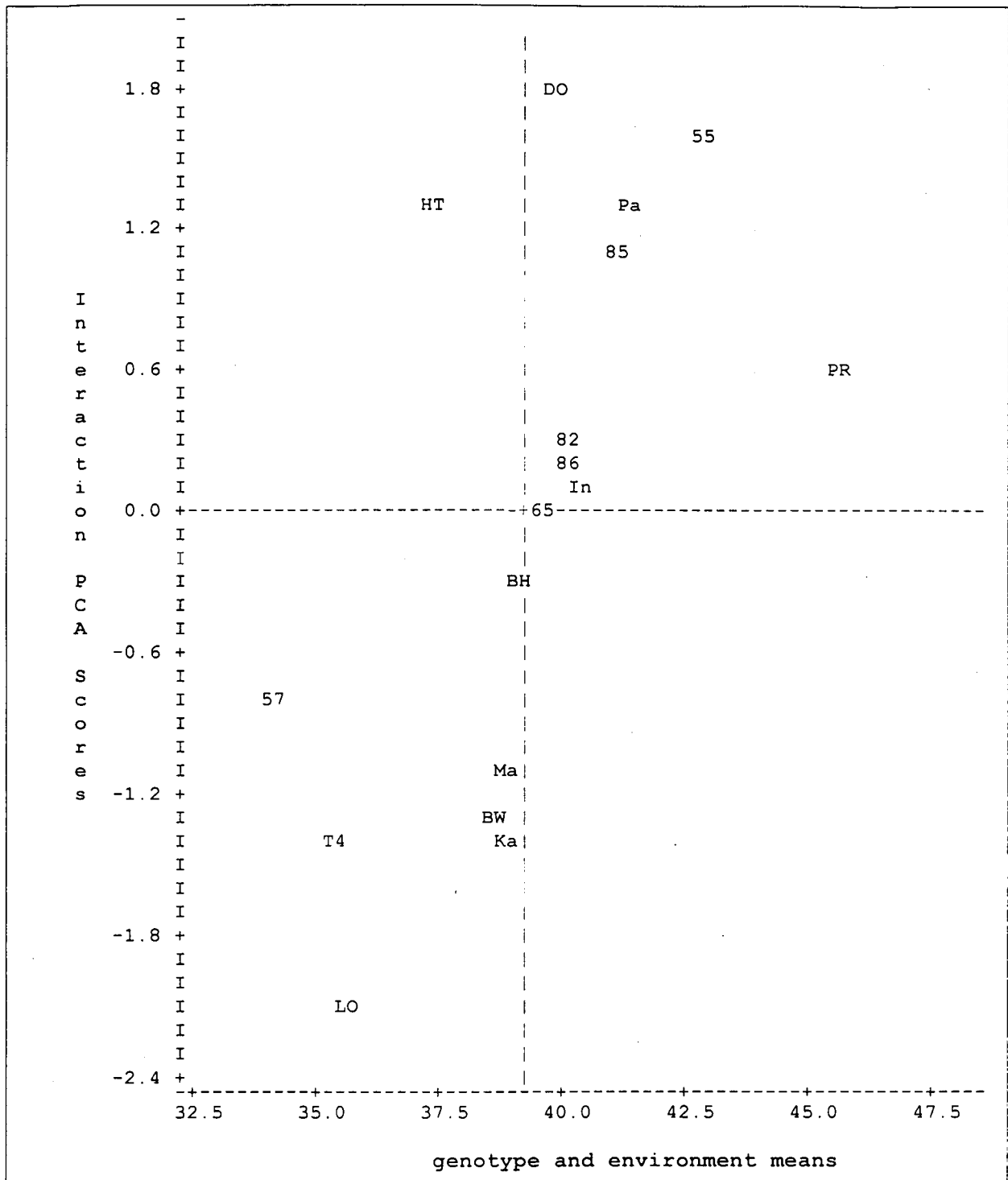


Figure 4.1.8 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at six localities (BH = Bull Hill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for single kernel characterisation system - weight in 1997.

Flour protein content – LECO

There are various methods to measure protein content and in this study two methods were used to determine flour protein content. Apart from influencing some of the physical characteristics already discussed, protein content plays a major role in the functionality of wheat flour (Koekemoer *et al.*, 1999). Very high and very low protein content is not desirable and in South Africa for example, $\pm 12\%$ flour protein content is recommended. The analysis of variance results (Table 4.1.17) shows that treatments, main sources of variation (environment and genotype), block effect, interactions and IPCA had highly significant F-values. This indicates different genotype performance, varying growth conditions among and within locations as well as presence of specific interactions between genotypes and environments for this parameter. The significant block effect ($p < 0.001$) indicates how sensitive the parameter is to environment with variations for particular genotypes even within a certain location. However, the residual was significant at $p < 0.05$ implying presence of noise effect.

In this study, environment contribution to the variation in protein content for this method was 18.4% which was less than that of interaction and slightly higher than genotype contribution (Table 4.1.17). This contrasts with the results of Nel *et al.* (1998a) in the Western and Southern Cape where environment contributed up to 94% in the variation of protein content. This shows that moisture stress (less water and/or availability at wrong time) to be one of the environmental factors which has more influence on wheat protein content. According to Sander *et al.* (1987) water can increase nitrogen availability in the crop by increasing root growth, mass flow of water, and therefore nitrogen, towards the plant; mineralization of nitrogen from soil organic matter; and movement of nitrogen fertilisers into the root zone. Rainfall prior to grain filling accelerates leaching and other forms of nitrogen loss, whereas later in the season it may cause nitrogen dilution by extending leaf life and maintaining photosynthesis and therefore, carbohydrate assimilation (Powelson *et al.*, 1992). All these are minimised under irrigation conditions and that is why environmental variance is less compared to rain-fed areas. Genotype contribution to the variation in protein content was 17.7%, close to that of environment. However, this was much higher compared to cultivar evaluation programme results under irrigation where the highest cultivar contribution was 5% for earlier planting dates in cooler irrigation areas. Except for a few genotypes, which showed interaction, and which had low genetic potential, in this study most of the genotypes had the potential to give higher protein contents where the environments were optimal (Table 4.1.18). Although the contribution of the interaction to the variation was 26.2% and higher than both main effects, nevertheless only two genotypes showed interactions. From the interaction effect the IPCA captured 44.5% of the variation.

Table 4.1.17 Analysis of variance results for flour protein content – LECO in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	346.3	1.753			
Treatment	65	215.8	3.320	4.760	0.000	
Environment (E)	5	63.8	12.765	18.300	0.000	18.4
Block	12	46.8	3.901	5.592	0.000	
Genotype (G)	10	61.3	6.127	8.784	0.000	17.7
G x E	50	90.7	1.814	2.601	0.000	26.2
IPCA	14	40.4	2.886	4.133	0.000	44.5
Residual	36	50.4	1.399	2.005	0.003	
Error	120	83.7	0.698			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The location means ranged between 11.35% to 12.93% at Prieska and Hopetown respectively. General observation showed two groups of environments. Those with means above the recommended value, which were, Hopetown, BullHill and Douglas, and with means below recommended value like Prieska, Barkly West and Loskop. The main reasons may be that in Prieska due to optimal environments as revealed by high hectolitre and kernel masses, the yields were also high, consequently resulting in low protein. This is supported by Nel *et al.* (1998a) whereby low and high proteins content were realised in high and low yielding environments respectively. However, at Loskop and Barkly West due to less optimal environments which accelerated evaporation and transpiration, both grain filling as revealed by low kernel mass as well as nitrogen assimilation and mineralization were affected and this caused low protein content. The genotype means (Appendix 1) ranged between 10.95 to 13.27 for T4 and Inia respectively and the genotype main effect showed three groups. Inia had values significantly higher than the mean and therefore ranked relatively higher at most of the sites. On the contrary, T4 had values significantly lower than the mean and ranked last at most of the sites. Other genotypes did not deviate significantly from the mean. SST822 and SST82 had slightly higher values than SST55. However, general observation shows that environment was primarily responsible for the variation in protein content.

Table 4.1.18 Ranking of genotypes in each location for flour protein content (%) - LECO and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	Inia (13.86)	Inia (12.78)	Inia (12.39)	Inia (14.22)	SST57 (14.39)	Inia (12.94)
2	SST825 (13.24)	SST57 (12.68)	SST57 (12.00)	Kariega (13.97)	Inia (13.45)	SST822 (12.28)
3	SST822 (13.02)	SST822 (12.32)	SST822 (11.86)	SST825 (13.79)	SST822 (13.25)	SST825 (12.23)
4	Kariega (12.99)	SST825 (11.96)	SST825 (11.61)	Marico (13.32)	SST876 (12.87)	SST57 (12.02)
5	Palmiet (12.91)	SST65 (11.82)	Palmiet (11.42)	Palmiet (13.29)	SST65 (12.69)	Palmiet (11.98)
6	Marico (12.72)	SST876 (11.81)	SST65 (11.38)	SST822 (13.03)	SST825 (12.51)	SST65 (11.82)
7	SST65 (12.61)	Palmiet (11.80)	SST876 (11.32)	SST65 (12.69)	Palmiet (12.46)	Kariega (11.78)
8	SST876 (12.32)	Marico (11.38)	Marico (11.05)	SST55 (12.44)	SST55 (12.06)	Marico (11.68)
9	SST57 (12.22)	SST55 (11.28)	Kariega (11.01)	T4 (12.28)	Marico (11.89)	SST876 (11.67)
10	SST55 (12.22)	Kariega (11.27)	SST55 (10.87)	SST876 (12.14)	Kariega (11.52)	SST55 (11.36)
11	T4 (11.67)	T4 (10.32)	T4 (9.99)	SST57 (11.12)	T4 (10.82)	T4 (10.62)
Mean	12.71	11.77	11.35	12.93	12.54	11.85

Grand mean = 12.19 LSD (0.05): treatment = 0.288 , environment = 0.955

The AMMI biplot for genotype and environment means (Figure 4.1.9), shows interaction for SST57 and Kariega with the environment implying higher ranking in some locations for these genotypes. Other genotypes showed stability but genotype main effect was also observed whereby Inia was higher and T4 lower than the mean.

The locations (Figure 4.1.9) showed slightly higher genotype interaction at Douglas and Hopetown and to a lesser extent Barkly West and BullHill. Kariega ranked higher at Hopetown and BullHill but intermediate to low in other locations, whereas SST57 ranked very low at Hopetown and BullHill but intermediate to very high in other locations. Loskop and Prieska showed stability but together with Barkly West they were lower than the mean.

Therefore in summary, for genotypes except for T4 and to some extent SST55 which seem to have low genetic potential for this parameter, others may give reliable ranking at all locations. For the locations with exception of Loskop and Barkly West other locations may give reliable ranking for protein content.

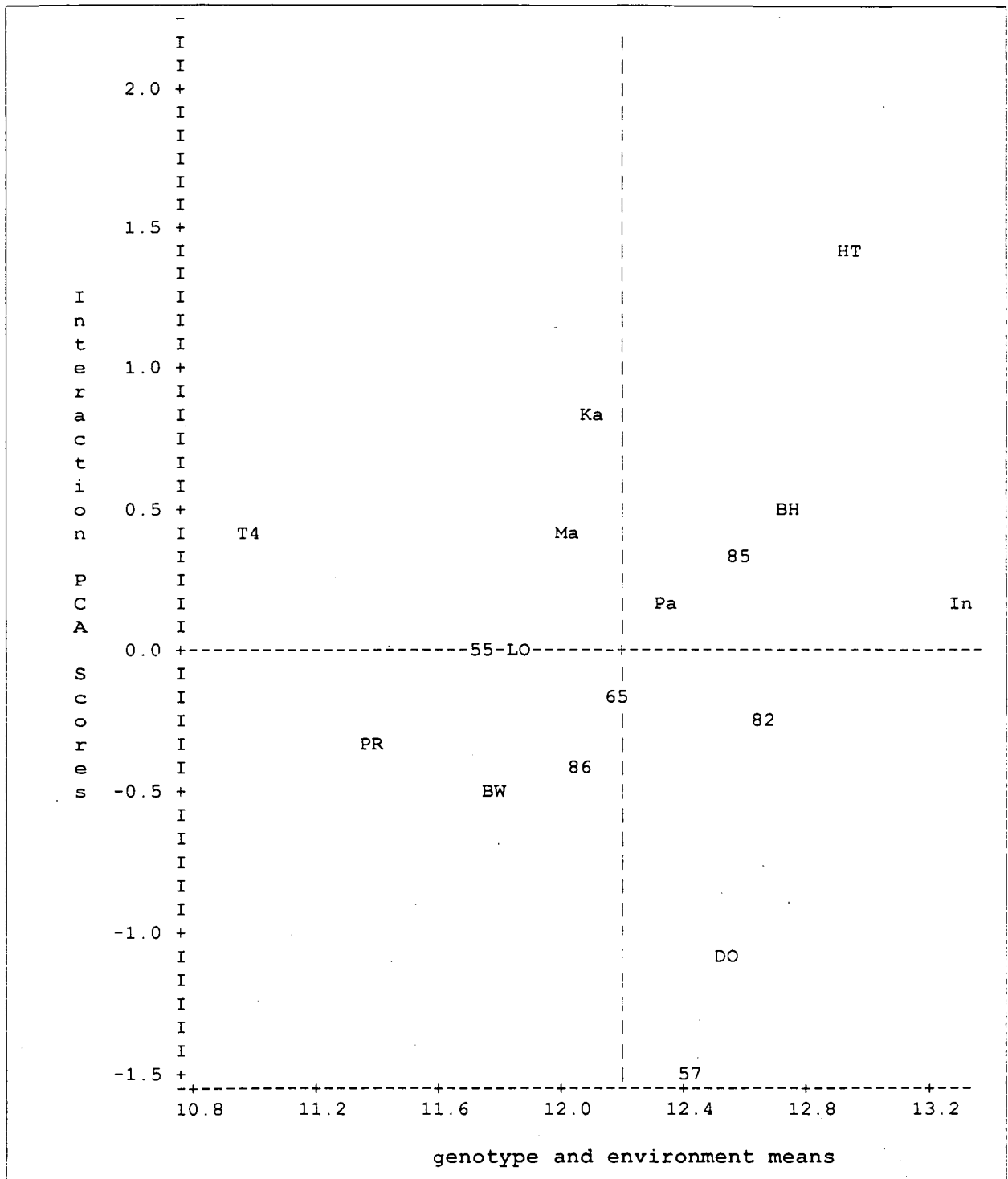


Figure 4.1.9 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at six localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for flour protein content-LECO method in 1997.

Flour protein content – NIR

This is the protein determination method using infrared reflectance equipment. The analysis of variance results (Table 4.1.19) show that the F-values for treatments, environments, genotypes, block effect and IPCA were highly significant. This indicates different genotype performance and varying growth conditions among and within locations. The significant block effect ($p < 0.001$) indicates how sensitive the parameter is to environment implying presence of variations for particular genotypes even within a certain location. However, the interaction effect was significant at $p < 0.05$ implying less variation in interaction effects and the residual was not significant, showing less noise effect. Compared to the former method (LECO) this method had slightly lower values than the previous one and it revealed to a larger extent the environmental main effect as well as interaction. The environment contribution to the variation was 25.2%, which was higher than the former method and almost twice to that of genotype contribution. The genotype contribution to the variation in this method was 12.2%, which was lower compared to the previous one. The interaction contributed 19.2% to the variation and IPCA captured 55.0% of this, implying more interaction effects being revealed by this axis and not others, as the residual was also non-significant.

Table 4.1.19 Analysis of variance results for flour protein content – NIR in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	346.2	1.757			
Treatment	65	196.1	3.017	3.380	0.000	
Environment (E)	5	87.4	17.485	19.586	0.000	25.2
Block	12	43.0	3.581	4.011	0.000	
Genotype (G)	10	42.2	4.215	4.722	0.000	12.2
G x E	50	66.6	1.331	1.419	0.040	19.2
IPCA	14	36.6	2.613	2.927	0.001	55.0
Residual	36	30.0	0.832	0.933	0.583	
Error	120	107.1	0.893			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means ranged between 10.88% to 12.92% at Prieska and Hopetown respectively and it showed at least three groups of environments. Hopetown and BullHill had values higher than the mean and recommended value, Barkly West, Douglas and Loskop had values close to but

slightly below the mean, whereas Prieska had values slightly lower than the mean (Table 4.1.20). However, this method shows Barkly West had slightly higher values than Douglas but probably higher yield was also realised at Douglas resulting in protein reduction. Hectoliter and kernel masses confirm this as Douglas ranked second and third for these parameters. The genotype means (Appendix 1) ranged between 10.69 to 12.65 for T4 and Inia respectively. Genotype main effects showed about three groups as it was for the previous method, and genotypes within groups are similar. Inia had values significantly higher than the mean, and T4 had values significantly lower than the mean. Others were closer to the mean with SST822 being slightly higher. However, beside low environment interaction and low genetic potential for some genotypes, most of them had values close to the mean.

Table 4.1.19 Ranking of genotypes in each location for flour protein content (%) – NIR method and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	Inia (13.19)	Inia (12.59)	Inia (11.76)	Marico (14.39)	Inia (12.36)	Inia (12.24)
2	SST822 (13.02)	SST822 (12.28)	SST822 (11.45)	Kariega (14.28)	Marico (11.95)	SST822 (12.00)
3	SST825 (12.87)	Palmiet (12.03)	Palmiet (11.20)	Inia (13.75)	SST65 (11.86)	SST825 (11.77)
4	Palmiet (12.73)	SST825 (12.01)	SST825 (11.19)	SST65 (13.63)	Kariega (11.78)	Palmiet (11.73)
5	SST65 (12.54)	SST65 (11.83)	SST65 (11.00)	SST822 (12.61)	SST822 (11.70)	SST57 (11.51)
6	SST57 (12.33)	SST57 (11.79)	SST57 (10.96)	Palmiet (12.57)	Palmiet (11.54)	SST65 (11.44)
7	SST55 (12.32)	SST55 (11.63)	SST55 (10.80)	T4 (12.53)	SST55 (11.19)	SST55 (11.32)
8	SST876 (12.13)	SST876 (11.48)	SST876 (10.65)	SST876 (12.38)	SST57 (11.18)	SST876 (11.15)
9	Marico (11.76)	Marico (11.45)	Marico (10.61)	SST55 (12.29)	SST876 (11.14)	Marico (10.98)
10	Kariega (11.55)	Kariega (11.24)	Kariega (10.40)	SST57 (12.05)	SST825 (11.13)	Kariega (10.77)
11	T4 (10.91)	T4 (10.45)	T4 (9.61)	SST825 (11.61)	T4 (10.59)	T4 (10.04)
Mean	12.30	11.71	10.88	12.92	11.49	11.36

Grand mean = 11.78 LSD (0.05): treatment = 0.326 , environment = 1.08

The AMMI biplot for genotype and environment means (Figure 4.1.10) shows higher environment interaction with genotype for Marico, Kariega, and SST825 and to a lesser extent T4, SST57 and SST822. Marico and Kariega ranked first and second and then second and third at Hopetown and Douglas respectively, but very low in other locations. SST825 ranked intermediate to higher in other locations except Hopetown and Douglas where it was last and second from last respectively. T4 ranked last in five locations except Hopetown where it was close to the middle. SST57 ranked intermediate in most locations but lower at Hopetown and Douglas whereas SST822 ranked second in four locations and intermediate at Hopetown and Douglas (Table 4.1.20). Therefore, before ranking these genotypes interactions should be taken into account. Other genotypes show stability and Inia seems to have higher and T4 lower genetic potential for this parameter.

For the locations (Figure 4.1.10), very high environment interaction is shown at Hopetown and to a lesser extent Douglas and BullHill. SST825 was responsible for interaction at BullHill and Marico, Kariega, SST65 and T4 at other locations.

In summary, all genotypes except Marico and Kariega may give reliable ranking at most of the locations. However, at Hopetown and Douglas, Marico and Kariega ranked much higher and this should not be generalised to other sites where they ranked very low. For the locations, reliable ranking is expected at all except Hopetown and Douglas which shows similar ranking for the two localities but different from other localities.

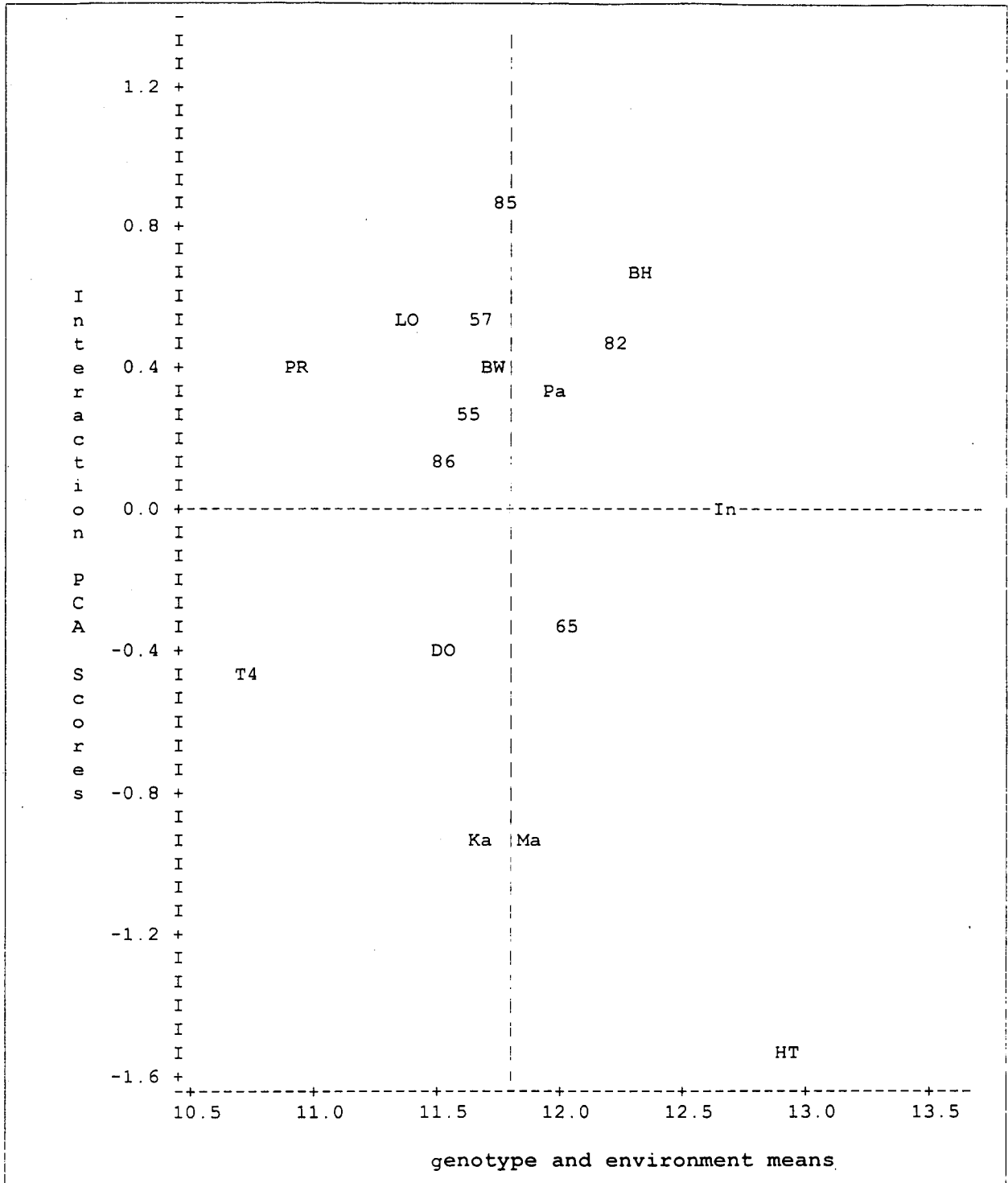


Figure 4.1.10 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at six localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for flour protein content-NIR method in 1997.

Farinograph water absorption

The wheat flour water absorption capacity is among the indicators of baking quality, and it shows the potential of protein molecules to absorb moisture. The analysis of variance results (Table 4.1.21) show that treatments, environments, genotypes, block effect, interaction, IPCA as well as residual were highly significant. This indicates different genotype performance, varying growth conditions among and within locations as well as presence of specific interactions between genotypes and environments for this parameter. The significant block effect ($p < 0.001$) shows this parameter to be sensitive to environment and this indicates presence of variations for particular genotypes even within a certain location. The significant residual shows presence of noise; nevertheless the IPCA1 explained a large percentage (60.1) of the interaction effect. The results show that environment made a large contribution (about 39.6%) to the variation in this parameter. The genotype contribution to the variation was 28.0%, showing a larger effect also probably due to difference among them. The contribution of interaction was 17.5%, therefore having less effect in variation for this parameter compared to the main sources of variation.

Table 4.1.21 Analysis of variance results for farinograph water absorption in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	1493.0	7.58			
Treatment	65	1268.7	19.52	15.13	0.000	
Environment (E)	5	590.6	118.13	91.58	0.000	39.6
Block	12	69.4	5.79	4.49	0.000	
Genotype (G)	10	417.4	41.74	32.36	0.000	28.0
G x E	50	260.7	5.21	4.04	0.000	17.5
IPCA	14	156.7	11.19	8.68	0.000	60.1
Residual	36	104.0	2.89	2.24	0.001	
Error	120	154.8	1.29			

IPCA = Interaction Principal Component Analysis
SS Percentage contribution:

Genotype (G), Environment (E)
 and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The location means (Table 4.1.22) ranged between 58.48 to 63.66 at Loskop and Douglas respectively with a grand mean of 61.77. Environment main effect showed at least three groups among locations. Douglas, Hopetown and also BullHill had the highest absorptions, followed by Prieska and Barkly West slightly above and below the mean respectively, whereas Loskop was far below the mean. It is clear that higher absorption was realised at locations with higher protein content and this agrees with Finney and Shogren (1972) who reported that higher flour protein

content results in higher water absorption. Breakflour yield contributes to flour water absorption capacity and as it was realised breakflour yield is more influenced by the starch – protein interaction. Therefore in addition to high protein, optimum grain filling is also important. This is revealed in this study in that despite Prieska having low protein content, due to optimum grain filling, its water absorption was higher compared to Barkly West and Loskop where grain filling was lower. This is also supported by Van Lill and Smith (1997) who reported that grains containing higher protein were inclined to be hard, increasing flour yield, and breakflour yield is also liable to increase.

The genotype means (Appendix 1) ranged between 59.51 to 64.18 for SST57 and SST825 respectively. General observation showed three groups according to mean values, although interaction was also present within the groups. The first group comprised of SST825, T4, Palmiet, SST822, SST876 and Inia with means above grand mean. Second group with means slightly below the grand mean included SST65, SST55 and Kariega, whereas Marico and SSST57 were far below the mean. This shows higher and low genetic potentials for those above and below the mean respectively.

Table 4.1.22 Ranking of genotypes in each location for farinograph water absorption and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	SST825 (65.76)	SST825 (63.15)	SST825 (64.83)	SST876 (66.04)	SST825 (66.70)	SST825 (60.85)
2	SST822 (64.85)	T4 (62.31)	SST822 (63.68)	SST57 (64.74)	SST822 (65.61)	T4 (59.96)
3	T4 (64.33)	Palmiet (61.91)	T4 (63.58)	T4 (64.00)	T4 (65.40)	Palmiet (59.57)
4	Palmiet (64.10)	SST876 (61.64)	Palmiet (63.30)	SST825 (63.82)	Palmiet (65.13)	SST822 (59.23)
5	Inia (63.29)	SST822 (61.45)	Inia (62.56)	Palmiet (63.29)	Inia (64.38)	SST876 (59.13)
6	SST876 (62.08)	Inia (61.35)	SST876 (61.82)	SST65 (63.18)	SST876 (63.51)	Inia (58.99)
7	SST55 (61.86)	SST65 (60.34)	SST55 (61.17)	Inia (63.18)	SST55 (62.98)	SST65 (57.92)
8	SST65 (61.68)	SST55 (60.05)	SST65 (61.14)	Kariega (63.07)	SST65 (62.91)	SST55 (57.68)
9	Kariega (61.19)	Kariega (59.98)	Kariega (60.69)	SST55 (62.12)	Kariega (62.44)	Kariega (57.55)
10	Marico (59.82)	SST57 (58.90)	Marico (59.31)	Marico (61.54)	Marico (61.07)	SST57 (56.31)
11	SST57 (58.50)	Marico (58.56)	SST57 (58.50)	SST822 (60.76)	SST57 (60.12)	Marico (56.13)
Mean	62.50	60.88	61.87	63.25	63.66	58.48

Grand mean = 61.77 LSD (0.05): treatment = 0.391, environment = 1.298

The AMMI biplot for genotype and environment means (Figure 4.1.11) shows high environment interaction for SST57, SST822 and to a lesser extent SST876 and SST825. Both SST57 and SST876 showed negative interaction as SST57 ranked lower and SST876 at the middle in most locations except Hopetown where they ranked second and first respectively. On the other hand SST822 and SST825 showed positive interaction as SST822 ranked second at three sites, intermediate at two but last at Hopetown. SST825 ranked first in other locations and intermediate at Hopetown, showing wide adaptability. Therefore ranking these genotypes in other locations may

be reliable except Hopetown where interactions were shown. Other genotypes show stability, except Marico, which was far below the mean. Ranking at all locations may therefore be reliable.

The locations (Figure 4.1.11) show high genotype interaction at Hopetown and to a lesser extent BullHill and Douglas. Hopetown contrasted with the other locations. Hopetown shows negative interaction due to SST876 and SST57 ranking first and second at this site but intermediate to very low in others. Genotypes like SST822 which ranked intermediate to higher at other sites was last at this location. BullHill and Douglas show positive interaction as SST822 and SST825 ranked higher, but also showed higher mean values at these two sites compared to others. Other locations showed stability, but for environment main effect Loskop and also Barkly West contrasted with other locations.

In conclusion we can say the genotypes, Inia, Kariega, Marico, SST825, SST822, Palmiet, SST55, T4, and SST65 with exception of SST876 and SST57 may give reliable ranking at most of the sites but at Hopetown SST876 and SST57 can be taken as references. However, the results at Hopetown for these two genotypes together with SST822 should not be generalised to other locations. For the locations, reliable ranking for flour absorption may be obtained at Douglas, BullHill, Prieska and to a lesser extent Barkly West. Hopetown contrast with the other locations and Loskop shows poor potential for this parameter.

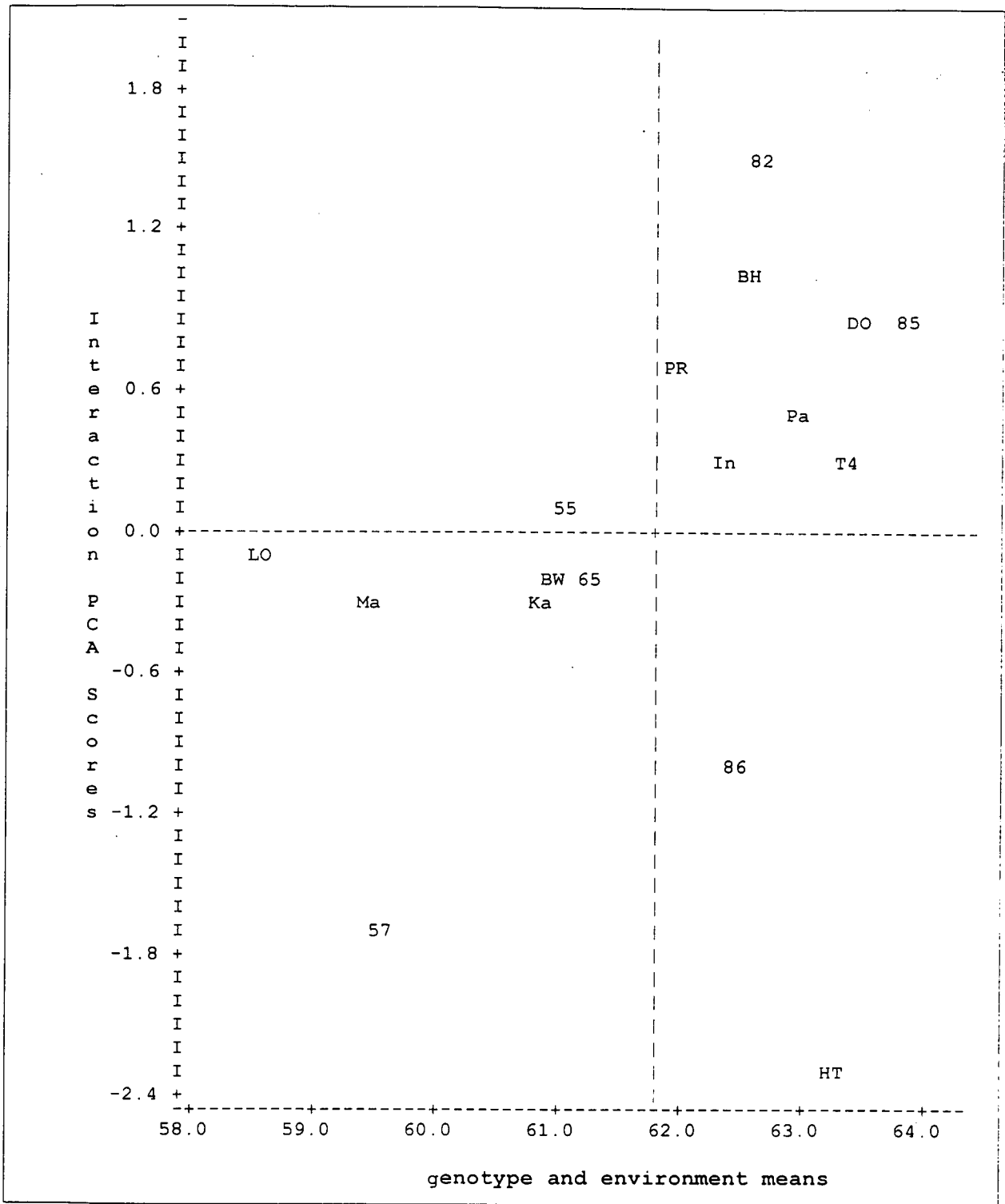


Figure 4.1.11 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at six localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for farinograph water absorption in 1997.

Grain Protein Content – whole wheat (WH)

The main effect and interaction responses were slightly different between grain and flour protein contents. The analysis of variance results (Table 4.1.23) shows significant F-values for treatments, environments, genotypes and block effect. This indicates different genotype performance and varying growth conditions among and within locations. The significant block effect ($p < 0.001$) signifies how sensitive the parameter is to environment implying presence of variations for particular genotypes even within a certain location. However, the interaction effect and IPCA were significant at $p < 0.1$ and $p < 0.05$ respectively implying much less variation in interaction effects. The residual was not significant, showing less noise effect. The environment contribution to the variation was 25.7%, which was similar to the NIR – flour method (Table 4.1.19). The genotype contribution to the variation was 18.3% and it was higher than both flour protein methods. The interaction contributed 14.8% to the variation, which was lower than for flour methods, and out of this the IPCA captured 48.3%. The non-significant residual shows that most of the interaction effects were represented by this axis with less/no noise effect. Therefore it seems few genotypes or locations showed interaction and thus the grain protein content method reveals the influence of main effects compared to flour methods.

Table 4.1.23 Analysis of variance results for grain protein content – WH in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	270.77	1.374			
Treatment	65	159.38	2.452	4.311	0.000	
Environment (E)	5	69.59	13.917	24.468	0.000	25.7
Block	12	43.13	3.594	6.319	0.000	
Genotype (G)	10	49.60	4.960	8.720	0.000	18.3
G x E	50	40.20	0.804	1.413	0.065	14.8
IPCA	14	19.41	1.386	2.437	0.005	48.3
Residual	36	20.79	0.577	1.015	0.458	
Error	120	68.26	0.569			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 4.1.24) ranged between 11.36% to 13.12% at Loskop and BullHill respectively with a grand mean of 12.33%. Environment main effect showed three groups. BullHill and Hopetown had higher mean values, followed by Douglas, Barkly West close to the mean and Prieska slightly below the mean, whereas Loskop had the lowest mean value. Therefore compared

to the two flour methods where Prieska showed lower values, for grain method it was slightly higher than Loskop. This shows that at a site with low protein levels but higher grain filling, after milling the flour protein content will tend to be lower compared to that of grain. However, at a sites with higher protein levels but low grain filling, due to shrivelled kernels during milling, part of endosperm is lost with bran or bran contamination to flour. As a result the flour protein content should be high, which is not true in this study. Therefore grain protein content gives the real potential of the location/genotype for protein content before interference with milling operations. The genotype means (Appendix 1) ranged between 11.23% to 13.21% for T4 and Inia respectively. The result shows Inia had the highest mean and thus unique (probably due to high genetic potential and positive interactions) to other genotypes. T4 and SST876 were lower than the mean, whereas others were very close and higher than the mean. This trend was also observed in flour methods.

Table 4.1.24 Ranking of genotypes in each location for grain protein content - WH and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	Inia (14.00)	Palmiet (13.21)	Inia (12.83)	Kariega (14.07)	Inia (13.25)	Inia (12.23)
2	SST822 (13.60)	Inia (13.05)	SST822 (12.45)	Inia (13.88)	Kariega (13.00)	SST822 (11.84)
3	Palmiet (13.34)	SST822 (12.69)	Palmiet (12.40)	SST822 (13.45)	SST822 (12.84)	Palmiet (11.70)
4	SST65 (13.25)	Marico (12.62)	Marico (12.13)	SST65 (13.10)	SST65 (12.49)	SST65 (11.49)
5	Kariega (13.25)	SST57 (12.51)	SST65 (12.10)	SST55 (13.03)	SST55 (12.39)	Marico (11.49)
6	Marico (13.19)	SST825 (12.37)	SST825 (12.01)	SST825 (12.88)	Palmiet (12.35)	SST825 (11.38)
7	SST55 (13.12)	SST65 (12.34)	SST55 (11.94)	Marico (12.86)	Marico (12.34)	SST55 (11.35)
8	SST825 (13.12)	SST876 (12.15)	SST57 (11.94)	Palmiet (12.76)	SST825 (12.31)	SST57 (11.28)
9	SST57 (12.97)	SST55 (12.11)	Kariega (11.65)	SST57 (12.58)	SST57 (12.09)	Kariega (11.25)
10	SST876 (12.42)	T4 (10.70)	SST876 (11.44)	T4 (12.16)	SST876 (11.47)	SST876 (10.75)
11	T4 (12.05)	Kariega (10.64)	T4 (10.79)	SST876 (11.91)	T4 (11.43)	T4 (10.23)
Mean	13.12	12.22	11.97	12.97	12.36	11.36

Grand mean = 12.33 LSD (0.05): treatment = 0.26 . environment = 0.862

The AMMI biplot for genotype and environment means (Figure 4.1.12) shows high environment interaction for Kariega and to a lesser extent Palmiet and SST876. Kariega ranked first and second at Hopetown and Douglas respectively, but intermediate to very low in other locations. Palmiet ranked first at BullHill, third in three locations but intermediate to low at Douglas and Hopetown. SST876 ranked eighth at Barkly West, but together with T4 it seems to have low genetic potential compared to others. Other genotypes proved to be stable and therefore they may give reliable ranking at all locations.

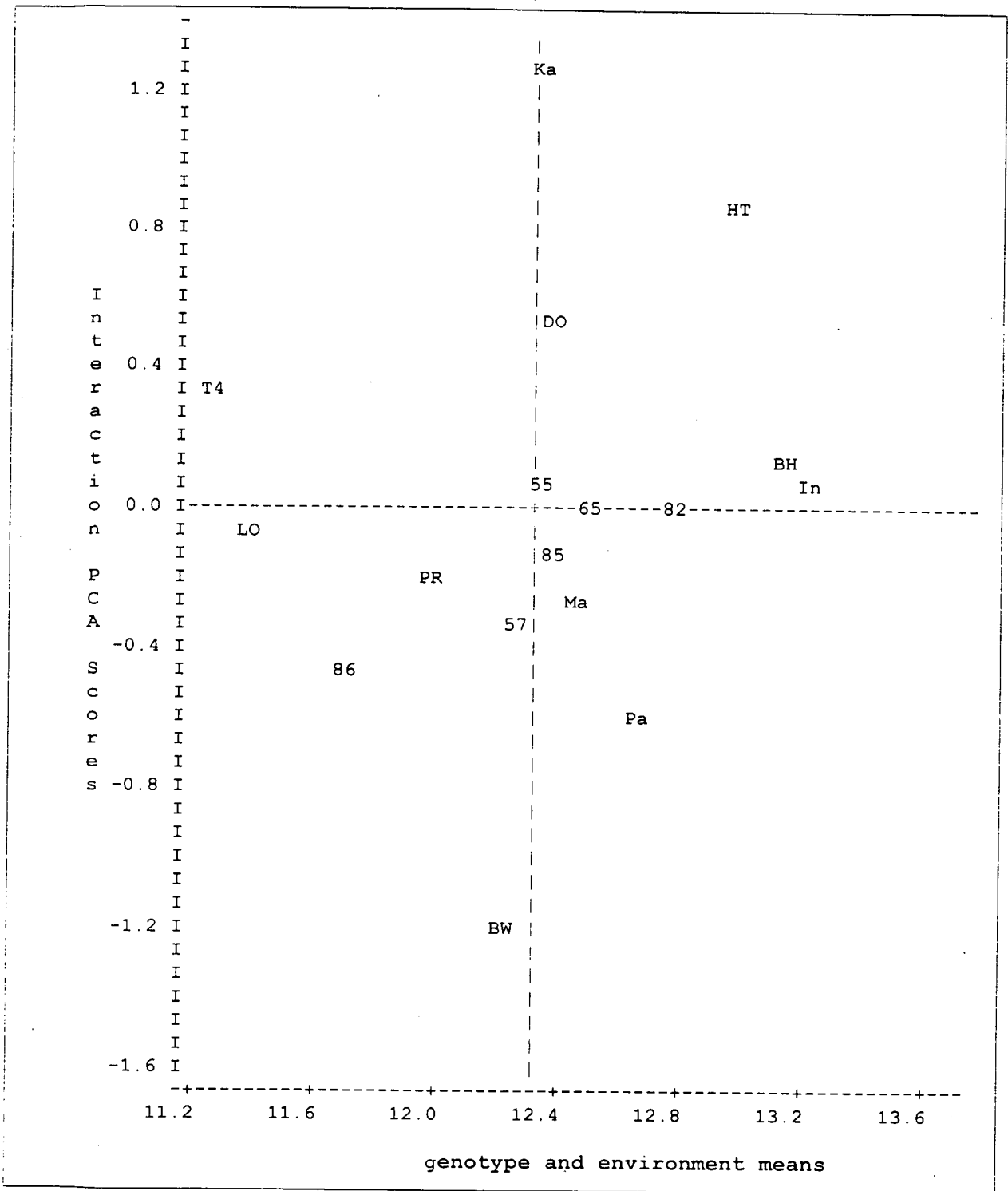


Figure 4.1.12 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at six localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for grain protein content - WH in 1997.

The locations (Figure 4.1.12) show genotype interaction at Barkly West, Hopetown and less at Douglas. Interaction at Barkly West was due to Palmiet, SST57 and SST876, which ranked higher at this location than at others, whereas for the other two interaction was due to Kariega. Other locations showed stability with BullHill having far higher values and Loskop far lower values than the mean.

In summary, Kariega may be expected to perform well at Hopetown and Douglas but the results in these two sites should not be generalised to other sites. However, other genotypes may give reliable ranking at all locations. For the locations, nearly all may give reliable ranking but at Hopetown and Barkly West care must be taken on the results of SST57, SST876 and Kariega respectively.

Loaf volume at 12% protein content

Most of the wheat flour characteristics (physical and chemical) are optimally observed at 12% protein content. According to Finney *et al.* (1987) and Van Lill *et al.* (1985a & b), the main indicators of baking quality include loaf volume and water absorption. Loaf volume as determined by rapeseed displacement (Shogren and Finney, 1984) gives an indication of the gas retention capacity of the dough. The analysis of variance results (Table 4.1.25) shows that treatments, main sources of variation (environment and genotype), interaction, IPCA as well as residual were highly significant. This indicates different genotype performance, varying growth conditions among locations as well as presence of specific interactions between genotypes and environments for this parameter. The block effect was not significant and this implies absence of variations for particular genotypes within locations. This shows the parameter to be less sensitive to environmental variations and that is why genotype and particularly interaction had more effects. The significant residual implies presence of noise; nevertheless the IPCA1 explained a large percentage (50.9) of the interaction effect. The environment contribution to the variation in loaf volume was 17.5%, which was less, compared to other sources of variation. This may be from the fact that moisture stress was almost minimized as Nel *et al.* (1998c), found it to be 8.3% under rain-fed conditions. The genotype contribution to the variation was 27.3% and that of interaction was 38.6%. The interaction contribution was higher than the main sources of variation, and of that the IPCA captured 51.9% (Table 4.1.25). This shows that in addition to genotype effects, the interaction had more influence on loaf volume and the highly significant residual indicates larger effects of other IPCA-axis.

Table 4.1.25 Analysis of variance results for loaf volume at 12% protein content in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	1049392	5327			
Treatment	65	875909	13476	10.26	0.000	
Environment (E)	5	184101	36820	28.04	0.000	17.5
Block	12	15891	1324	1.01	0.446	
Genotype (G)	10	286701	28670	21.83	0.000	27.3
G × E	50	405106	8102	6.17	0.000	38.6
IPCA	14	210340	15024	11.44	0.000	51.9
Residual	36	194767	5410	4.12	0.000	
Error	120	157592	1313			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G × E) } = (SS for Genotype, Environment or G × E / SS for total) × 100

IPCA = (SS for IPCA / SS for G × E) × 100

The environment means ranged between 901.0 to 989.8 at Barkly West and Hopetown respectively, with a grand mean of 935.4. A general observation from the means and biplot shows at least three groups of environments. Hopetown had the highest mean and most of the genotypes performed well as indicated by the low variance in this location. The second group with slightly higher means includes Loskop and Douglas, however, Douglas showed more contrast with other locations due to higher interaction and variance as that is where the genotypes with highest and lowest values were found. The other three sites (BullHill, Prieska and Barkly West) were below the mean with Barkly West being much lower. The genotype means (Appendix 1) ranged between 838.7 to 974.1 for T4 and Inia respectively. According to genotype main effect at least four groups were observed. The first consists of Inia, SST65 and SST55, which had means far above the grand mean and ranked higher in most locations, showing a wide adaptability for this parameter. The second group comprised of Palmiet, Kariega, SST822, SST825 and Marico, which had means close to and slightly higher to the grand mean. However the interaction effect made some genotypes in this group to rank lower in some locations. The third group included SST876, SST57 and the fourth group T4 that ranked below the grand mean.

Table 4.1.26 Ranking of genotypes in each location for loaf volume at 12% protein content and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	Inia (962.3)	Inia (940.1)	Inia (942.7)	Inia (1028.7)	SST55 (1042.5)	Inia (986.2)
2	SST65 (959.0)	SST65 (932.3)	SST65 (936.1)	SST65 (1024.9)	SST65 (1016.7)	SST65 (982.7)
3	SST55 (947.8)	Palmiet (924.6)	Palmiet (926.5)	SST55 (1013.2)	Marico (1008.7)	SST55 (971.3)
4	Palmiet (943.9)	SST55 (916.3)	SST55 (921.3)	Palmiet (1010.6)	Kariega (994.0)	Palmiet (967.3)
5	Kariega (934.7)	SST876 (916.1)	SST876 (914.1)	Kariega (1000.6)	SST822 (989.1)	Kariega (958.4)
6	SST822 (927.3)	Kariega (907.7)	Kariega (911.6)	SST822 (993.1)	Inia (984.4)	SST822 (951.0)
7	SST825 (926.0)	SST57 (907.0)	SST825 (908.6)	SST825 (992.8)	T4 (948.8)	SST825 (950.0)
8	SST876 (920.0)	SST825 (906.7)	SST57 (904.4)	SST876 (988.5)	Palmiet (943.5)	SST876 (944.7)
9	Marico (915.8)	SST822 (900.0)	SST822 (903.9)	Marico (981.2)	SST825 (925.8)	Marico (939.3)
10	SST57 (908.4)	Marico (884.5)	Marico (889.4)	SST57 (977.1)	SST876 (799.6)	SST57 (933.1)
11	T4 (812.5)	T4 (775.7)	T4 (782.0)	T4 (877.3)	SST57 (767.6)	T4 (835.8)
Mean	923.4	901.0	903.7	989.8	947.3	947.3

Grand mean = 935.42 LSD (0.05): treatment = 12.49 , environment = 41.42

The AMMI biplot for genotype and environment means (Figure 4.1.13) showed stability for about five genotypes at most locations. High environment interaction was shown for SST57, SST876, and T4 and to a lesser extent SST55, Marico and SST822. SST57 and SST876 ranked intermediate and slightly higher at Barkly West and Prieska respectively, but low to very low at other locations. It was also at these two locations where SST822 ranked very low but it ranked intermediate at other locations. At Douglas SST55, Marico and T4 ranked first, second and seventh respectively. However, except for SST55 that also ranked higher at other locations Marico and T4 were very low and last respectively at other sites (Table 4.1.26). This agrees with the well known linear correlation, which exists between protein content, and loaf volume (Finney, 1945) as was revealed by genotypes, which had intermediate to high protein content. However, since protein quality also has an influence (Finney *et al.*, 1987) this was revealed by genotypes like SST822, SST825 and SST57 which had high to intermediate protein contents but showed intermediate to low loaf volumes, implying poorer protein quality. Marico and T4 proved to have lower potential for both protein content and quality, whereas Inia, SST65, Palmiet, SST55 and Kariega proved to have high quality potential. Therefore despite these genotypes having low protein contents at some locations, the loaf volume may be maintained due to good protein quality. Although high water absorption also indicates high loaf volume (Finney *et al.*, 1987; Van Lill *et al.*, 1995a & b), in this study most of the genotypes that showed higher water absorption had low to very low loaf volumes (Tables 4.1.22 and 4.1.26). This signifies the importance of protein quality in addition to protein content and water absorption when considering loaf volume.

Douglas (Figure 4.1.13) showed very high interaction with genotypes, which contrasts this location from others. This was from the fact that genotypes like Inia, Palmiet and SST825 which ranked

first, higher and intermediate respectively at other locations ranked below the middle at this location.

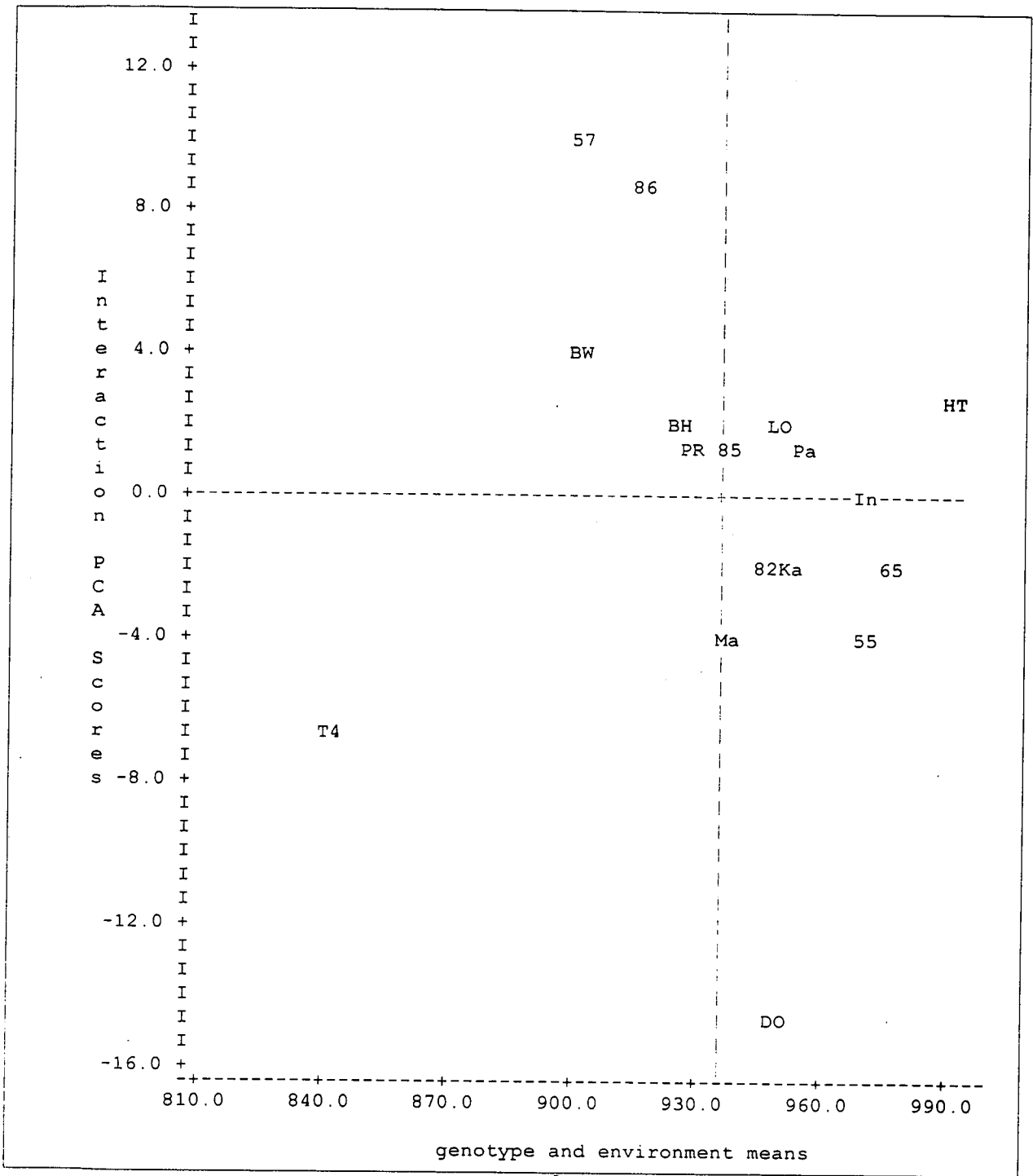


Figure 4.1.13 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at six localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hepetown, DO = Douglas and LO = Loskop) for loaf volume at 12% protein content in 1997.

Marico and T4 which ranked very low in other locations ranked third and seventh respectively at this location (Table 4.1.26).

In conclusion we can say all genotypes except T4, Marico, SST57 and SST876 may give reliable ranking at most of the locations. For the locations, reliable ranking are expected at all sites, except Douglas which showed much contrast due to genotype interactions and the results for genotypes like SST55, Marico, Inia, T4 and Palmiet obtained at this location must not be generalised to other sites.

Sodium dodecyl sulphate (SDS) – sedimentation

The SDS – sedimentation is used for measuring relative gluten strength as it indicates differences in the quantities of the polymeric glutenins (gel protein). Sedimentation values can range from 20 or less for low – protein wheat of inferior bread baking strength to as high as 70 or more for high – protein wheat of superior bread-baking strength. The analysis of variance results (Table 4.1.27) shows significant F-values for treatments, environments, genotypes, interaction and IPCA. The block effect was significant at $p < 0.05$. This indicates different genotype performance and varying growth conditions among and within locations. The residual was significant at $p < 0.01$ implying presence of noise effect. The environment contribution to the variation was 24.6%. However, the genotype contribution to the total variation was 55.0%, higher than environment and interaction effects. This is from the fact that according to János (1998), the SDS-sedimentation volumes are considered to be a relatively stable quality feature, not very sensitive to environmental effects and highly heritable. Despite slight interaction observed for two genotypes, most of them had similar values with slight genotype main effect differences. The interaction contributed 10.8% to the variation and out of this the IPCA captured 55.3%. This shows that main effect, especially genotype, had more influence on this parameter compared to loaf volume.

Table 4.1.27 Analysis of variance results for sodium dodecyl sulphate - sedimentation in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	14561	73.9			
Treatment	65	13164	202.5	20.69	0.000	
Environment (E)	5	3583	716.5	73.18	0.000	24.6
Block	12	222	18.5	1.89	0.042	
Genotype (G)	10	8007	800.7	81.78	0.000	55.0
G x E	50	1575	31.5	3.22	0.000	10.8
IPCA	14	871	62.2	6.36	0.000	55.3
Residual	36	703	19.5	1.99	0.003	
Error	120	1175	9.8			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The location means ranged between 53.70 to 66.56 at Prieska and Loskop respectively. Loskop had a SDS-sedimentation higher than the grand mean, whereas the remaining locations were close and Prieska slightly lower than the mean. Since SDS-sedimentation is more associated with polymeric glutenins (high molecular weight), the higher sedimentation realised at Loskop was due to the fact that the yields at this location were lower as revealed by kernel and hectolitre masses (Tables 4.1.4 and 4.1.6) and therefore protein content was less affected. According to MacDonald (1994) higher hectoliter mass or test weight is indicative of grain plumpness, following favourable growth conditions during grain filling (Evans *et al.*, 1975). However, at a site like Prieska the situation was the other way round, leading to low sedimentation values. Taking into account that high molecular weight - glutenins (HMW - GS) make up only 10% of the total gluten and only 1% of the whole endosperm (Pomeranz, 1988), higher sedimentation values may be realised even at poor grain filling environments. Therefore there is a need for SDS-sedimentation evaluation to be associated with good grain filling conditions, as most of the other quality parameters are also influenced by the effects of starch - protein interactions as seen earlier for vitreous kernels and SKCS-hardness index.

The genotype means (Appendix 1) ranged between 45.17 to 69.11 for T4 and Kariega respectively, which also showed contrast with other genotypes. Three genotype groups were realised. Kariega on its own ranked first at five locations with interactions showed at Hopetown and Douglas where it

had higher mean values compared to other genotypes. It was intermediate at Prieska. T4 on the other hand was last in five sites and second from last at Loskop. Together with SST876 and SST57 they ranked lower in all locations showing less potential for this parameter. Other genotypes showed stability and ranked intermediate to higher in most locations.

Table 4.1.28 Ranking of genotypes in each location for sodium dodecyl sulphate (SDS) – sedimentation and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	Kariega (70.42)	Kariega (64.72)	SST55 (60.73)	Kariega (79.92)	Kariega (66.92)	Kariega (76.41)
2	SST55 (61.67)	SST55 (62.01)	SST822 (60.58)	SST55 (63.22)	SST55 (60.12)	SST55 (72.12)
3	Inia (60.94)	SST822 (61.36)	Inia (59.32)	Inia (62.91)	Inia (59.29)	SST822 (71.36)
4	SST822 (60.59)	Inia (60.97)	SST65 (56.70)	Marico (62.05)	SST822 (59.18)	Inia (71.17)
5	Marico (58.57)	SST65 (58.25)	Kariega (56.28)	SST822 (61.59)	Marico (56.55)	SST65 (68.42)
6	SST65 (58.13)	Marico (57.45)	SST825 (54.62)	SST65 (58.98)	SST65 (56.51)	Marico (67.94)
7	SST825 (55.66)	SST825 (55.95)	Marico (54.43)	SST825 (57.27)	SST825 (54.09)	SST825 (66.08)
8	Palmiet (53.72)	Palmiet (53.89)	Palmiet (52.40)	Palmiet (55.51)	Palmiet (52.11)	Palmiet (64.04)
9	SST57 (51.25)	SST57 (51.69)	SST57 (50.52)	SST57 (52.69)	SST57 (49.74)	SST57 (61.78)
10	SST876 (49.00)	SST876 (49.84)	SST876 (49.14)	T4 (52.12)	SST876 (47.61)	SST876 (59.82)
11	T4 (45.43)	T4 (41.87)	T4 (35.96)	SST876 (49.91)	T4 (42.62)	T4 (53.00)
Mean	56.85	56.18	53.70	59.74	54.98	66.56

Grand mean = 58.0 LSD (0.05): treatment = 1.079 , environment = 2.662

The AMMI biplot for genotype and environment means (Figure 4.1.14) shows high environment interaction for Kariega and T4, with other genotypes being stable. Locations (Figure 4.1.14) showed genotype interaction at Hopetown and Prieska. That of Hopetown may be due to Kariega and T4, which had higher values, compared to other sites, whereas at Prieska it was also Kariega which ranked intermediate compared to other sites where it was first. Therefore in conclusion, nearly all genotypes (except Kariega at Prieska where it ranked slightly lower), may give reliable ranking at all locations. This also applies to all locations but the results from Loskop need to be judged on the basis of other quality parameters such as mixograph development time and point score, alveograph strength and P/L ratio, farinograph absorption and loaf volume at 12% protein if they are also acceptable.

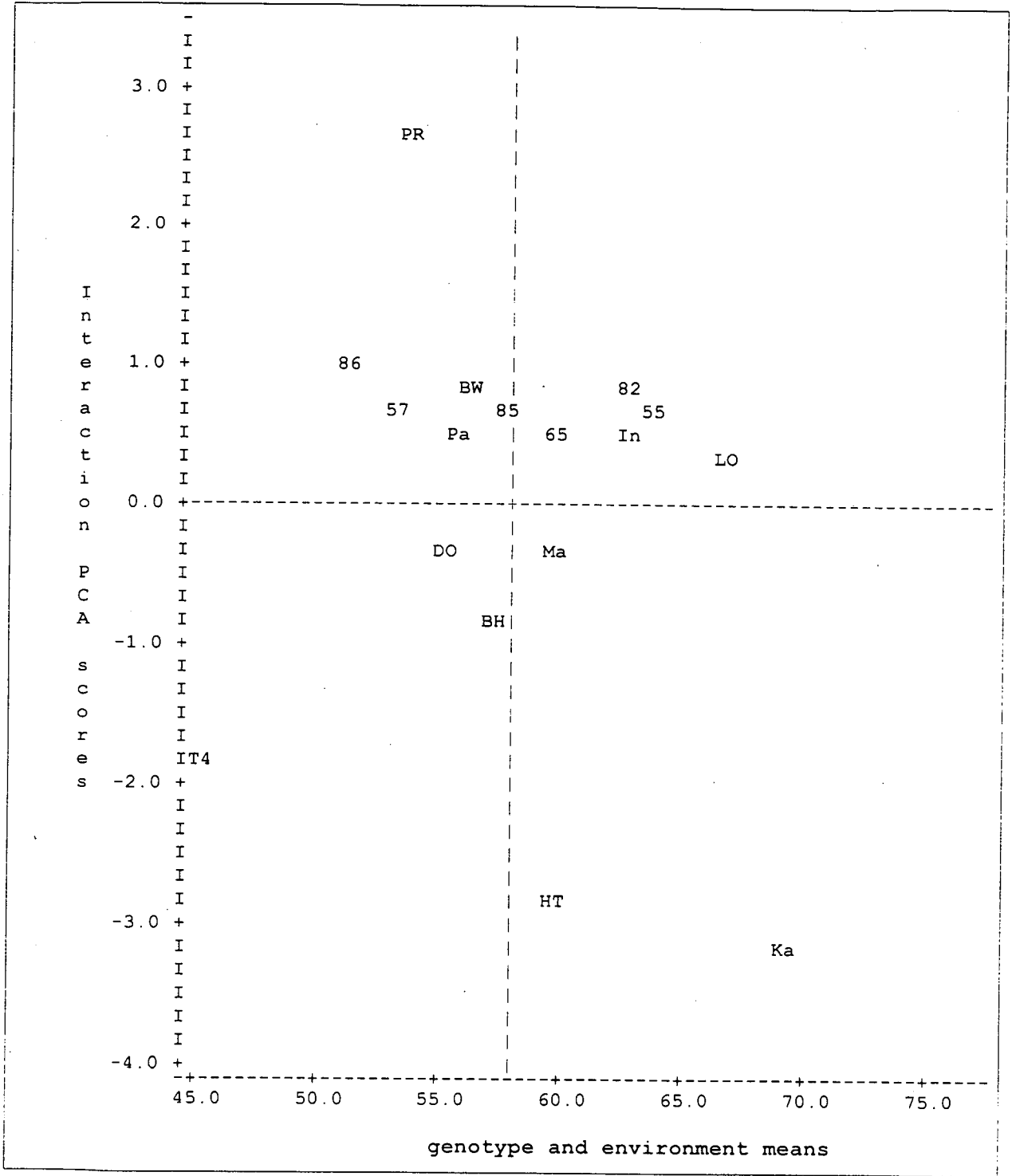


Figure 4.1.14 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825,b In = Inia, 86 = SST876 and 57 = SST57) at six localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for sodium dodecyl sulphate - sedimentation in 1997.

Wet gluten content at 12% protein content

Gluten is an insoluble wheat protein, which consists of gliadins and glutenins. The former are responsible for extensibility and viscosity of the dough, whereas the latter determines its elasticity (Colt, 1990; Shewry *et al.*, 1995). As seen from loaf volume and sedimentation, gluten proteins have major influence on breadmaking quality. The analysis of variance results (Table 4.1.29) shows that treatments, environments, genotypes, block effect, interaction as well as IPCA were highly significant. This indicates different genotype performance, varying growth conditions among and within locations as well as presence of specific interactions between genotypes and environments for this parameter. The significant block effect ($p < 0.001$) indicates presence of variations for particular genotypes even within a certain location. The residual was not significant and this shows absence of noise effect. The environment contribution to the variation was 15.0%, which was slightly higher for genotype, but less for interaction. This shows environment as one of the main effects than had more influence on gluten content than genotype, but still this was low when compared to rain-fed conditions, which was 86.6% (Nel *et al.*, 1998b). The genotype contribution to the variation was 12.2%, lower than both environment and interaction. Nevertheless this value was higher than that by Nel *et al.* (1998b) under rain-fed conditions, which was only 3.4%. This shows again a reduced environmental stress under irrigation for especially moisture. Nevertheless the lower genotype contribution to the variation was from the fact that gluten content (gliadin and glutenin) involves the main part of protein influencing quality and therefore it is liable to environmental and interaction influences more than genetic. The interaction contributed 23.0% to the variation, which was higher than both environment and genotype, and out of this the IPCA captured 50.7%. The non-significant residual also signifies that most of the interaction effects were explained by this axis. Therefore interaction was more responsible for the significant differences observed in both environments and genotypes.

The environment means ranged between 32.09% to 35.32% at Loskop and Hopetown respectively and there were two groups. The first group with means above the grand mean included, Hopetown, BullHill and Barkly West, which also showed high variance implying a big range between genotypes with high and low values. The second group that was below the mean included Douglas, Prieska and Loskop. However, the range between the lower and higher means was not so large and therefore the highly significant environmental effect was due more to interaction effects. The genotype means (Appendix 1) ranged between 30.97% to 34.99% for Marico and Inia respectively. At least three groups of genotypes were observed on the basis of their main effects. The first group with means above the grand mean included; SST876, SST55, SST822, SST825, SST65 and Inia, with the first two and the last showing slight interactions. The second group with means close to the grand mean comprised of, Kariega, Palmiet and SST57, whereby the first two

showed high and the last slight interactions. The last group with means far below grand mean was T4 and Marico. T4 showed slight interaction.

Table 4.1.29 Analysis of variance results for wet gluten content at 12% protein content in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	97	2050.4	10.41			
Treatment	65	1030.3	15.85	3.355	0.000	
Environment (E)	5	307.8	61.57	13.031	0.000	15.0
Block	12	453.2	37.77	7.993	0.000	
Genotype (G)	10	250.8	25.08	5.308	0.000	12.2
G x E	50	471.6	9.43	1.996	0.001	23.0
IPCA	14	239.3	17.10	3.618	0.000	50.7
Residual	36	232.3	6.45	1.366	0.108	
Error	120	567.0	4.39			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The AMMI biplot for genotype and environment means (Figure 4.1.15) shows high environment interaction for Karioga followed by T4, Palmiet and to a lesser extent Inia, SST876, SST57 and SST55. Karioga showed very low rank at two locations and it ranked last at one but it was first and third at Hopetown and BullHill respectively. T4 on its own showed slightly higher rank (below the middle) at Hopetown but together with Marico which was stable but with low mean they ranked last at most of the locations. These two together with Karioga showed much contrast to others. Most of the interaction for the rest was realised at Barkly West. Palmiet ranked first at this location but below the middle to very low at other sites. SST876 and SST55 ranked second and third respectively at Barkly West with the former also above intermediate at Prieska but in other locations they were all intermediate to lower. SST57 and T4 ranked fourth and sixth at Barkly West and Hopetown but they ranked very low at other locations. Therefore this shows that all these genotypes may not give reliable ranking at all sites. Inia on its own ranked first in four locations, second in one, but it was eighth at Barkly West (Table 4.1.30) showing negative environment interaction. Other genotypes like SST65, SST825 and SST822 showed stability with higher mean values, and together with Inia might give reliable rank at most locations.

Table 4.1.30 Ranking of genotypes in each location for wet gluten content at 12% protein content and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	Inia (36.45)	Palmiet (37.33)	Inia (33.59)	Kariega (39.08)	Inia (34.43)	Inia (33.30)
2	SST65 (35.94)	SST876 (36.80)	SST65 (33.44)	Inia (37.74)	SST65 (33.98)	SST65 (33.08)
3	Kariega (35.82)	SST55 (36.21)	SST825 (33.25)	SST65 (36.60)	SST825 (33.65)	SST825 (32.86)
4	SST825 (35.57)	SST57 (35.76)	SST876 (33.22)	SST825 (35.93)	Kariega (33.57)	SST822 (32.79)
5	SST822 (35.45)	SST822 (35.53)	SST822 (33.18)	SST822 (35.71)	SST822 (33.54)	SST876 (32.75)
6	SST876 (35.01)	SST825 (35.45)	SST55 (32.99)	T4 (35.67)	SST876 (33.20)	SST55 (32.54)
7	SST55 (34.91)	SST65 (35.19)	Palmiet (32.73)	SST55 (34.58)	SST55 (33.07)	Palmiet (32.19)
8	SST57 (34.19)	Inia (34.43)	SST57 (32.34)	SST876 (34.45)	Palmiet (32.39)	SST57 (31.88)
9	Palmiet (34.12)	Marico (32.29)	Kariega (31.82)	SST57 (33.73)	SST57 (32.36)	Kariega (31.72)
10	T4 (33.86)	T4 (30.75)	T4 (30.70)	Palmiet (32.86)	T4 (31.77)	T4 (30.45)
11	Marico (32.01)	Kariega (29.73)	Marico (29.80)	Marico (32.18)	Marico (30.12)	Marico (29.40)
Mean	34.85	34.50	32.46	35.32	32.92	32.09

Grand mean = 33.69 LSD (0.05) : treatment = 0.749 , environment = 2.484

Locations (Figure 4.1.15) showed high genotype interaction at Hopetown, Barkly West and to a lesser extent BullHill. Kariega and T4 showed environment interaction at Hopetown with Kariega also contributing to interaction at BullHill. Palmiet, SST876, SST55, SST57 and Inia were responsible for interaction at Barkly West with the former four showing positive and the last negative interactions. Besides showing interactions all three locations proved to have higher environment main effects as they were above the mean. The other three sites showed stability but with lower main effects as they were all below the mean, especially Loskop.

In conclusion we can say, except for SST65, SST825 and SST822 others cultivars may not give reliable ranking at the three locations where they showed different interactions. Palmiet as such, SST876 and SST55 performed well and may be included as references at Barkly West but together with SST57 and Inia their results at this location must not be generalised to other sites. Kariega also may be taken as a reference at Hopetown and BullHill but together with T4 at Hopetown their results should not be generalised to other locations. For the locations, nearly all may give reliable ranking except for Hopetown and Barkly West, where higher environment interactions were observed with some genotypes.

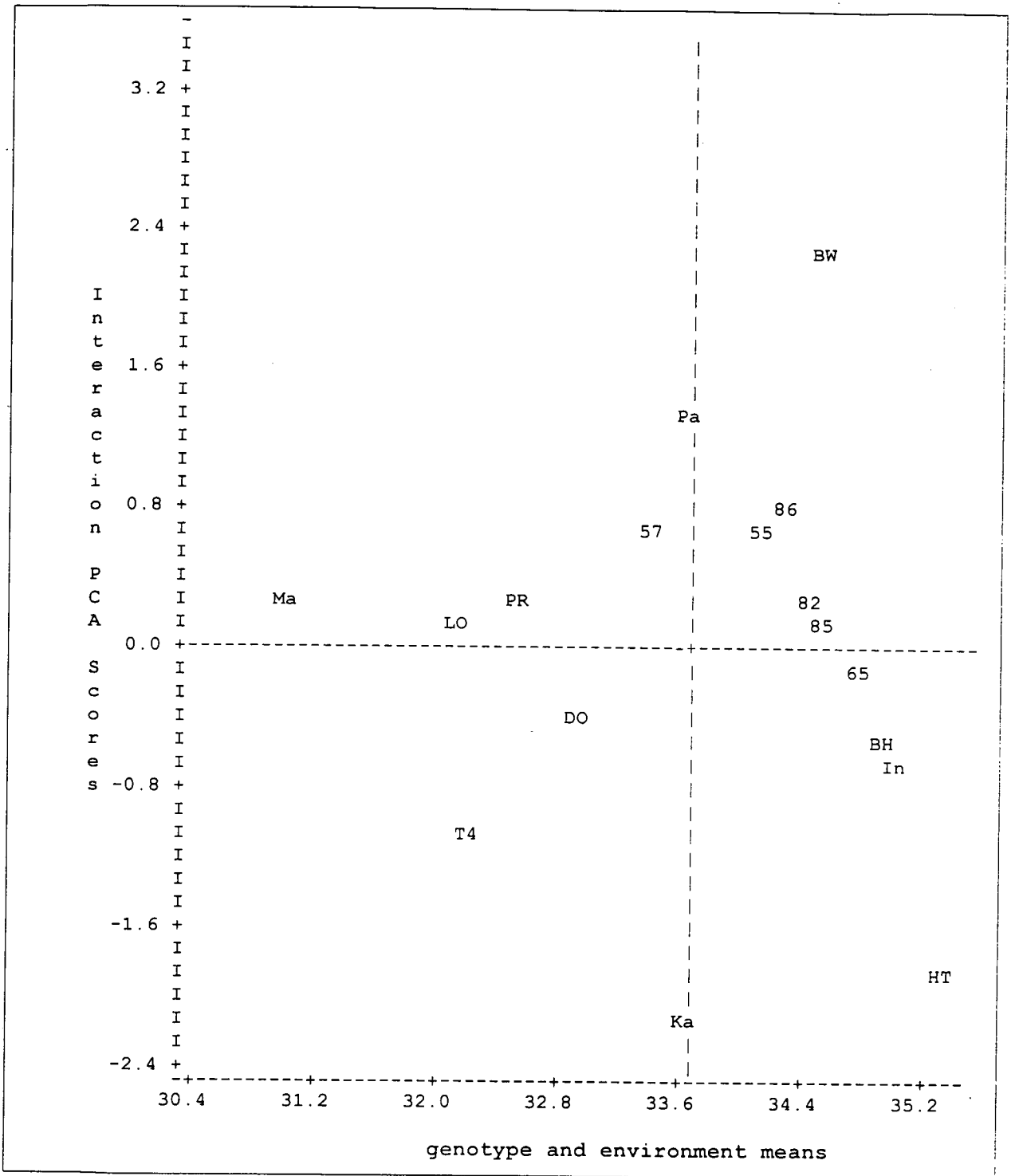


Figure 4.1.15 AMMI biplot of genotype and environment IPCA1 scores versus means For eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T₄ = T₄, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at six localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for wet gluten content at 12% protein in 1997.

Falling number

Falling number (in seconds) gives an indication as to what extent starch has been converted to sugar in the wheat grain, as determined by the alpha-amylase concentration (Hagberg, 1960). Usually values less than 250 s indicate flour that will be unacceptable for bread-baking purposes (Van Lill and Smith, 1997). The analysis of variance results (Table 4.1.31) show highly significant F-values for only interaction and the IPCA. The significance of treatment effect ($p < 0.01$) for this parameter was therefore due to highly significant interaction and IPCA. The environments, genotypes, block effect and residual were non-significant. The higher mean values exceeding the minimum required value for both environments and genotypes were similar to the results by Nel *et al.* (1998c). Nevertheless the higher variances at all sites, especially Prieska and Hopetown show different genotype performance in each location and thus gave a big range between the lowest and the highest in rank. The environment contribution to the variation was 1.3%, which was much lower, compared to the result by Nel *et al.* (1998c), which was 47.1%. This shows that environmental conditions, especially rain, is more associated with falling number due to sprouting effect. The genotype contribution to the variation was 6.1%, slightly higher than that reported by Nel *et al.* (1998c) which was 4.4%. This shows that with reduced moisture stress, genotypes were able to show their potential. The contribution of interaction to the variation was 40.4% showing that most of the variations in falling number were due to interaction effects. This agrees with the results by Baker and Kosmolak (1977) and also that by Nel *et al.* (1998c) who reported a value of 48.7%. Of the interaction effect the IPCA explained 49.7% of the variation.

Table 4.1.31 Analysis of variance results for falling number in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	165974	843			
Treatment	65	79478	1223	1.870	0.002	
Environment (E)	5	2198	440	0.672	0.645	1.3
Block	12	8018	668	1.022	0.434	
Genotype (G)	10	10179	1018	1.556	0.128	6.1
G x E	50	67102	1342	2.052	0.001	40.4
IPCA	14	33383	2384	3.646	0.000	49.7
Residual	36	33719	937	1.432	0.078	
Error	120	78478	654			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 4.1.32) ranged between 281.3 s to 291.7 s at Barkly West and BullHill respectively, showing a very small difference. Therefore for environment main effect it was only BullHill and Prieska, which showed to be above, and Barkly West below the mean. In general almost all sites had the same effect. The genotype means ranged between 277.2 s to 302.1 s for SST876 and SST57 respectively. Genotypes ranking higher showed more environment interactions (Appendix 1). From genotype main effect at least three groups were observed; those with means higher than the grand mean which include, SST57, Marico and SST825. The second group had means very close to the grand mean such as Palmiet, SST822, Kariega, Inia and SST65. The third group had means far below the grand mean, which included T4, SST55 and SST876.

Table 4.1.32 Ranking of genotypes in each location for falling number and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	SST57 (316.4)	Marico (293.9)	SST57 (329.5)	Marico (343.1)	SST57 (312.7)	Marico (312.0)
2	SST825 (306.4)	SST57 (293.5)	SST825 (318.2)	SST65 (304.6)	SST825 (302.5)	SST57 (291.3)
3	Palmiet (300.4)	SST825 (284.6)	Palmiet (310.2)	Inia (301.9)	Palmiet (296.1)	SST65 (291.1)
4	SST822 (295.4)	SST822 (282.3)	SST822 (296.9)	Kariega (294.0)	SST822 (289.7)	Inia (290.9)
5	Kariega (288.5)	Kariega (281.2)	SST876 (284.2)	T4 (283.3)	Kariega (281.6)	Kariega (289.3)
6	Marico (285.9)	Inia (280.5)	Kariega (283.2)	SST822 (281.2)	SST876 (277.6)	SST822 (286.5)
7	Inia (284.1)	Palmiet (280.1)	T4 (280.9)	SST55 (280.1)	T4 (277.5)	SST825 (283.2)
8	T4 (284.0)	SST65 (279.7)	SST55 (280.3)	SST876 (271.5)	Inia (276.5)	T4 (281.7)
9	SST876 (283.4)	T4 (274.9)	Inia (274.6)	SST57 (269.0)	SST55 (276.3)	Palmiet (279.8)
10	SST55 (282.7)	SST55 (273.0)	SST65 (270.7)	SST825 (262.8)	Marico (275.9)	SST55 (279.5)
11	SST65 (281.9)	SST876 (271.0)	Marico (262.8)	Palmiet (262.2)	SST65 (274.0)	SST876 (275.7)
Mean	291.7	281.3	290.1	286.7	285.5	287.4

Grand mean = 287.12 LSD (0.05): treatment = 8.814 , environment = 29.234

The AMMI biplot for genotype and environment means (Figure 4.1.16) shows very high environment interaction for SST57 and Marico, followed by SST825, Palmiet and to a lesser extent SST65 and Inia. SST57 ranked first in three locations, second in two but very low at one. Marico ranked first at three, intermediate at one but last and second from last at other two sites. SST825 ranked second or third in four sites but below the middle and next from last at the other two sites. Palmiet ranked third at three sites, below middle at one and very low at two sites. SST65 ranked second and third at two locations but very low to last at four sites. Inia ranked close to the middle at four sites but very low at other two. Other genotypes like Kariega, SST822, T4, SST55 and SST876 were stable. T4, SST55 and SST876 had lower values compared to others, although it was still above the recommended value (Table 4.1.32).

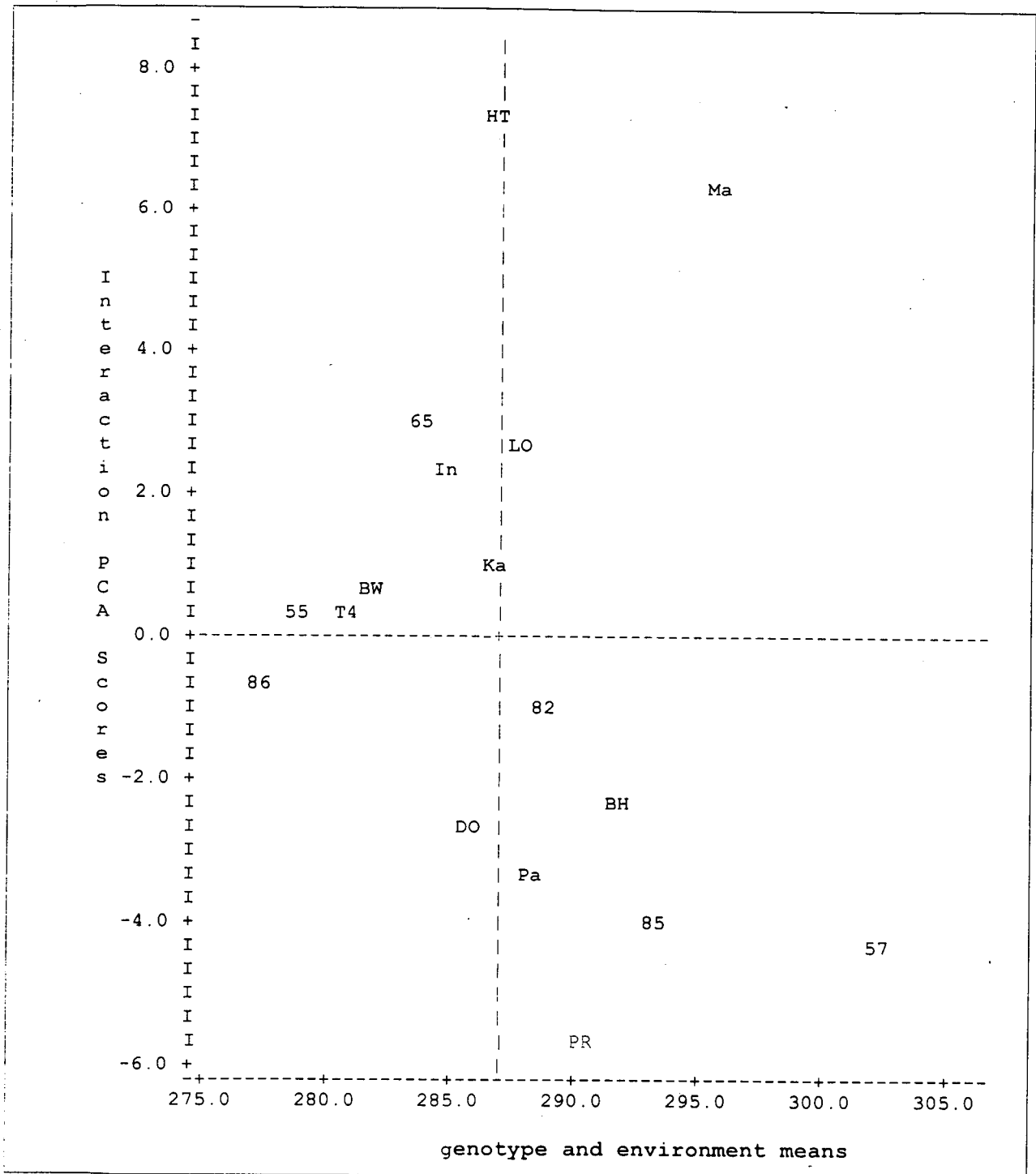


Figure 4.1.16 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at six localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for falling number in 1997.

Higher genotype interaction was shown at Hopetown, Prieska and to a lesser extent Douglas, BullHill and Loskop, with Barkly West being stable (Figure 4.1.16).

In summary, for the genotypes reliable ranking may be achieved for stable cultivars. For those which showed environment interaction, care must be taken in sites where the interaction was more, not to be generalised to other locations. For the locations reliable ranking could be expected at Barkly West but for other sites interaction effects should be considered. However, since all genotypes and locations had values above the minimum requirement, this shows absence of alpha-amylase activity. This is also confirmed by loaf volume, which is influenced by falling number. The results showed despite a genotype having a lower falling number it was capable of giving higher loaf volume provided it has high protein content with good quality. Therefore this confirms that if falling number values are above the recommended value their influence is negligible and only protein related characteristics need to be monitored.

Mixograph development time

Before the baking process wheat flour needs to be mixed with a given amount of water and other ingredients to form dough. During dough mixing, the resistance of the system to extension increases progressively until the point of minimum mobility is reached. This is referred to as the dough development time and is considered as the point where dough is optimally mixed (Finney *et al.*, 1987). The mixograph mixing time (in minutes) indicates the rate at which the flour and water are blended together into a quasi-homogeneous mixture. By that time a gluten matrix is developed, so as to incorporate air during fermentation (Spies, 1990). The method proved to be valuable in the selection of wheat cultivars with superior quality (Van Lill and Purchase, 1995). Taking South Africa as an example a mixing time of 2.5 to 3 min is recommended by the baking industry. The optimum mixing time of 2.5 min, however, is strongly influenced by both the protein content and oxidation ability of the flour (Finney and Yamazaki, 1967).

The analysis of variance results (Table 4.1.33) shows that treatments, environments, genotypes, interaction, IPCA as well as residual were highly significant. This indicates different genotype performance, varying growth conditions among locations as well as presence of specific interactions between genotypes and environments for this parameter. The block effect was not significant and this implies absence of variations for particular genotypes within locations. This is from the fact that, although the parameter is associated with protein content, however, it is largely genetically controlled. As a result this may not be influenced by small environment variations within locations for particular genotypes. The significant residual implies presence of noise; nevertheless the IPCA1 explained a very high percentage (91.4) of the interaction effect. The

contribution of environment to the variation was 33.8%, slightly higher than interaction but below that of genotype. The observed higher environmental contribution may be due to Loskop which showed higher mixing time to some of the genotypes and this made it contrast more with other locations. However, this was still low compared to that of Nel *et al.* (1998b) under rain-fed conditions which was 69.6%. Genotype contribution to the variation in mixing time was 35.4%, higher than both environment and interaction (Table 4.1.33). Van Lill (1992) who also noted that mixograph-mixing requirements were largely genetically determined supports this. However, this was higher compared to that under rain-fed conditions by Nel *et al.* (1998b) which was 14.5%, showing reduced stress under irrigation for especially moisture. The interaction contribution to the variation was 27.7%, slightly higher. Of this the IPCA captured 91.4%. This shows that, much of the interaction effect was explained by the IPCA1 despite the residual showing high significance.

Table 4.1.33 Analysis of variance results for mixograph development time in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	244.92	1.243			
Treatment	65	237.39	3.652	68.33	0.000	
Environment (E)	5	82.71	16.541	309.48	0.000	33.8
Block	12	1.12	0.093	1.75	0.065	
Genotype (G)	10	86.76	8.676	162.31	0.000	35.4
G x E	50	67.92	1.358	25.42	0.000	27.7
IPCA	14	62.07	4.434	82.95	0.000	91.4
Residual	36	5.85	0.163	3.04	0.000	
Error	120	6.41	0.053			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means ranged between 2.07 min to 3.95 min at Prieska and Loskop respectively, with a grand mean of 2.54 min, almost optimum. Apart from Loskop, other locations were very similar to each other with means below the optimum value and yet two groups were identified. Hopetown and Barkly West had means closer to the optimum value and more than half of the genotypes had values above optimum. Douglas, BullHill and Prieska had values much lower than optimum and also very few (less than half) genotypes had means above the optimum. In all locations it shows that both protein content and quality was responsible for the realised higher or low mixing time. Loskop, had very low protein contents as shown by the grain method (Table 4.1.24). According to Van Lill (1992) low flour protein content appeared to increase mixograph

mixing time requirement. Again on the basis of quality, this location had lower gluten content compared to other sites. Percentage of protein present as gliadin and non-gluten is more sensitive to environmental fluctuations (Robert *et al.*, 1996). The high temperature at this location may have affected quality in terms of glutenin-to-gliadin ratio, visco-elasticity and thus complete dough behaviour. For the other locations it seems protein quality was not much affected but low protein due probably to higher yield and poor soil fertility, may have been the major cause of the low mixing time. According to Van Lill and Purchase (1995) for winter wheat, increased values for mixograph dough development time were associated with favourable growth conditions during grain filling.

The genotype means (Appendix 1) ranged between 1.26 min to 3.86 min for T4 and Marico respectively and at least three groups were realised. Marico and SST57 had higher mixing times and were above the recommended value, but this was due to higher environment interactions observed at Loskop. The second group included Inia, SST822, SST825, Kariega and Palmiet, which were close and above the mean and almost within the recommended range. SST55, SST822, SST825 and T4 were below the SST mean and thus optimum value.

Table 4.1.34 Ranking of genotypes in each location for mixograph development time (minutes) and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	Marico (3.17)	Marico (3.37)	Marico (3.28)	Marico (2.92)	Marico (3.09)	SST57 (7.49)
2	Inia (2.56)	Inia (2.84)	SST57 (2.61)	Inia (2.75)	Inia (2.56)	Marico (7.35)
3	SST57 (2.42)	SST822 (2.67)	Inia (2.46)	SST822 (2.58)	SST822 (2.39)	Inia (4.35)
4	SST822 (2.93)	SST825 (2.62)	SST822 (2.29)	Palmiet (2.57)	SST825 (3.91)	SST822 (4.19)
5	SST825 (2.34)	SST57 (2.59)	SST825 (2.21)	SST825 (2.57)	SST57 (2.31)	SST825 (3.91)
6	Kariega (2.28)	Kariega (2.57)	Kariega (2.14)	Kariega (2.55)	Kariega (2.30)	Kariega (3.63)
7	Palmiet (2.25)	Palmiet (2.55)	Palmiet (2.07)	SST65 (2.27)	Palmiet (2.27)	Palmiet (3.28)
8	SST55 (1.88)	SST55 (2.19)	SST55 (1.70)	SST55 (2.23)	SST55 (1.91)	SST55 (2.83)
9	SST65 (1.85)	SST65 (2.17)	SST65 (1.63)	SST876 (2.20)	SST65 (1.89)	SST876 (2.39)
10	SST876 (1.79)	SST876 (2.11)	SST876 (1.58)	SST57 (2.00)	SST876 (1.83)	SST65 (2.36)
11	T4 (1.06)	T4 (1.38)	T4 (0.85)	T4 (1.46)	T4 (1.10)	T4 (1.72)
Mean	2.181	2.461	2.073	2.372	2.182	3.953

Grand mean = 2.54 LSD (0.05) : treatment = 0.079 , environment = 0.263

The AMMI biplot for genotype and environment means (Figure 4.1.17) shows high environment interaction for SST57 (negative), Marico (negative) and SST65 (positive). SST57 ranked first at Loskop, second and third at Prieska and BullHill respectively, intermediate in an other two sites but second from last at Hopetown, where it also had low protein content. Marico ranked first in five locations but second at Loskop. However, except Douglas where it was slightly below the

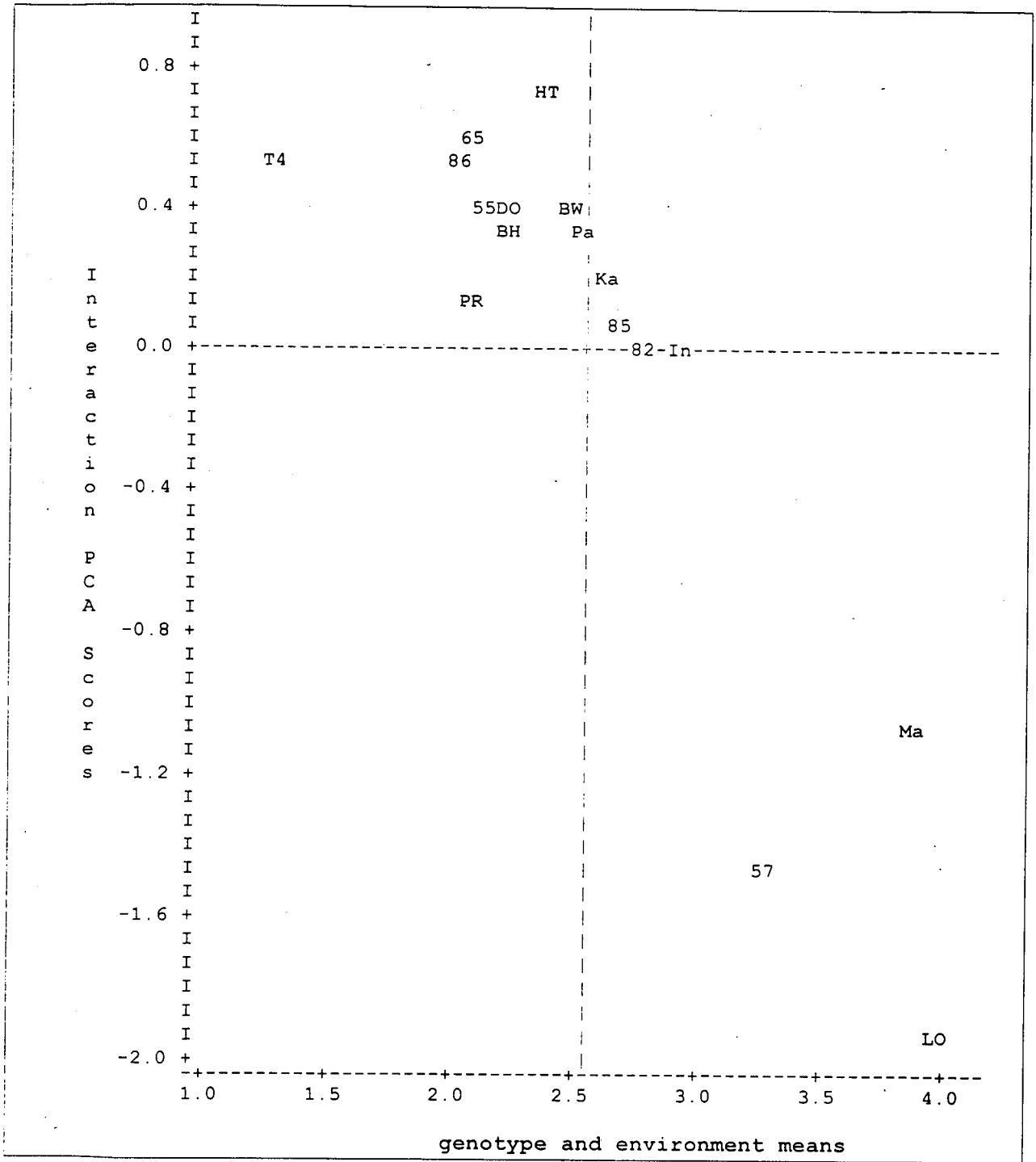


Figure 4.1.17 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST622, 85 = SST625, In = Inia, 86 = SST876 and 57 = SST57) at six localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for mixograph development time in 1997.

maximum limit, at other sites it was above the recommended value proving to be stronger (higher mixing time). SST65 ranked very low at most of the locations, except Hopetown where it was below intermediate. Other genotypes showed stability and may give reliable rank at all sites. The locations (Figure 4.1.17) showed very high and negative environment interaction at Loskop and only a slight positive interaction at Hopetown. Interaction of Loskop was due to its contrasting environmental conditions when compared to other locations and except for SST57, which ranked higher most of the genotypes ranked lower. Interaction of Hopetown was also due to SST57 which ranked lower with Palmiet and SST65 ranking higher compared to other locations.

In conclusion, for the genotypes except for SST57 (that needs to be monitored at Loskop, Hopetown and Prieska) others may give reliable ranking at all locations. However, those below the mean and especially T4 seems to be genetically inferior. For the locations except for Loskop, others may give reliable rank for most of the genotypes but Hopetown and Barkly West shows to be more ideal as most of the genotypes had values above the optimum.

Mixograph point score

The mixograph curve (mixogram) indicates optimum development time, tolerance to over-mixing (shown by angle between ascending and descending curve), descending graph width, peak height and other dough characteristics. The mixograph point score is one of the parameters used at the Small Grain Institute quality laboratory to evaluate mixograph curve (mixogram) by considering its general outlook using the above-mentioned characteristics. Therefore it adds information to the development time to assist in making selections and recommendations. Research showed that mixograph mixing time, peak height and bandwidth are dependent on both protein quality and quantity (Khathar *et al.*, 1994), which in turn is strongly influenced by the amount of fertilized nitrogen (Kilian *et al.*, 1990) as well as water stress (Neales *et al.*, 1963) and high temperatures (Campbell and Read, 1968) during kernel filling. The parameter uses a scale of 1 – 5, with 1 being poor; with a very short mixing time, early break-down, and thin break-down band. Scores 2 and 3 still have a short mixing time, less defined peak, flatter curve, and thin band. Score 4 is the ideal with ± 2.5 min mixing time, clearly defined peak, breakdown band not thin and breaks down gradually. Score 5 is over-stable, long mixing time which is difficult to determine and long flat mixogram. The analysis of variance results (Table 4.1.35) shows highly significant F-values for treatments, environments, genotypes, interaction, IPCA as well as residual. This was similar to that of development time. The block effect was not significant and this indicates absence of variations for particular genotypes within locations. This is due to the fact that the parameter is more genetically controlled than development time, and may not be influenced by small environment variations within locations for particular genotypes. The significant residual implies presence of

noise; nevertheless the IPCA1 explained a higher percentage (66.0) of the interaction effect. The environment and genotype contribution to the variation were 18.8% and 49.6% respectively. The interaction contributed 20.3% to the variation showing a larger influence than environment.

Table 4.1.35 Analysis of variance results for mixograph point score in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	456.9	2.319			
Treatment	65	405.4	6.237	15.82	0.000	
Environment (E)	5	85.9	17.179	43.59	0.000	18.8
Block	12	4.2	0.351	0.89	0.559	
Genotype (G)	10	226.7	22.674	57.53	0.000	49.6
G x E	50	92.7	1.855	4.71	0.000	20.3
IPCA	14	61.2	4.375	11.10	0.000	66.0
Residual	36	31.5	0.875	2.22	0.001	
Error	120	47.3	0.394			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means ranged between 2.09 to 4.24 for Prieska and Loskop respectively, with a grand mean of 3.07. At least three environmental groups were realised. Loskop that was slightly above ideal, Hopetown and Barkly West on a scale of 3 towards ideal. Douglas and BullHill very close to the scale of 3 whereas Prieska was at the scale of 2 far below the mean. However, the trend is similar to that in development time where Loskop contrasts, by more genotypes being over-stable. Hopetown and Barkly West had more genotypes slightly above and below the mean but close to ideal. Except for a few genotypes which didn't vary much with other sites and one interaction especially BullHill, and also Douglas had more genotypes at the scale of 3. At Prieska, except for one interaction and three genotypes which did not vary much with other sites, most of the genotypes were at the scale of 1.

The genotype means ranged between 1.00 to 4.89 for T4 and Marico respectively the same as for development time (Appendix 1). From genotype main effect, four groups were identified. Marico, which was above ideal and showed to be over-stable in some locations. The second group, which included Inia, SST822, SST825, Kariega, Palmiet and SST55, had means above the grand mean and most of them, except Palmiet, approached the ideal, but SST57 seems to contrast more due to

interaction. The third group with SST55, SST65 and SST876 had a mean below the grand mean and fell in the scale of 2, whereas T4 had the lowest mean and fell in the scale of 1.

Table 4.1.36 Ranking of genotypes in each location for mixograph point score and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	Marico (4.67)	Marico (5.03)	SST57 (5.27)	Kariega (4.62)	Marico (4.63)	Marico (5.90)
2	Inia (3.82)	Inia (4.31)	Marico (4.67)	Marico (4.42)	Inia (3.64)	Inia (5.27)
3	SST822 (3.38)	SST825 (3.93)	Inia (2.83)	Inia (4.40)	SST57 (3.58)	SST825 (4.93)
4	SST825 (3.37)	SST822 (3.89)	SST822 (2.30)	SST825 (4.35)	SST822 (3.19)	Kariega (4.93)
5	SST57 (3.36)	Kariega (3.88)	SST825 (1.91)	Palmiet (4.09)	SST825 (3.13)	SST822 (4.86)
6	Kariega (3.26)	Palmiet (3.66)	Palmiet (1.63)	SST822 (4.05)	Kariega (2.96)	Palmiet (4.66)
7	Palmiet (3.10)	SST57 (3.45)	Kariega (1.35)	SST55 (2.70)	Palmiet (2.86)	SST57 (4.15)
8	SST57 (3.45)	SST55 (2.46)	SST65 (1.01)	SST876 (2.64)	SST55 (1.73)	SST55 (3.44)
9	SST55 (2.46)	SST876 (2.31)	T4 (0.85)	SST65 (2.28)	SST65 (1.68)	SST876 (3.30)
10	SST876 (2.31)	SST65 (2.30)	SST55 (0.74)	SST57 (1.53)	SST876 (1.55)	SST65 (3.25)
11	T4 (0.78)	T4 (1.13)	SST876 (0.43)	T4 (0.49)	T4 (0.75)	T4 (2.00)
Mean	2.842	3.303	2.091	3.233	2.700	4.242

Grand mean = 3.07 LSD (0.05) : treatment = 0.216 , environment = 0.718

The AMMI biplot for genotype and environment means (Figure 4.1.18) shows high environment interaction for SST57 and Kariega. SST57 ranked first at Prieska, third at Douglas, second from last at Hopetown and below the middle at other locations. Kariega ranked close to the middle in most locations and first at Prieska. Others showed stability but genotype main effect still showed differences among them with Marico being far above and T4 far below the mean.

For the locations (Figure 4.1.18) it shows negative environment interaction at Prieska and positive at Hopetown. The effect at Hopetown was due to Kariega that ranked first but intermediate at other sites. For Prieska, SST57 ranked first, but intermediate to very low at other sites. Most of the genotypes showed very low values at this site compared to others. Consequently this site showed negative environment interaction. Other locations were more stable but again the higher scores realised at Loskop contrasts with other locations, even to those with interaction.

In conclusion, most of the genotypes were stable at most of the sites, except SST57, which showed both positive and negative environment interactions and care must be taken for this cultivar. The positive environment interaction for Kariega at Hopetown should not be generalised to other locations. Kariega together with Marico, Inia, SST822 and SST825 may be taken as references at most of the locations. All the locations except for Loskop and Prieska may give reliable ranking particularly Hopetown and Barkly West. The problem with Loskop is the less optimal environment that causes most of the genotypes to be over-stable. Therefore for this site

medium to less strong wheat may give good results. On the other hand for Prieska, probably due to high yields, and thus low protein levels, most of the genotypes appeared to be weak except those with stability and environment interaction. This site therefore needs mostly genotypes with an ideal score and soil management to improve fertility and fertilisation are important.

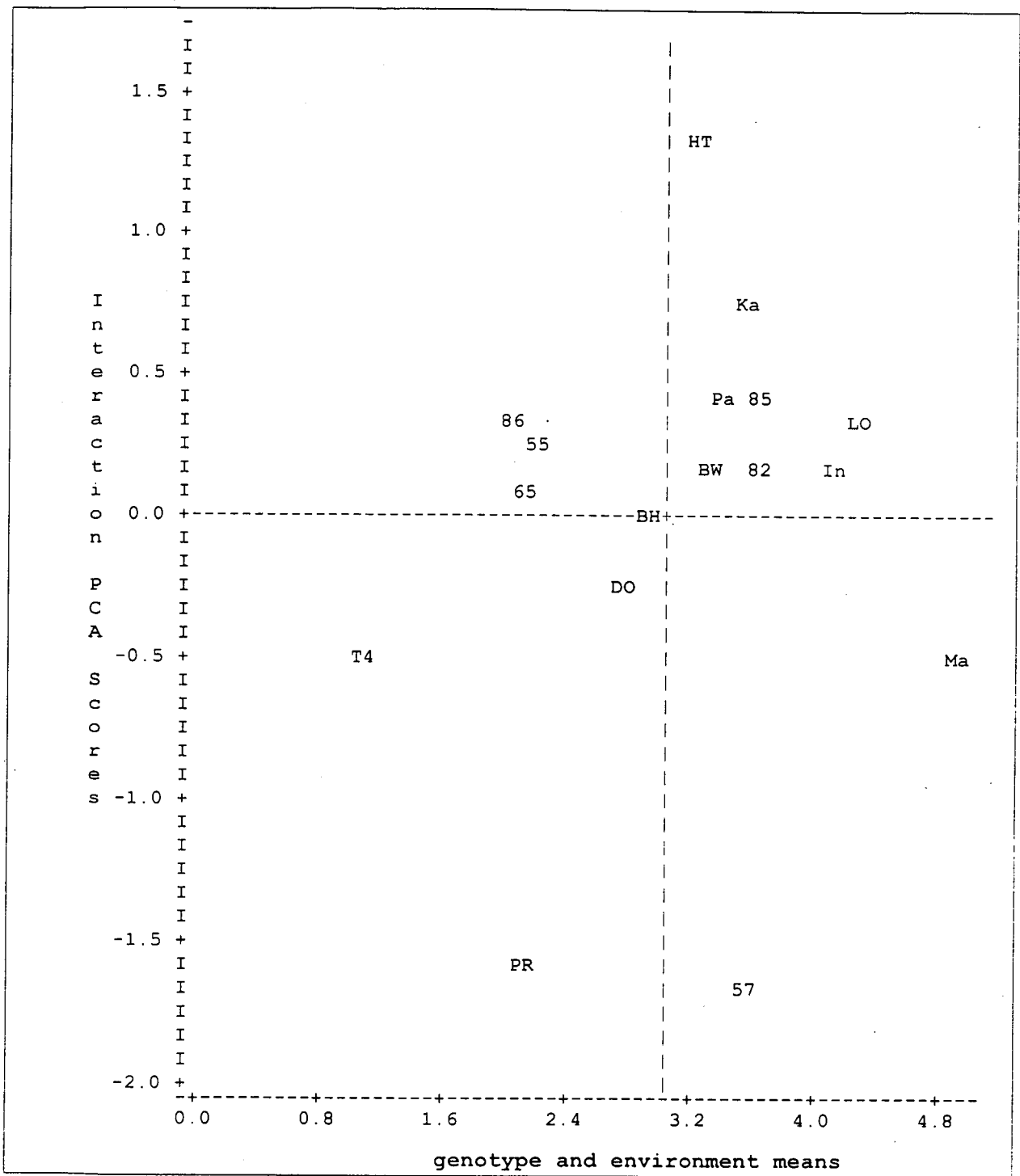


Figure 4.1.18 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Maricc, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST7) at six localities BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for mixograph point score in 1997.

The alveograph P/L ratio

This is a unitless value, which serves as an index of protein quantity and quality. "P" relates to the dough's tenacity and elastic resistance and it predicts the dough's ability to retain gas. Weak and strong dough's shows low and high "P" respectively. On the other hand "L" gives information about dough extensibility with longer and shorter "L" values indicating weak and strong doughs respectively. Therefore the ratio between the two values is important in wheat quality. In South Africa, P/L values between 0.5 to 0.8 produce good quality bread with 0.8 being optimum (F.P. Koekemoer – personal communication).

The analysis of variance results (Table 4.1.37) shows that treatments, environments, genotypes, interaction, IPCA as well as residual were highly significant. The block effect was significant at $p < 0.01$ implying presence of variations for particular genotypes even within locations. This indicates different genotype performance, varying growth conditions among and within locations as well as presence of specific interactions between genotypes and environments for this parameter. The significant residual implies presence of noise effect. The environment contribution to the variation was 29.5% but it was less compared to the results by Nel *et al.* (1998c) under rain-fed conditions, which was 56.0%. The genotype contribution to the variation was 32.8%, slightly higher, showing more genetic influence on this parameter. The interaction contributed 25.2% to the variation, slightly below the main effects, and out of this the IPCA captured 53.9%.

Table 4.1.37 Analysis of variance results for the alveograph P/L ratio in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	11.525	0.585			
Treatment	65	10.080	0.155	15.91	0.000	
Environment (E)	5	3.400	0.680	69.76	0.000	29.5
Block	12	0.276	0.023	2.36	0.009	
Genotype (G)	10	3.776	0.378	38.74	0.000	32.8
G x E	50	2.904	0.058	5.96	0.000	25.2
IPCA	14	1.566	0.112	11.48	0.000	53.9
Residual	36	1.338	0.037	3.81	0.000	
Error	120	1.170	0.010			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 4.1.38) ranged between 0.43 to 0.834 at Loskop and Douglas respectively, with a grand mean of 0.6. From environmental main effect at least three groups were identified. Douglas had a mean equal to the optimum; all genotypes were above the mean with most being close to the optimum and few above. The second group with means within the recommended range included Hopetown, Barkly West and Prieska. In these locations at least half of the genotypes were above the mean with two to three being close to optimum. For the third group with BullHill and Loskop, most of the genotypes were below the optimum range, at least three above the mean and only one close to optimum value. This shows again that in addition to high protein content that played major role in some locations such as Hopetown, optimum environments for improvement of protein quality are important. This was revealed by the higher values obtained at Douglas and Prieska despite that these sites had low protein contents comparable to Loskop. The low values were probably due to poor protein quality realised in this location. The genotype means (Appendix 1) ranged between 0.374 to 0.813 for SST65 and SST825 respectively and from genotype main effect four groups were observed. SST825, and T4 showed higher means close to the optimum value. SST876, Marico, Palmiet and Inia were above the grand mean and showed slightly higher values. SST822 and SST57 were below the mean and close to the minimum value of 0.5. However, Kariega and especially SST555 and SST65 were far below the mean and even the minimum range value. Nevertheless within each group interaction effects were still observed.

Table 4.1.38 Ranking of genotypes in each location for the alveograph P/L ratio and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	SST825 (0.80)	SST825 (0.86)	SST825 (0.78)	SST876 (1.12)	SST825 (1.04)	SST825 (0.82)
2	T4 (0.66)	T4 (0.76)	T4 (0.74)	T4 (0.87)	T4 (1.03)	Marico (0.61)
3	Marico (0.61)	Marico (0.68)	SST876 (0.63)	Palmiet (0.84)	SST876 (0.95)	T4 (0.60)
4	Inia (0.51)	Inia (0.61)	Marico (0.61)	Inia (0.71)	Palmiet (0.90)	Inia (0.46)
5	Palmiet (0.49)	Palmiet (0.60)	Palmiet (0.61)	SST57 (0.71)	Inia (0.88)	SST822 (0.43)
6	SST822 (0.46)	SST876 (0.57)	Inia (0.59)	SST825 (0.59)	Marico (0.87)	Palmiet (0.42)
7	SST876 (0.42)	SST822 (0.55)	SST822 (0.51)	SST822 (0.53)	SST822 (0.79)	Kariega (0.41)
8	Kariega (0.42)	Kariega (0.49)	SST57 (0.47)	Marico (0.50)	SST57 (0.77)	SST876 (0.29)
9	SST57 (0.35)	SST57 (0.46)	Kariega (0.43)	SST65 (0.47)	Kariega (0.70)	SST57 (0.27)
10	SST55 (0.28)	SST55 (0.37)	SST55 (0.35)	SST55 (0.45)	SST55 (0.63)	SST55 (0.23)
11	SST65 (0.26)	SST65 (0.36)	SST65 (0.34)	Kariega (0.36)	SST65 (0.63)	SST65 (0.20)
Mean	0.478	0.572	0.548	0.651	0.834	0.431

Grand mean = 0.586 LSD (0.05): treatment = 0.034 , environment = 0.113

The AMMI biplot for genotype and environment means (Figure 4.1.19) shows high environment interaction for SST825, SST876 and to a lesser extent Marico and Kariega. SST825 ranked first in five locations but intermediate at Hopetown. Together with T4 that also ranked higher at all site they seem to have wide adaptability. SST876 ranked below average at three sites but it was first at

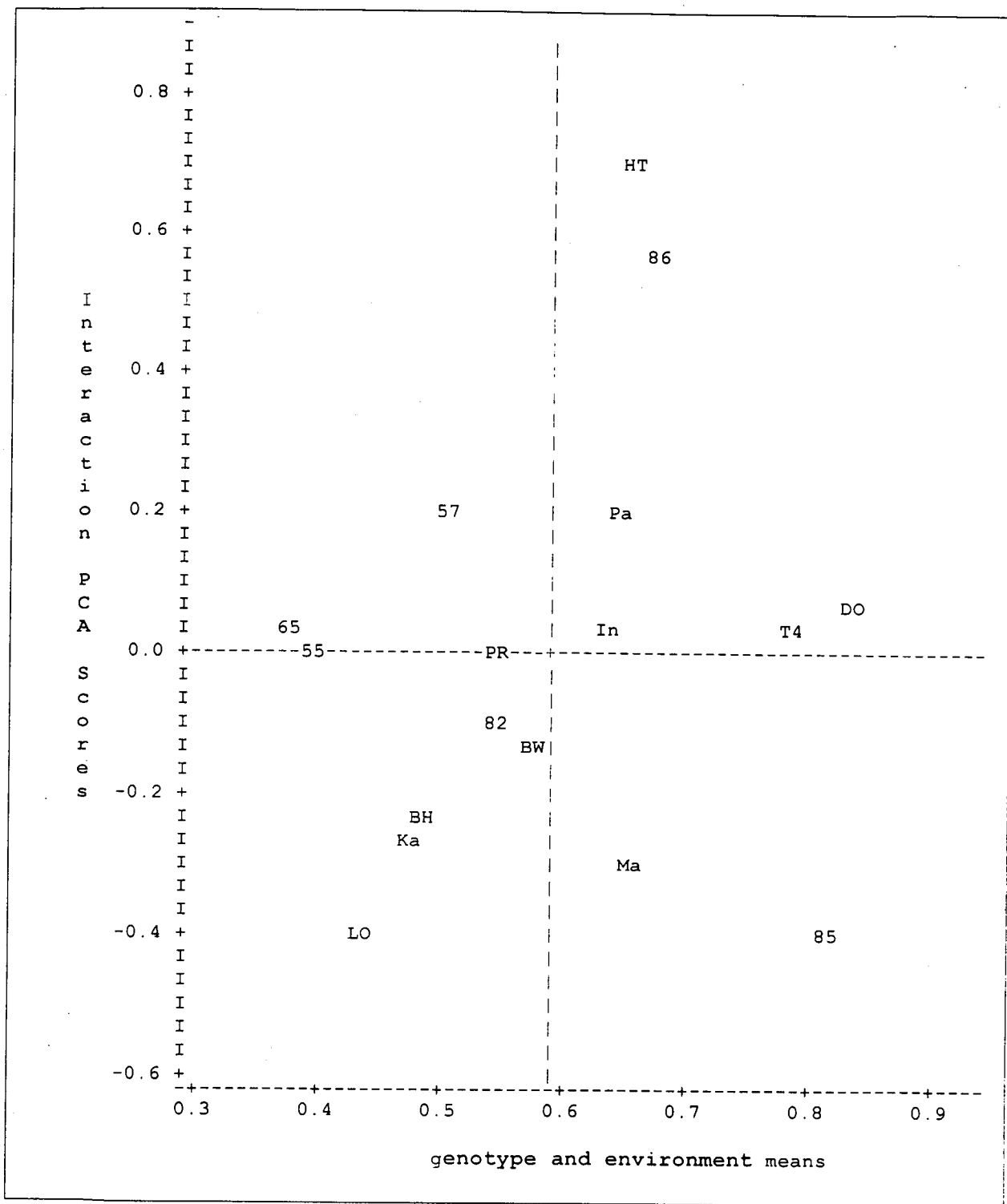


Figure 4.1.19 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at six localities (BH = Bull Hill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for alveograph P/L ratio in 1997.

Hopetown and third at Prieska and Douglas. Marico was second at Loskop, and close to the middle at other sites. Kariega on the other hand ranked third to fourth from last at most locations but it was last at Hopetown. Therefore, except for SST825 the others showed negative interactions. The locations (Figure 4.1.19) showed high environment interaction at Hopetown and lower at Loskop. The effect at Hopetown was mainly due to SST876 and for Loskop it was due to Marico and Kariega, which were slightly higher compared to other sites.

In summary, all genotypes may give reliable rank at most of the locations except for SST876 at Hopetown, Prieska and Douglas, SST825 at Hopetown and Marico and Kariega at Loskop. Results for these cultivars should not be generalised to other locations. SST825 and T4 may be taken as references in all locations. For the locations in descending order Douglas, Hopetown, Barkly West and Prieska may give reliable ranking with care been taken for genotypes showing environment interaction. However, the low values realised at BullHill and especially Loskop suggest less reliability of the results from these two sites.

Alveograph strength (W/6.54)

This is the deformation action of the dough, based on one gram of dough, evaluated in 10^{-4} joules. It tells the amount of work required for the deformation of the dough and is related to the baking "strength" of the dough. Strength is always derived from alveographic parameter "W" (area under the curve). Since lower and higher W values indicate weak and strong flours respectively, W-value close to 250 is usually recommended so that it, when divided by a constant 6.54, will result to a strength of ± 35 in joules which is also popular with bakers. Therefore the discussion on strength will also cover the parameter W. The results for analysis of variance shows that treatments, environments, genotypes, block effect, interaction as well as IPCA were highly significant (Table 4.1.39). This indicates different genotype performance, varying growth conditions among and within locations as well as presence of specific interactions between genotypes and environments for this parameter. However, the residual was significant at $p < 0.01$ and this implies presence of noise. The significant block effect ($p < 0.001$) shows this parameter to be sensitive to environment and this indicates presence of variations for particular genotypes within certain locations.

Environment contribution to the variation in strength was 6.2%, that was very low compared to the results by Nel *et al.* (1998c), which was 65.8%. This is also supported by Van Lill and Smith (1997) who reported that for winter wheat, alveograph measurements were more affected by environmental effects than genotypes. This shows moisture stress to be one of the environmental factors influencing the strength. The genotype contribution to the variation was 50.7%, much higher compared to 18.2% realised by Nel *et al.* (1998c). This is from the fact that despite the parameter being genetically controlled, under irrigation, moisture stress is minimised. The contribution of the interaction to the variation was 19.0% slightly higher than environment contribution. Of this the IPCA captured 47.0% of the variation.

Table 4.1.39 Analysis of variance results for alveograph strength (W/6.54) in 1997.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	197	17867	90.7			
Treatment	65	13553	208.5	8.260	0.000	
Environment (E)	5	1114	222.7	8.823	0.000	6.2
Block	12	1285	107.1	4.241	0.000	
Genotype (G)	10	9053	905.3	35.864	0.000	50.7
G x E	50	3387	67.7	2.683	0.000	19.0
IPCA	14	1591	113.6	4.502	0.000	47.0
Residual	36	1796	49.9	1.796	0.003	
Error	120	3029	25.2			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment mean ranged between 27.15 to 34.71 at Prieska and BullHill respectively. The higher variances for this parameter especially at Barkly West and Loskop indicate a large deviation from the mean for the genotypes with higher and lower values. General observations showed at least two groups; BullHill, Barkly West, Hopetown, Loskop and Douglas had higher means, close to the grand mean with the first two very close to the recommended value. More than half of the genotypes at these locations had values higher or very close to the recommendation. Prieska on its own was below the grand mean and far from the recommended value. Despite Hopetown showing contrast from other sites due to interaction, the difference among localities was more associated with protein content, especially being close to 12% and not much higher or low. Sites like BullHill and Barkly West had protein contents for most of the genotypes close to 12% and this was associated with higher strengths observed at these sites. At Hopetown with more genotypes having protein contents above 12%, alveograph strength was comparable to Douglas and Loskop where few genotypes attained 12% protein content. This shows that protein quality in terms of components and molecular weight distribution has a large influence on strength. The genotype means (Appendix 1) ranged between 16.41 to 41.03 for T4 and Inia respectively and from genotype main effect three groups were realised. SST825, Inia and Marico showed higher alveograph strength, above the recommended value at most of the locations, even at Prieska where most of the genotypes showed lower values, SST825 and Inia were still higher. For the other genotypes except T4, which had values far below the mean, others were close to the mean 32.12 with SST55 and Kariega deviating slightly.

Table 4.1.40 Ranking of genotypes in each location for alveograph strength (W/6.54) and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	SST825 (46.20)	Inia (42.35)	SST825 (36.97)	SST876 (44.84)	SST825 (42.38)	SST825 (45.19)
2	Inia (43.64)	SST825 (41.48)	Inia (36.06)	Marico (41.49)	Inia (41.11)	Inia (41.53)
3	Marico (41.22)	Marico (40.62)	Marico (33.97)	Inia (41.48)	Marico (38.95)	Marico (38.89)
4	SST822 (38.28)	Kariega (36.36)	Kariega (29.92)	Kariega (36.22)	Kariega (34.94)	SST822 (37.16)
5	Kariega (37.36)	SST822 (33.89)	SST822 (29.21)	Palmiet (34.05)	SST822 (34.58)	Kariega (35.16)
6	SST57 (33.64)	Palmiet (32.87)	Palmiet (26.15)	SST825 (32.06)	Palmiet (31.11)	SST57 (31.77)
7	Palmiet (33.33)	SST876 (31.83)	SST57 (25.69)	SST65 (30.64)	SST57 (30.82)	Palmiet (30.96)
8	SST65 (32.18)	SST57 (31.59)	SST65 (24.68)	SST57 (28.85)	SST65 (29.71)	SST65 (30.01)
9	SST55 (30.25)	SST65 (31.07)	SST876 (22.64)	SST822 (25.32)	SST55 (27.35)	SST55 (28.45)
10	SST876 (27.54)	SST55 (27.99)	SST55 (22.20)	SST55 (24.72)	SST876 (27.10)	SST876 (23.64)
11	T4 (18.21)	T4 (17.88)	T4 (11.09)	T4 (19.41)	T4 (16.04)	T4 (15.80)
Mean	34.71	33.45	27.15	32.64	32.19	32.60

Grand mean = 32.12 LSD (0.05) : treatment = 1.73 , environment = 5.74

The AMMI biplot for genotype and environment means (Figure 4.1.20) shows high environment interaction for SST876 and to a lesser extent SST825 and SST822. Most of the interactions were observed at Hopetown where SST825 and SST822 ranked sixth and ninth respectively but they were first or second and intermediate or higher in other locations and thus showed positive interaction. However, SST876 ranked first at Hopetown and seventh at Barkly West but it was third or second from last at other locations, thus showing negative interaction. Other genotypes were stable but Inia and Marico were far above and SST55 and T4 far below the mean (Table 4.140).

The sites (Figure 4.1.20) showed high genotype interaction at Hopetown, which also shows much contrast with other sites. Interaction also occurred to a lesser extent at Loskop and BullHill. Negative interaction at Hopetown was due to SST825 and SST822 that ranked lower at Hopetown but higher at other sites. Despite SST876 ranking higher at this site it was lower in others. The positive environment interactions shown at Loskop and BullHill were due to SST825 and SST822 that showed higher values at these two sites compared to others sites.

In conclusion we can say, nearly all genotypes may give reliable ranking at most of the sites except SST876, SST825 and SST822 at Hopetown, which should not be generalised to other sites. However, Inia, Marico, Kariega, SST825 and Palmiet may be taken as references in most locations. For the locations however, except Hopetown, most of them may give reliable ranking for most of the genotypes. Nevertheless the lower values realised at Prieska needs to be taken into account not to underrate potentially good genotypes.

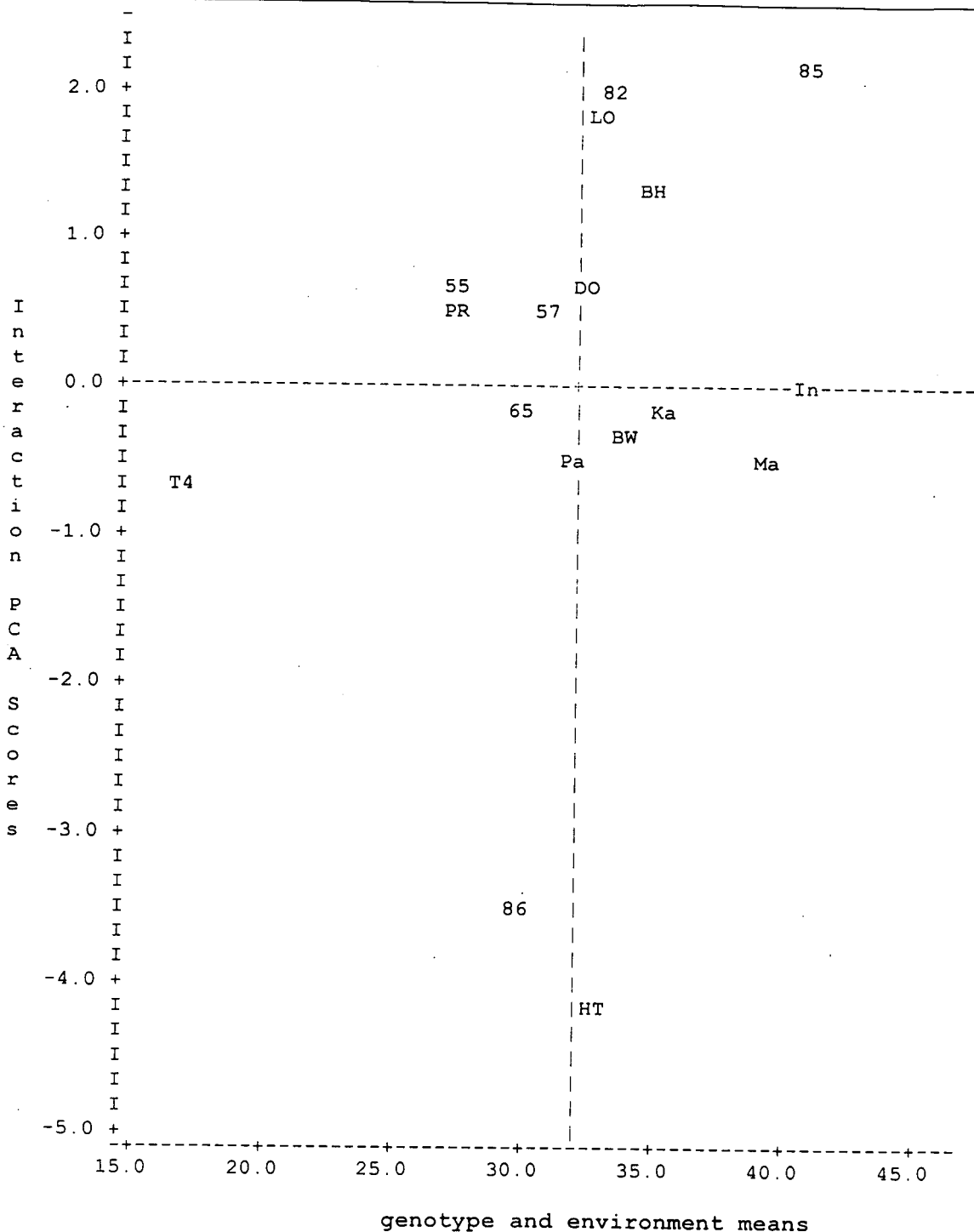


Figure 4.1.20 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at six localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for alveograph strength (W/6.54) in 1997.

Flour colour

A white flour colour is desired, and both millers and bakers use the degree of colour as an important indication of flour quality. Colour from carotenoid pigments normally does not present a problem to the baker and is usually bleached away by the miller. Different methods are used for colour determination and taking Small Grain Institute quality lab as an example, colour grader series III is used. Flour categories are;

Cake flour	=	-2.5	to	1.0
White bread	=	1.5	to	4.5
Brown bread	=	9	to	14

The analysis of variance results (Table 4.1.41) shows highly significant F-values for treatments, environment, genotype, interaction, IPCA as well as residual. This indicates different genotype performance, varying growth conditions among locations as well as presence of specific interactions between genotypes and environments for this parameter. The block effect was not significant and this implies absence of variations for particular genotypes within locations. The significant residual also indicates presence of noise effect but a larger percentage (61.7) of the interaction effect was explained by the IPCA1. The environment contribution to the variation in flour colour was 52.7%, showing that environment had more influence than interaction and genotype. The genotype contribution to the variation was 13.1%, much lower than that of interaction, showing less genetic effect. The interaction contributed 22.9% to the variation showing a large effect.

Table 4.1.41 Analysis of variance results for flour colour in 1997.

Source	DF	SS	MS	F - value	Pr>F	SS%
Total	197	655.5	3.33			
Treatment	65	581.2	8.94	15.97	0.000	
Environment (E)	5	345.3	69.06	123.33	0.000	52.7
Block	12	7.2	0.60	1.07	0.395	
Genotype (G)	10	85.7	8.57	15.31	0.000	13.1
G x E	50	150.2	3.00	5.36	0.000	22.9
IPCA	14	92.6	6.62	11.82	0.000	61.7
Residual	36	57.5	1.60	2.85	0.000	
Error	120	67.2	0.56			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 4.1.42) ranged between 0.36 to 4.31 at Douglas and Barkly West respectively, with a grand mean of 2.05. Based on the above-mentioned grading system, two groups of environments were observed. Douglas and Loskop with means below 1.0 gave flours that will be graded as not suitable for white bread. Other sites fell within the white bread category. However, environment main effect showed three groups with Barkly West and BullHill being far above the mean, followed by Prieska and Hopetown which were close to the mean, whereas Loskop and Douglas were far below the mean. The genotype means (Appendix 1) ranged between 1.34 to 3.38 for Marico and Palmiet respectively. Referring to the flour categories mentioned, it was only Marico and SST876, which appeared to be slightly below the white bread category. Therefore most of the genotypes were potentially capable of producing white bread flour. However, Palmiet, Inia, SST822 and SST825 were far above the mean and thus had less risk of falling into another group, unless the environment is less ideal.

The AMMI biplot for genotype and environment means (Figure 4.1.21) shows a wide spread of genotypes due to both genotype main effects and interaction. Higher environment interaction was shown by Kariega, followed by SST57, SST876, SST825, Marico and to a lesser extent T4 and SST822. Kariega ranked first and third at Hopetown and Douglas respectively but it was very low to last in other locations. SST57 ranked second from last at these two sites but at the middle in others. SST822 and SST825 showed the same trend as they ranked higher in most locations except Hopetown where they ranked lower especially SST825, which was also, lower at Douglas. Marico ranked last or second from last in most of the locations except again at the above two sites where it was intermediate. SST876 was last at these two sites and second from last at BullHill but almost at the middle at the other three sites. This shows most of the interaction effects were at Hopetown and Douglas. The other four genotypes showed stability but Palmiet and Inia were far above the mean compared to SST65 and SST55, which were below the mean and ranked below the middle at most of the locations. Palmiet and Inia also have a wide adaptability for this parameter (Table 4.1.42).

For the locations (Figure 4.1.21) high interaction was shown at Hopetown followed by Douglas, Loskop, and Prieska and to a lesser extent Barkly West. The positive interaction at Barkly West was due to SST876 and SST57, which ranked in the middle and also Palmiet and SST822 had higher values compared to other sites. Therefore this site together with BullHill seems to be reliable for this parameter. The environment interaction at Hopetown and Douglas was due to Kariega, Marico and T4 that ranked higher compared to most of the sites. Whereas at Prieska and Loskop it was due to SST57 and SST876 which ranked at the middle comparable to Barkly West but were low in other locations.

Table 4.1.42 Ranking of genotypes in each location for flour colour and environmental means in 1997.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop
1	Palmiet (4.27)	Palmiet (5.68)	Palmiet (3.45)	Kariega (3.68)	Palmiet (1.63)	Palmiet (2.15)
2	SST822 (3.72)	SST822 (5.34)	SST825 (3.34)	Palmiet (3.08)	Inia (1.15)	SST825 (2.07)
3	Inia (3.61)	SST825 (5.27)	SST822 (3.29)	Inia (2.76)	Kariega (0.99)	SST822 (1.10)
4	SST825 (3.49)	Inia (4.93)	Inia (2.63)	T4 (2.68)	SST822 (0.69)	Inia (1.32)
5	T4 (2.72)	SST57 (4.49)	SST57 (2.59)	Marico (2.47)	T4 (0.66)	SST57 (1.31)
6	SST57 (2.67)	SST876 (4.10)	SST876 (2.17)	SST65 (2.20)	SST65 (0.33)	SST876 (0.89)
7	SST65 (2.56)	SST55 (3.81)	SST55 (1.59)	SST822 (1.76)	Marico (0.29)	SST55 (0.29)
8	SST55 (2.41)	T4 (3.80)	SST65 (1.34)	SST55 (1.23)	SST825 (0.16)	SST65 (0.02)
9	Kariega (2.37)	SST65 (3.74)	T4 (1.33)	SST825 (0.93)	SST55 (-0.22)	T4 (0.01)
10	SST876 (2.33)	Marico (3.18)	Marico (0.64)	SST57 (-0.01)	SST57 (-0.72)	Marico (-0.69)
11	Marico (2.18)	Kariega (3.09)	Kariega (0.33)	SST876 (-0.23)	SST876 (-1.00)	Kariega (-1.02)
Mean	2.940	4.312	2.064	1.868	0.362	0.758

Grand mean = 2.05 LSD (0.05): treatment = 0.258 , environment = 0.855

In summary, Kariega may be taken as a reference at Hopetown and Douglas where it performed well. However, its results together with that of Marico, T4, SST825, SST822, SST57 and SST876 from these two locations should not be generalised to other sites. On the other hand other genotypes may give reliable ranking in most locations and Palmiet, Inia, SST822 and SST825 may be taken as references. For Hopetown and Douglas more environment interactions were shown which should be taken into account. Nevertheless other sites showed reliable ranking although there were slight variations. However, from the environmental main effect, Douglas and Loskop showed less potential for white bread flour. These two sites therefore need genotypes with high stability for this parameter.

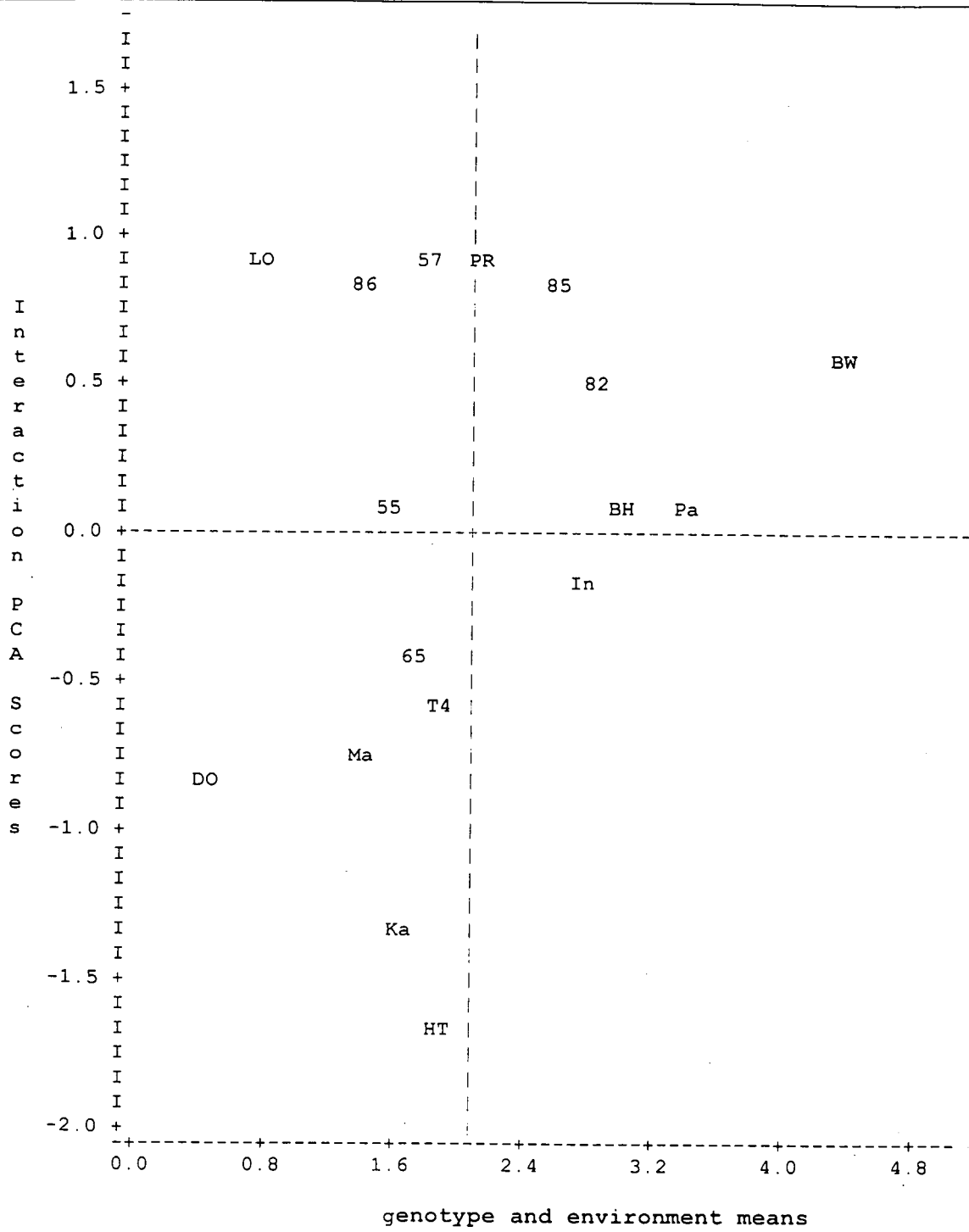


Figure 4.1.21 AMMI biplot of genotype and environment IPCA1 scores versus means for eleven genotypes (Pa = Palmiet, 65 = SST65, 55 = SST55, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at six localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas and LO = Loskop) for flour colour in 1997.

4.2 Correlation matrix

Correlation indicates the relative association between two parameters, with zero (0) indicating absence of correlation, whereas one (1) indicates very high or almost identical magnitudes. Positive and negative signs imply that an increase in one parameter leads to an increase and decrease respectively in another parameter. Values were significant above 0.185 ($p = 0.01$). To give better discrimination, only values above 0.4 are therefore discussed.

The results (Table 4.2.1) shows hectoliter mass had positive correlation ($r \geq 0.4$) with most of the kernel parameters. These include, thousand kernel mass, single kernel characterisation system – weight and diameter, vitreous kernel and that of SKCS–hardness index and farinograph water absorption were $r = 0.55$ and $r = 0.49$ respectively. This shows that an increase in hectoliter mass will lead to an increase in all these parameters and vice-versa. Negative correlations were observed with; moisture content ($r = -0.68$), sedimentation and breakflour yield both at ($r = -0.54$) and mixograph development time and point score at ($r = -0.50$) and ($r = -0.43$) respectively. Correlation with moisture content reveals that in locations where grain filling was slightly better, harvesting was done when the grains were dry enough and thus giving higher hectolitre mass and less moisture content. Nevertheless in locations with poor grain filling harvesting might have been done earlier while grains had higher moisture but less mass per volume due to shrivelled kernels. Correlation with mixograph parameters (MDT, MPT) and sedimentation are from the fact that higher hectoliter mass is also associated with higher yield. According to MacDonald (1994), higher hectoliter mass is an indication of grain plumpness, following favourable growth conditions during grain filling (Evans *et al.*, 1975). However, low protein content is always realised in higher yielding environments consequently affecting parameters associated with protein content. Since protein content also contributes to kernel hardness, it is possible for breakflour yield also to decrease in higher yielding environments especially if the fertility (nitrogen availability) is also low. However, the positive farinograph water absorption indicates higher hectoliter mass (due to optimum grain filling) to be important also in improving water absorption. This will improve if soil fertility is also adequate to satisfy the nitrogen needs for yield and protein assimilation.

The three-grain protein methods (GPC–WH, GPC–FL and GPC–LECO) showed very high positive correlation ($r \geq 0.90$) among themselves indicating that they measure the same effects. They also showed high correlation ($r \approx 0.7$) with wet gluten at 12% protein and flour protein methods (FPC–LECO and FPC–NIR). Positive correlations were also observed with estimated loaf volume and alveograph strength ($r \geq 0.5$) whereas correlation with SDS –sedimentation was ($r \geq 0.4$) for FL and LECO methods but slightly lower with the WH – method. However, when loaf volume was converted to 12% protein content, the correlation became low. Nevertheless grain protein content showed positive correlation with most parameters and none of the negative correlations were high. This indicates the reliability in making selections and wheat

evaluation. Breakflour yield showed mainly negative correlations. Positive correlation were observed with moisture content and sedimentation ($r \geq 0.50$) and flour yield ($r = 0.42$). Correlation with flour yield and sedimentation indicates that with optimum grain filling conditions and enough protein, the endosperm hardness increases, which in turn results in increased flour yield and thus breakflour yield. However, correlation with moisture content may be due to environmental effects as it was seen at Loskop where breakflour yield was high despite the location having shrivelled kernels. This might have caused problems during milling due to bran contamination and that is why this parameter showed more negative correlation with others; such as SKCS –hardness index and hectoliter mass ($r \geq -0.5$), SKCS – diameter, alveograph P/L ratio, farinograph water absorption, flour colour and vitreous kernels ($r \geq -0.4$). This indicates breakflour yield to be an indicator of high protein content and grain filling. This must not be extrapolated to more contrasting environments.

Flour yield, one of the parameters given more priority by millers, showed low correlations (mostly negative) with most of the parameters. The only higher positive correlation was ($r = 0.42$) with breakflour yield, whereas other correlations were with flour colour and wet gluten ($r = -0.70$) and ($r = -0.39$) respectively. Correlation with breakflour yield may be due to the contrasting environments at Loskop where both flour and breakflour yields were higher. However, the higher flour and breakflour yields at Loskop was not realised (probably due to bran contamination). This location showed very low hectoliter and kernel masses, which normally have an association with flour yield, but their correlation with flour yield was very low. The negative correlation with flour colour was also due to Loskop and Douglas where flour yields were high but both sites showed much contrast in colour from other locations. Correlation of wet gluten with flour yield may be due to the low protein levels at Loskop and Prieska where flour yields were high.

Both grain filling conditions and protein content influences vitreous kernels. They showed negative correlations with few parameters. Correlations were observed with hectoliter mass ($r = 0.621$), grain protein content-WH ($r = 0.532$), and farinograph water absorption ($r = 0.527$). Others high correlations were with thousand-kernel mass ($r = 0.499$), SKCS-weight ($r = 0.472$) and SKCS-hardness index ($r = 0.473$). Despite this parameter showing slight negative correlation with flour yield, its correlation with most of the kernel parameters, hectoliter mass and farinograph water absorption shows its potential to reveal correct flour yields without bran contamination. The positive correlation with both grain protein ($r > 0.38$) and flour protein ($r > 0.26$) contents also shows the ability to reveal effective protein assimilation especially quality. This may be in terms of composition and glutenin-to-gliadin ratio. This is indicated by the low vitreous kernel realised at Loskop where protein content was low, similar to Prieska. However, Prieska showed higher vitreous kernels than Loskop, probably due to high protein quality. Correlations were observed with moisture content ($r = -0.571$) and breakflour yield ($r = -0.493$). Again this was mainly due to Loskop where these two parameters together with sedimentation and mixograph development time which also showed negative correlations with

vitreous kernels gave higher values. This shows vitreous kernels to be an important parameter for both breeder's selection as well as quality grading.

Thousand-kernel mass is almost identical to single kernel characterisation system – weight as seen in their correlation ($r = 0.946$). High correlations were also observed with SKCS–diameter ($r = 0.872$) and hectoliter mass ($r = 0.685$). Another positive correlation was with vitreous kernels ($r = 0.499$). Most of the negative correlations were low except with moisture content ($r = -0.438$) and mixograph point score ($r = -0.351$) and this was again due to Loskop where these parameters ranked higher with kernel mass being low. However, negative correlations with protein contents and related parameters, despite being low, indicates the well known negative association between high yield and protein content and this calls for proper management to increase both yield and quality. Falling number being more genetically controlled in terms of alpha-amylase activity, showed very low correlations with other parameters. Flour colour in addition to the correlations it showed with breakflour and flour yields, also showed positive (low) correlation with all grain protein methods and flour method (NIR). However, the correlation with wet gluten at (12%) protein was slightly higher ($r = 0.423$). This indicates that with higher protein, especially gluten content, endosperm hardness increases which in turn improves the milling operations, thus resulting in more white bread flour.

For wet gluten we will consider only the values at 12% protein as this is related to optimum dough characteristics. In addition to the positive correlations shown with grain protein, wet gluten (12%) also showed high positive correlation with flour protein methods (FPC–NIR and FPC–LECO) which were $r = 0.689$ and $r = 0.711$ respectively. Other correlations were also observed with alveograph strength and loaf volume at normal protein, ($r = 0.424$) and ($r = 0.434$).

The loaf volume at 12% showed less correlation with gluten, implying gluten content to be affected by low protein contents. Also a positive correlation with vitreous kernels ($r = 0.312$) confirms protein content and especially gluten to be responsible for kernel hardness. The only negative correlation was observed with flour yield $r = -0.384$ again supporting the negative relation between yield and protein content. The two flour protein content methods (FPC–NIR and FPC–LECO) also followed the same trend as wet gluten, and as mentioned earlier they had high correlation with grain protein methods. Other correlations were with alveograph strength and loaf volume at normal protein content which were above $r = 0.576$. However, the correlation between the two flour methods themselves was not very high ($r = 0.784$) and this again shows (NIR) to be more effective. This is from the fact that to other positive correlations, which were lower with LECO system for loaf volume at 12%, sedimentation, mixograph point score, flour absorption, flour colour and vitreous kernel, and was higher with the NIR – method for most of the parameters. Low negative correlations were observed with flour yield and SKCS–diameter. Therefore high protein with good quality is important for most of the quality parameters.

Farinograph water absorption, as already mentioned, showed positive correlation with most of the parameters and with protein content (both grain and flour). This signifies the importance of protein in hardness. Other positive correlations were observed with SKCS-hardness index ($r = 0.547$) and alveograph P/L ratio ($r = 0.55$). This confirms the importance of polymeric proteins (glutenin) as they influence the alveograph P/L ratio and are responsible for increased hardness, which results in more breakflour and thus higher water absorption. A high negative correlation was also observed with mixograph development time ($r = -0.546$) and moisture content ($r = -0.561$). All these were associated with Loskop where the moisture and protein content was higher but with low quality. The negative correlation with sedimentation and mixograph point score ($r = -0.304$) and ($r = -0.352$) shows again these two parameter to be associated with protein content and not much with quality. Therefore since farinograph water absorption and vitreous kernels were the only parameters, which showed high correlations with alveograph P/L ratio, the two parameters seem to be important in confirming if the protein quality was optimum.

Mixograph development time and point score in addition to other parameters already discussed, also showed positive and high correlation among themselves ($r = 0.715$) and with alveograph strength ($r = 0.418$ and $r = 0.60$), SDS-sedimentation ($r = 0.478$ and $r = 0.509$) and moisture content (0.46 and 0.352). This shows again the two parameters to be more influenced by protein content and not quality as they all ranked higher at Loskop. For the alveograph P/L ratio positive correlation was also observed with SKCS-hardness index ($r = 0.618$). Since correlation with hectoliter mass was ($r = 0.376$), it seems for this parameter both protein content and quality including optimum grain filling are important. This is from the fact that in this test a sheet of gluten protein into which starch granules are embedded forms a bubble. The negative correlation ($r \geq -0.41$) with sedimentation and moisture content were also observed and this may be the consequence of Loskop where protein content was high but probably with poorer quality. Alveograph strength also showed positive correlation with SDS-sedimentation ($r = 0.476$) and loaf volume at normal protein ($r = 0.44$), showing the parameter to be more influenced by protein content which was higher at Loskop. However, its positive correlation with most of the parameters especially those related with protein, indicates its importance in selection and grading.

Loaf volumes at normal protein content (EST-LFV) and at 12% protein content were not highly correlated among themselves ($r = 0.726$). Flour yield also showed positive correlation with SDS-sedimentation ($r = 0.477$) and ($r = 0.395$) respectively. This shows this parameter to be more influenced by protein content especially EST-LFV, and therefore the correlation at 12% protein is desirable as it also accounts for quality. The SKCS-weight also showed positive and high correlation with SKCS-diameter ($r = 0.938$) the correlation with moisture was negative ($r = -0.484$). Moisture content also showed correlation with SKCS-diameter ($r = -0.526$) and SKCS-hardness index ($r = -0.562$). The main cause was Loskop where moisture content was high but SKCS-diameter and SKCS-hardness index were low due to shrivelled kernels.

In summary, hectoliter and kernel masses (SKCS-W/TKM), SKCS-diameter, SKCS-hardness index and vitreous kernel are important to ensure flour yield with good quality. For breakflour yield it is better to verify whether farinograph water absorption is also high, otherwise with high protein but with low quality, breakflour yield may be high but less effective. In addition to high protein and sedimentation, for protein related parameters selection for; high loaf volume and gluten content both at 12% protein, alveograph strength, farinograph water absorption, alveograph P/L ratio, vitreous kernels and optimum mixing time will ensure also the quality of the protein.

4.3 Canonical Variate Analysis to find groupings between genotypes

The analysis of variance (ANOVA) is a univariate technique, which shows statistically real differences between the 11 wheat genotypes for each variate separately. The evidence of differences between genotypes for all parameters (variates) measured as seen from the previous analyses was significant ($p < 0.001$). Nevertheless, it does not give an indication of how they group, or which variate(s) are most important in discriminating between groups. Therefore canonical variate analysis (CVA) better known as linear discriminant analysis is used when it is of more interest to show differences between groups than between individuals. The variability in a large number of variates is first reduced to a smaller set that accounts for most of the variability. The new sets of variates (also called canonical variates) are linear combinations of the original measurements. In this approach a set of directions are obtained in such a way that the ratio of between group variability to within group variability in each direction is maximised. The scores found for each of the canonical variates are then correlated with the original variates to find those that are the most important between the groups. De Lange (1999) used canonical variate analysis to better understand those variates discriminating most between six canning bean cultivars. Van Lill *et al.* (1995b) also used canonical variate analysis to understand environmental factors, which contribute to variation in bread-making quality.

In 1997 the variates were 26 quality characteristics measured on each of 11 genotypes at six localities. Those variates, which were not important, were then deleted one-by-one from the analysis until only those with reasonable correlation coefficients were retained. About seven variates were retained, which includes;

mixograph development time, mixograph point score, alveograph P/L ratio, alveograph strength, loaf volume at 12% protein and SDS-sedimentation. Therefore this shows that genotypes had a large influence on these variates, because the heritability is also high for these variates.

The first two canonical variates (CV1 and CV2) together accounted for 82.5% of the total variation among groups. Tables 4.3.1 and 4.3.2, shows the canonical variate mean scores and percentages for the two CVs as well as correlation coefficients between the variates and the first two CV's respectively.

Table 4.3.1 Canonical variate percentage variation and mean scores of the first two canonical variates of the eleven genotypes.

Variates	CVA1	CVA2
	43.4%	39.1%
Palmiet	0.5921	-0.0849
SST65	-1.4283	-0.0402
SST55	-2.1285	-0.0817
T4	0.0392	-3.0832
Marico	1.8225	1.0952
Kariega	-1.7991	1.0772
SST822	-0.4333	0.5178
SST825	1.0870	0.6549
Inia	0.3277	1.3727
SST876	0.4289	-1.0106
SST57	1.4918	-0.4172

It is evident from Table 4.3.1 that SST55, SST65 and Kariega showed contrast with the other genotypes though not very high. This is due to slightly higher negative CV1 scores (particularly SST55 and Kariega) versus small negative and positive scores. The horizontal separation (CV1) accounted for nearly 43.4% of the total variation showing contribute more. Grouping of the 11 genotypes is more clearly shown by a plot of the two canonical variates mean scores (Figure 4.3.1). Points closer or further apart in such a plot are similar or dissimilar respectively, with respect to their general response to the variates that discriminate between them.

Considering all the variates included in the final CVA, the genotypes SST55, SST65 and Kariega were somehow dissimilar to most other genotypes. It was mainly alveograph P/L ratio which was responsible, as the three genotypes had lower values for this parameter. However, considering other variates (alveograph strength, sedimentation and mixograph point score), T4 is dissimilar to most other genotypes. This is due to the fact that different cultivars may respond differently to environment (Huebner and Bietz, 1994).

The variate which discriminated between genotypes for CV1 (x-axis) (Figure 4.3.1) was alveograph P/L ratio ($r = 0.486$). This variate correlated intermediately positive with this CV1 scores than other variates. Thus

SST55, SST65 and Kariega had low rating and other genotypes intermediate to optimum rating for this parameter.

The CV2 (y-axis) accounted for 39.1% of the variation. The main variates, which discriminated between genotypes for this axis, were mixograph development time ($r = 0.572$), mixograph point score ($r = 0.762$), alveograph strength ($r = 0.843$), loaf volume at 12% protein ($r = 0.546$) and SDS – sedimentation ($r = 0.804$). All these variates correlated intermediate to strongest, positive with the CV2 scores. Thus generally T4 had low rating for these variates than the other genotypes.

Table 4.3.2 Correlation coefficients of those variates retained in the final CVA with each other and the first two canonical variates.

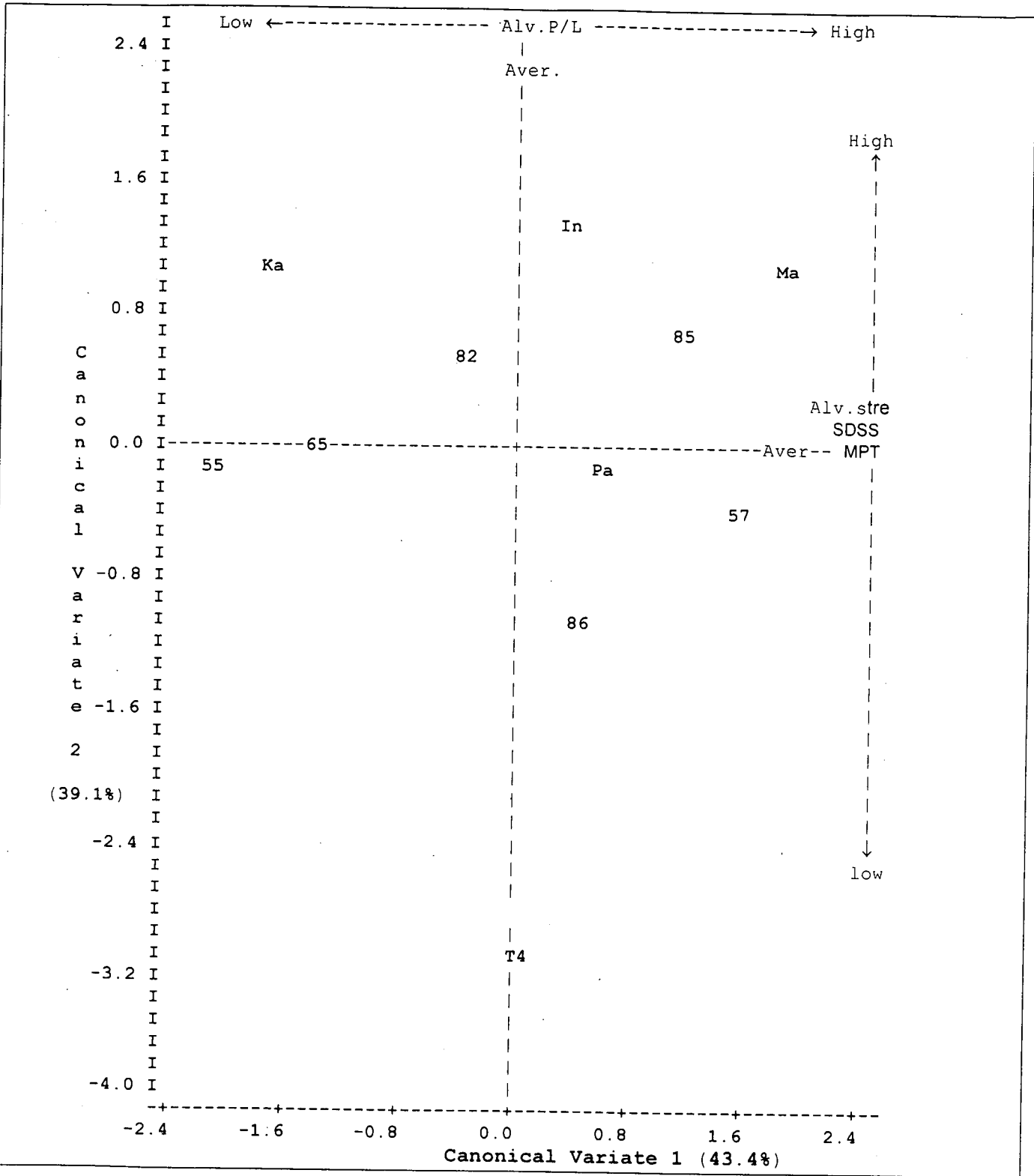
MDT	1.000					
MPT	0.713	1.000				
Alv.P/L	-0.104	-0.078	1.000			
Alv.stre	0.413	0.614	0.098	1.000		
LFV12%	0.090	0.199	-0.091	0.247	1.000	
SDSS	0.478	0.513	-0.411	0.481	0.402	1.000
CV1	0.399	0.416	0.486	0.285	-0.254	-0.479
CV2	0.572	0.762	-0.199	0.843	0.546	0.804
	MDT	MPT	Alv.P/L	Alv.stre	LFV12%	SDSS

From the plot of mean scores of genotypes (Figure 4.3.1) and the table to find low and high values for CVA (Table 4.3.3), it shows Inia and Marico to be higher for MPT, strength and sedimentation. Whereas T4 was very low for these parameters and thus showed much contrast from other genotypes. Also for other parameters except for alveograph P/L ratio, most of the genotypes were close to the average (0.0) except T4. This is also revealed from the ranking tables where T4 was lower/last for most of these parameters except alveograph P/L where it ranked second in most locations. Therefore for genotypes, T4 shows to have less potential for most of the parameters. However, it may be used as a donor parent to improve alveograph P/L ratio for which it performed well. For the other variates, except for T4 and SST876, other genotypes may be used as donor parents also.

Taking into account the mean values for most of the variates, the genotypes T4 and SST876 were below the grand means for mixograph development time, mixograph point score and alveograph strength. Therefore mixing these genotypes with others particularly Inia, SST825, Kariega, Marico and SST822 will improve the quality of these parameters. On the other hand SST65, SST55, Kariega, and SST57 need to be mixed with other genotypes to improve the alveograph P/L ratio.

Table 4.3.3 Mean values of the eleven genotypes for all variates considered in the canonical variate analysis.

GEN	MDT	MPT	Alv.P/L	W	Alv.stre	LFV12%	SDSS
Palmiet	2.500	3.333	0.6439	205.4	31.41	952.8	55.28
SST65	2.028	2.056	0.3744	194.3	29.72	975.3	59.66
SST55	2.122	2.167	0.3856	175.4	26.83	968.7	63.31
T4	1.261	1.000	0.7750	107.3	16.41	838.7	45.17
Marico	3.862	4.889	0.6450	256.2	39.19	936.5	59.50
Kariega	2.578	3.500	0.4672	228.9	34.99	951.2	69.11
SST822	2.750	3.611	0.5433	216.3	33.07	944.1	62.44
SST825	2.664	3.600	0.8134	266.2	40.71	935.0	57.28
Inia	2.920	4.044	0.6267	268.3	41.03	974.1	62.43
SST876	1.983	2.000	0.6650	193.6	29.60	913.8	50.89
SST57	3.234	3.556	0.5039	198.8	30.39	899.6	52.94
Mean	2.537	3.069	0.5858	210.1	32.12	935.4	58.00



NB: T4 contrasts with other genotypes for most of the parameters while SST55, SST65 and Kariega is due to low alveograph P/L ratio, compared to others including T4
Figure 4.3.1 Plot of mean scores of genotypes, canonical variate one plotted against canonical variate two.
 Ma = Marico, In = Inia, Ka = Kariega, Pa = Palmiet, 85 = SST825, 82 = SST822, 86 = SST876, 38 = SST38, T4 = T4 and 57 = SST57.

4.4 Canonical Variate Analysis to find groupings between environments

Similarly to the genotypes, those variates, which were not important, were deleted one-by-one from the analysis until only those with reasonable correlation coefficients were retained. About 10 variates were retained which includes; hectoliter mass, vitreous kernels, thousand kernel mass, flour colour, farinograph absorption, mixograph development time, estimated loaf volume, SKCS-diameter, SKCS-hardness index and moisture content.

The first two canonical variates (CV1 and CV2) together accounted for 81.9% of the total variation among groups. Tables 4.4.1 and 4.4.2, shows the canonical variate mean scores and percentages for the two CVs as well as correlation coefficients between the variates and the first two CVs respectively.

Table 4.4.1 Canonical variate percentage variation and mean scores of the first two canonical variates of the six locations.

Variates	CV1	CV2
	45.93%	35.94%
BullHill	1.156	1.066
Barkly West	0.704	2.701
Prieska	1.364	1.427
Hopetown	0.600	-2.735
Douglas	1.229	-2.525
Loskop	-5.053	0.066

Table 4.4.1 shows that Loskop contrasts the most with other locations. This is due to very high negative CV1 score versus small positive scores for the other sites. The horizontal separation (CV1) accounted for 45.93% of the total variation, and thus showing a larger contribution. Grouping of the six locations is more clearly shown by a plot of the two canonical variates mean scores (Figure 4.4.1). Points closer or further apart in such a plot are similar or dissimilar respectively, with respect to their general response to the variates that discriminate between them. Taking into account all the variates included in the final CVA, Loskop was dissimilar to most of the other sites. This was particularly for vitreous kernels, hectoliter mass and SKCS-hardness index, though it showed to have average loaf volume. Other sites showed to be similar for the three variates but they also showed sub-groups due to estimated loaf volume. Hopetown and Douglas had higher estimated loaf volumes than BullHill, Prieska and Barkly West.

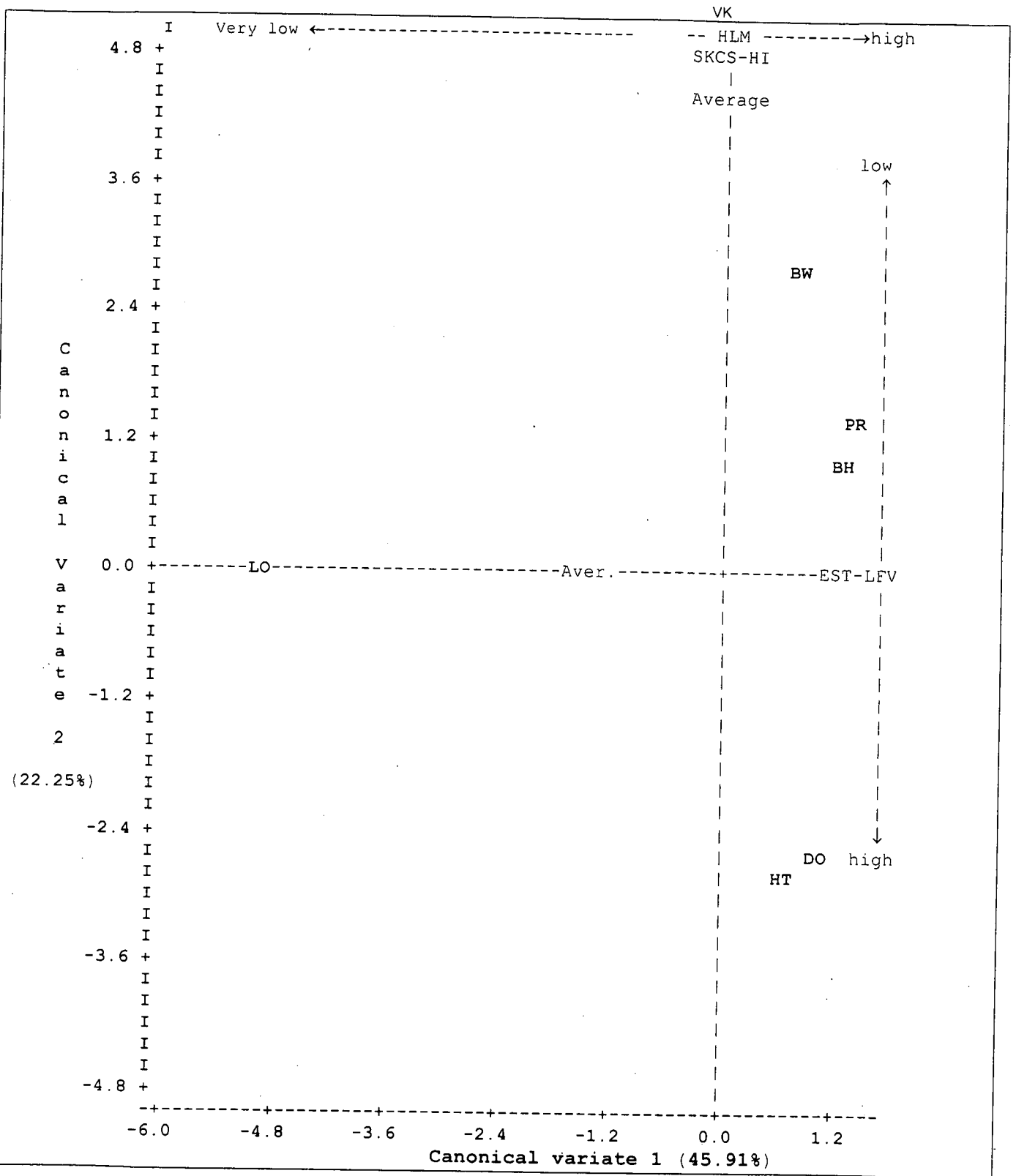
Therefore the main variates which discriminated between locations for CV1 (x-axis) (Figure 4.4.1) were hectoliter mass ($r = 0.802$), vitreous kernels ($r = 0.849$) and to a lesser extent SKCS-hardness index ($r = 0.649$). All these variates correlated strongest positive with the CV1 scores. Generally Loskop had lower

rating for these variates and all these showed deficiency in optimum grain filling conditions and protein quality.

Table 4.4.2 Correlation coefficients of those variates retained in the final CVA with each other and the first two canonical variates.

HLM	1.000										
VK	0.623	1.000									
TKM	0.685	0.497	1.000								
FCL	-0.048	0.266	-0.044	1.000							
FABS	0.495	0.533	0.299	0.160	1.000						
MDT	-0.498	-0.320	-0.275	-0.094	-0.538	1.000					
EST-LFV	-0.141	0.166	-0.121	0.019	0.221	0.100	1.000				
SKCS-DIAM	0.645	0.373	0.872	0.053	0.309	-0.263	-0.246	1.000			
SKCS-HI	0.553	0.479	0.065	0.098	0.556	-0.330	0.129	0.185	1.000		
Moist	-0.679	-0.576	-0.432	-0.246	-0.570	0.451	0.061	-0.515	-0.570	1.000	
CV1	0.802	0.849	0.458	0.595	0.586	-0.630	-0.631	0.392	0.649	-0.799	
CV2	-0.088	-0.031	0.150	-0.490	-0.353	0.016	-0.346	0.257	-0.414	-0.022	
	HLM	VK	TKM	FCL	FABS	MDT	EST-LFV	SKCS-DIAM	SKCS-HI	Moist	

The CV2 (y-axis) accounted for 35.94% to the total variation and has high contribution, also close to that of CV1. The main variate, which discriminated between locations, was loaf volume at normal protein content ($r = -0.346$). This variate correlated slightly negative with the CV2 score but it showed a clear trend of differences between the sites. Therefore Douglas and Hopetown proved to be more isolated by having higher loaf volumes compared to other sites. Probably the main cause for this difference was protein quality as these two sites showed slightly high alveograph P/L ratio for most of the genotypes and this parameter is very important in loaf characteristics. For Prieska the main cause of reduced loaf volume may be due to the low protein content realised at this site. For Barkly West and BullHill probably because they are closer to Loskop, environmental conditions such as high temperature might have interfered with protein quality and thus caused low loaf volume. This is from the fact that according to Ciaffi *et al.* (1996) much variation in the composition of polymeric proteins, related to a loss of dough strength may occur in the presence of frequent episodes of daily maximum temperatures above 35°C during grain filling. Therefore Loskop needs separate strategies for selecting genotypes, which show good interaction for both grain filling and protein quality. For Barkly West, Prieska and BullHill, management practices to increase protein content (especially Prieska) and also genotypes, which show high loaf volume and alveograph P/L ratio, will be necessary. To improve the quality, it is therefore necessary to mix the products from Loskop with most of the other sites. Also those from Barkly West, BullHill and Prieska when mixed with the products from Hopetown and Douglas may improve loaf volume.



NB: Loskop contrasts with others and three environmental groups are realised; LO; BW, BH and PR; HT and DO

Figure 4.4.1 Plot of mean scores of environments, canonical variate one plotted against canonical variate two.

PR = Prieska, BH = BullHill, BW = Barkly West, DO = Douglas, HT = Hopetown, and LO = Loskop.

Table 4.4.3 Mean values of the six locations for all variates considered in the canonical variate analysis.

ENVIR.	HLM	VK	TKM	FCL	FABS	MDT	EST-LFV	DIAM	HI	Moist
BullHill	79.10	86.67	40.41	2.940	62.50	2.181	961.7	2.658	65.23	11.70
BarkWes	78.00	79.03	36.14	4.312	60.88	2.461	894.7	2.684	70.16	11.56
Prieska	81.02	81.21	45.63	2.064	61.87	2.073	879.8	2.994	70.06	11.37
Hopetown	78.45	79.24	36.49	1.868	63.25	2.372	1169.5	2.580	75.92	11.55
Douglas	80.64	84.38	39.64	0.362	63.66	2.182	1002.7	2.721	78.30	11.57
Loskop	74.28	54.67	34.86	0.758	58.48	3.953	962.9	2.550	56.38	12.18
Mean	78.58	77.53	38.86	2.050	61.77	2.537	978.5	2.698	69.34	11.65

4.5 Canonical Variate Analysis to find groupings between environment x genotypes

The interpretation of the performance of a number of genotypes evaluated in a broad range of environments is always affected by genotype x environment interaction. Differential genotype responses to variable environmental conditions, especially associated with changes in ranks of genotypes, limit accurate estimate of yield and other parameters and thus identification of superior, stable genotypes. With the biplot facility from the AMMI analysis, both genotypes and locations occur on the same scattergram, and inferences about specific genotype x location combinations can be made (Crossa *et al.*, 1991).

Similarly to genotypes and environments, those variates, which were not important, were deleted one-by-one from the analysis until only those with reasonable correlation coefficients were retained. About 11 variates were retained and general observation shows both grain filling and hardness and also protein content and protein quality had larger effects. The variates includes hectoliter mass, breakflour yield, vitreous kernels, farinograph water absorption, mixograph development time, SKCS-hardness index and moisture content. Therefore these were the parameters more associated with interaction effect.

The first two canonical variates (CV1 and CV2) together accounted for 68.2% of the total variation among groups. Tables 4.5.1 and 4.5.2, shows the canonical variate mean scores and percentages for the two CVs as well as correlation coefficients between the variates and the first two CVs respectively.

Table 4.5.1 Canonical variate percentage variation and mean scores of the first two canonical variates of the sixty six G x E interaction combinations.

Envi x Gen	CV1	CV2	Envi x Gen	CV1	CV2
	45.91%	22.25%			
BH Pa 1	-0.785	0.323	HT 55 36	-0.629	3.210
BH 65 2	4.528	5.436	HT T4 37	-7.432	2.574
BH 55 3	4.629	6.031	HT Ma 38	-0.843	-2.156
BH T4 4	-4.223	4.698	HT Ka 39	4.992	6.364
BH Ma 5	1.610	-1.198	HT 82 40	-2.183	-1.931
BH Ka 6	4.285	4.035	DO 85 41	-6.802	-2.625
BH 82 7	-2.138	0.781	DO In 42	-3.300	-1.751
BH 85 8	-3.789	-2.285	DO 86 43	-8.862	-5.333
BH In 9	-0.353	1.010	DO 57 44	-5.385	0.767
BH 86 10	-1.004	1.953	DO Pa 45	-7.852	-3.921
BW 57 11	1.549	1.551	DO 65 46	-1.944	0.984
BW Pa 12	-0.320	-4.115	DO 55 47	-0.950	2.734
BW 65 13	2.821	2.568	DO T4 48	-10.492	1.813
BW 55 14	3.734	4.358	DO Ma 49	-4.367	-2.810
BW T4 15	-4.981	2.790	DO Ka 50	0.512	0.804
BW Ma 16	1.885	-3.471	LO 82 51	-7.411	-2.917
BW Ka 17	1.748	1.875	LO 85 52	-9.620	-4.959
BW 82 18	-3.875	-3.107	LO In 53	-5.265	-3.232
BW 85 19	-2.460	-4.720	LO 86 54	-7.485	-3.346
BW In 20	0.759	-1.169	LO 57 55	-2.796	-1.719
PR 86 21	-1.819	0.528	LO Pa 56	6.336	1.050
PR 57 22	-0.979	-0.916	LO 65 57	9.937	8.750
PR Pa 23	-3.731	-1.450	LO 55 58	12.310	9.349
PR 65 24	1.335	3.186	LO ma 59	6.352	9.430
PR 55 25	1.410	2.244	LO Ma 60	20.358	-15.041
PR T4 26	-6.790	4.352	KK Ka 61	14.477	5.492
PR Ma 27	-0.185	-2.528	KK 82 62	9.123	-2.419
PR Ka 28	0.781	3.826	KK 85 63	5.614	-4.961
PR 82 29	-3.163	0.552	KK In 64	10.653	-3.304
PR 85 30	-8.178	-3.053	KK 86 65	5.455	3.981
HT In 31	-2.524	-1.996	KK 57 66	20.146	-15.245
HT 86 32	-5.389	-0.276			
HT 57 33	-1.361	-2.026			
HT Pa 34	-4.308	-1.844			
HT 65 35	-1.366	2.423			

It is evident from Table 4.5.1 that the interaction combinations LoMa(60) and Lo57(66) contrasts the most with other interaction combinations. This is due to very high positive and negative CV1 and CV2 scores respectively. Other interaction combinations, which showed higher positive/negative scores for the CV1, were LoKa(61), LOIn(64), LO55(58), LO65(57), LO82(62), HT86(43), PR85(30), DOPa(45) and DOT4(48). Other interactions showed intermediate to very low scores with this axis. The horizontal separation (CV1) accounted for nearly 45.91% (more than half) of the total variation and thus contributed more. Grouping of the

66 GxE interactions is more clearly shown by a plot of the two canonical variates mean scores (Figure 4.5.1). Points closer or further apart in such a plot are similar or dissimilar respectively, with respect to their general response to the variates that discriminate between them. Taking into account all the variates included in the final CVA, most of the interactions realised at Loskop were dissimilar to those of the other sites. This was particularly due to the fact that most of the interactions were associated with decrease in hectoliter mass, farinograph water absorption, vitreous kernels, SKCS-hardness index and alveograph P/L ratio. The variation in mixing time as explained by axis-2, the codes (60 and 66) represents the genotypes Marico and SST57 at Loskop, where they showed very high mixing time (> 7.4 min) and this contrasts more with other codes. It was in the same location where the genotypes; T4, SST65 and SST55 also showed low mixing time (codes 59, 57 and 58) and became isolated from others. For these parameters the interactions of T4 at Douglas (48), SST825 (30) at Prieska, SST876 (43) at Hopetown, and Palmiet (45) at Douglas, proved to be high but still most of the interactions were close to the mean and higher. At BullHill, SST55 and SST65 also showed low mixing time (2 and 3) and T4 at Hopetown (4). Therefore for the locations, Loskop needs much attention and to a lesser extent Hopetown and BullHill in terms of interaction effects.

The main variates which discriminated the interaction effects for CV1 (x-axis) (Figure 5.5.1) were hectoliter mass ($r = -0.734$), farinograph water absorption ($r = -0.758$), alveograph P/L ratio ($r = -0.593$), breakflour yield ($r = 0.627$), sedimentation ($r = 0.639$), moisture content ($r = 0.765$) and vitreous kernels ($r = -0.547$). All variates correlated strongest or intermediate positive/negative with the CV1 scores. However, not all showed a clear trend and that is why some were not discussed. Also for mixograph development time, though the correlations were not so different for both axes, a clear trend was shown by CV2 than CV1. Therefore mixograph development time ($r = -0.678$) was the only variate, which discriminated the interaction effects for CV2 (y-axis). This accounted for 22.6% of the total variation showing a low contribution.

Table 4.5.2 Correlation coefficients of those variates retained in the final CVA with each other and the first two canonical variates.

HLM	1.000											
BFLY	-0.542	1.000										
VK	0.623	-0.493	1.000									
FABS	0.495	-0.494	0.533	1.000								
MDT	-0.498	0.338	-0.320	-0.538	1.000							
MPT	-0.423	0.230	-0.171	-0.332	0.713	1.000						
Alv. P/L	0.381	-0.441	0.219	0.559	-0.104	-0.078	1.000					
Alv.stre	-0.152	-0.047	0.224	0.145	0.413	0.614	0.098	1.000				
SDSS	-0.536	0.501	-0.127	-0.289	0.478	-0.513	-0.411	0.481	1.000			
SKCS-HI	0.553	-0.609	0.479	0.556	-0.330	-0.128	0.625	-0.015	-0.495	1.000		
Moist	-0.679	0.550	-0.576	-0.570	0.451	0.330	-0.421	0.027	0.466	-0.570	1.000	
CV1	-0.734	0.627	-0.547	-0.758	0.703	0.405	-0.593	0.117	0.639	-0.849	0.765	
CV2	-0.101	0.307	-0.106	0.026	-0.678	-0.434	-0.442	-0.414	0.063	-0.366	0.146	
	HLM	BFLY	VK	FABS	MDT	MPT	ALv.P/L	Alv. stre	SDSS	SKCS- HI	Moist	

Loskop was the site which showed contrasting interactions with most of the other sites. This was the result of low grain filling as revealed by low hectoliter mass (Table 4.5.3). High protein does not mean high quality and this was the case for Loskop also: Although the site had protein content much closer to other sites, probably the quality was poor. That is why the parameters which showed lower mean values were those influenced by protein composition (quality) and protein-starch interaction more than those influenced more by protein content such as sedimentation and mixograph development time.

This site needs genotypes with shorter grain filling period, and with stability or positive environment interaction for alveograph P/L ratio, SKCS-hardness index, farinograph absorption, vitreous kernels and hectoliter mass. For the genotypes care should also be taken for Marico, SST57, Kariaga, SST55, SST65, T4 and to a lesser extent Inia and SST822, which showed negative interactions particularly at Loskop. The parameters (SKCS-HI, P/L ratio, FABS, VK and HLM) showed similar trends and thus it is possible to deal with them simultaneously. However, mixograph development time, mixograph point score, alveograph strength and sedimentation which showed slightly different trends, each needs individual consideration to see which genotype x environment combination will result in optimum values.

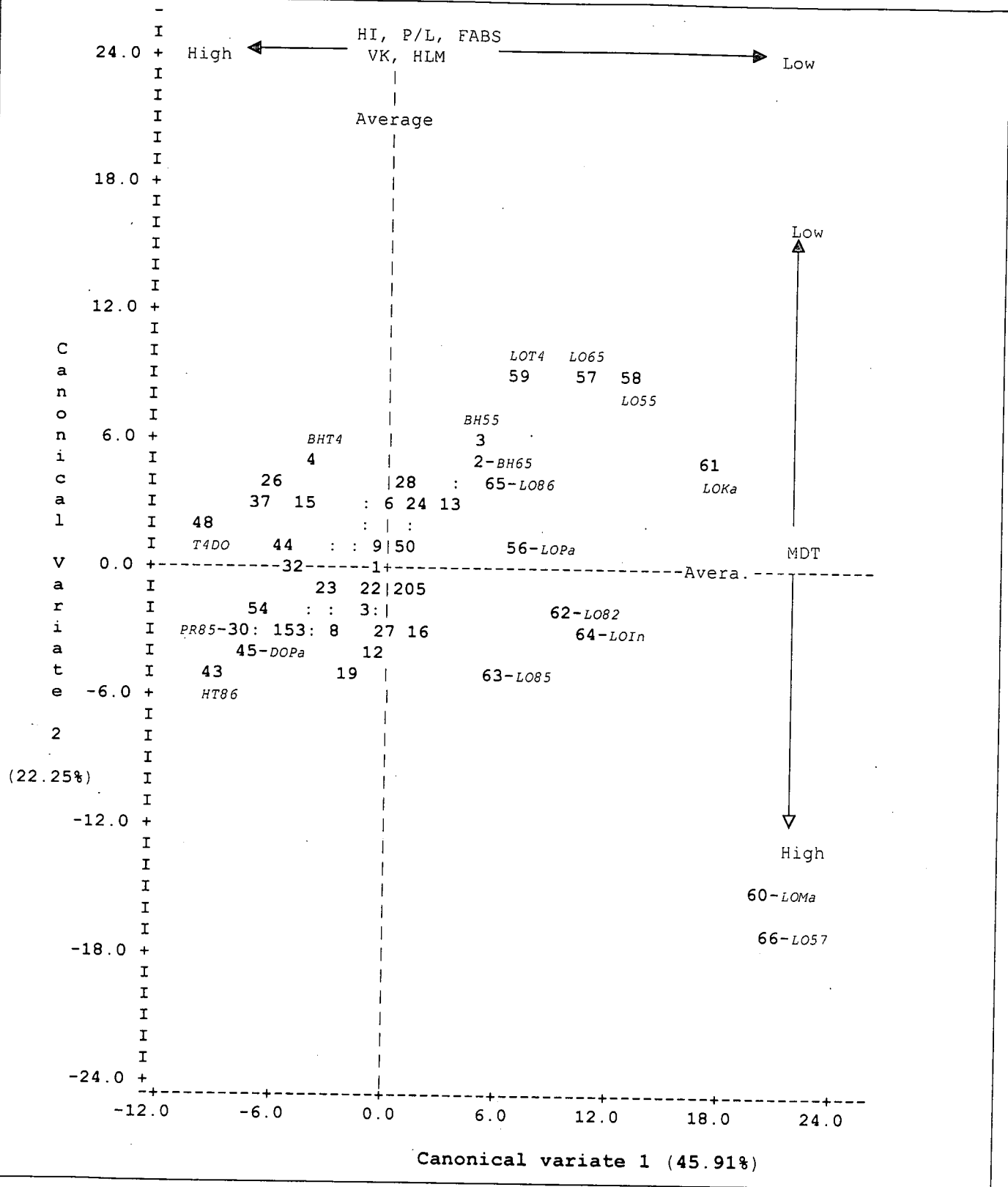


Figure 4.5.1 Plot of mean scores of genotypes x environments interactions, canonical variate one plotted against canonical variate two.

Table 4.5.3 Mean values of the 66 G x E interaction combinations for all variates considered in the canonical variate analysis.

ENVIR x GENO	HLM	BFLY	VK	FABS	MDT	MPT	Alv. P/L	Alv.stre	SDSS	SKCS-HI	MOIST
BH Pa 1	79.07	17.83	89.33	63.80	2.100	2.667	0.4633	31.93	50.67	66.48	11.57
BH 65 2	77.80	23.57	86.67	60.00	1.867	1.333	0.2967	30.30	58.33	57.66	11.78
BH 55 3	78.80	24.40	88.00	61.28	1.967	1.667	0.2933	27.57	64.00	55.95	11.66
BH T4 4	79.20	21.33	79.33	65.53	1.167	1.000	0.7433	19.07	47.67	66.87	11.46
BH Ma 5	80.27	23.57	92.67	60.67	3.167	5.000	0.6167	39.30	57.67	66.18	11.80
BH Ka 6	78.33	24.80	86.67	61.50	2.500	4.000	0.4900	43.00	69.33	59.22	11.94
BH 82 7	79.47	22.17	90.67	64.83	2.233	3.333	0.4367	39.90	58.00	70.73	11.71
BH 85 8	79.07	19.92	88.00	65.16	2.453	3.933	0.6873	47.35	56.67	74.33	11.64
BH In 9	78.87	22.43	90.00	64.50	2.467	4.000	0.4833	44.57	59.39	63.62	11.53
BH 86 10	80.73	20.73	86.67	61.17	1.633	1.000	0.3767	28.33	50.67	69.85	11.80
BH 57 11	78.53	23.47	75.33	59.03	2.433	3.333	0.3733	30.53	53.00	66.62	11.80
BW Pa 12	78.47	17.20	76.67	61.80	2.867	4.000	0.5633	39.57	56.33	74.52	11.81
BW 65 13	78.43	20.20	81.33	60.32	2.133	2.667	0.4000	30.43	57.33	63.44	11.83
BW 55 14	76.93	22.13	80.00	59.97	2.100	2.333	0.3967	23.20	57.33	61.69	11.77
BW T4 15	78.93	20.47	72.00	61.40	1.233	1.000	0.7533	16.57	45.33	72.67	11.31
BW Ma 16	78.10	21.97	80.67	59.07	3.333	5.000	0.6267	48.97	59.67	66.01	11.49
BW Ka 17	77.47	21.50	78.00	59.38	2.333	3.333	0.5133	30.57	62.00	68.01	11.68
BW 82 18	79.23	19.03	84.00	62.77	2.600	4.000	0.6233	35.67	59.00	77.29	11.29
BW 85 19	75.77	18.07	83.33	63.37	2.967	4.000	0.8333	39.20	56.33	77.35	11.43
BW In 20	77.53	23.40	79.33	60.35	3.033	4.667	0.5500	40.83	61.00	66.14	11.30
BW 86 21	79.60	20.47	81.33	61.02	1.933	2.000	0.5533	29.37	53.33	72.98	11.69
BW 57 22	77.50	22.30	72.67	60.20	2.533	3.333	0.4833	33.57	50.33	71.64	11.59
PR Pa 23	81.80	20.90	86.00	63.20	2.067	1.333	0.7100	29.27	54.00	72.89	11.36
PR 65 24	79.93	22.20	88.00	61.77	1.867	1.000	0.2967	24.83	57.33	64.17	11.59
PR 55 25	81.93	22.93	87.33	61.07	2.033	1.000	0.3700	26.20	60.33	61.52	11.35
PR T4 26	79.47	23.93	64.00	63.40	1.100	1.000	0.7567	9.83	33.00	70.00	11.38
PR Ma 27	79.33	23.90	82.00	57.40	3.200	5.000	0.4800	30.90	53.33	74.93	11.65
PR Ka 28	80.07	25.03	76.00	60.87	1.833	1.000	0.3767	25.17	58.33	63.47	11.51
PR 82 29	81.20	22.57	93.33	63.40	2.133	2.333	0.4633	27.67	63.33	75.52	11.42
PR 85 30	82.13	19.63	84.67	65.85	1.900	1.667	0.8567	34.00	53.33	78.10	11.07
PR In 31	81.60	19.63	86.00	62.58	2.333	2.667	0.6967	37.87	60.33	68.23	11.10
PR 86 32	83.00	18.70	73.33	62.58	1.500	1.000	0.5467	21.77	46.67	72.07	11.22
PR 57 33	80.80	21.53	72.67	58.45	2.833	5.000	0.4767	31.10	50.67	69.74	11.37

Table 4.4.3 - continued

ENVIR x GENO	HLM	BFLY	VK	FABS	MDT	MPT	P/L	Strength	SDSS	HI	MOIST
HT Pa 34	79.60	21.03	75.33	63.53	2.433	3.667	0.7700	31.67	58.00	78.78	11.64
HT 65 35	77.47	23.87	79.33	62.68	2.033	2.333	0.5033	29.80	60.00	73.18	11.74
HT 55 36	80.00	24.93	79.33	61.92	2.100	2.667	0.4767	25.37	61.67	68.42	11.60
HT T4 37	78.53	23.60	80.00	64.72	1.333	1.000	0.7467	19.90	49.67	79.63	11.40
HT Ma 38	76.60	25.13	81.33	61.73	3.267	5.000	0.5967	39.93	62.33	74.29	11.50
HT Ka 39	72.73	27.20	76.67	63.15	2.600	4.333	0.3567	37.83	81.33	63.14	11.82
HT 82 40	80.07	24.63	87.33	60.18	2.967	4.000	0.5033	24.97	64.33	82.12	11.60
HT 85 41	80.80	23.47	84.00	63.62	2.533	4.000	0.5633	34.27	56.00	81.62	11.29
HT In 42	78.40	23.53	82.35	63.77	2.755	4.233	0.6917	41.55	64.17	75.10	11.37
HT 86 43	81.47	21.83	75.33	65.98	2.433	3.333	1.1433	46.33	48.00	80.86	11.54
HT 57 44	77.27	22.20	70.67	64.47	1.633	1.000	0.8067	27.47	51.67	77.99	11.57
DO Pa 45	82.13	17.87	85.33	66.25	2.267	3.333	1.0133	28.50	52.33	82.26	11.50
DO 65 46	80.20	22.10	88.67	63.25	1.967	2.000	0.5367	36.23	57.67	71.69	11.76
DO 55 47	81.33	23.37	87.33	63.28	1.767	1.000	0.5267	29.53	59.33	66.55	11.61
DO T4 48	80.20	22.30	75.33	65.75	1.067	1.000	1.2767	16.90	42.67	82.66	11.59
DO Ma 49	79.87	23.50	88.00	62.22	2.800	4.333	0.7767	36.03	54.33	80.07	11.68
DO Ka 50	76.93	23.93	80.00	62.00	2.533	3.333	0.7067	39.97	67.33	73.19	11.97
DO 82 51	81.67	22.00	92.00	64.52	2.300	3.000	0.8633	34.17	58.33	83.46	11.41
DO 85 52	81.93	18.47	89.33	66.08	2.200	3.000	1.0933	37.53	54.33	82.62	11.08
DO In 53	80.59	21.43	87.48	64.18	2.565	3.700	0.8750	41.09	59.40	77.48	11.38
DO 86 54	82.33	19.93	84.67	63.82	1.967	1.333	1.0000	24.27	47.67	84.22	11.65
DO 57 55	79.80	23.43	70.00	58.90	2.567	3.667	0.5067	29.87	51.33	77.15	11.61
LO Pa 56	74.57	23.33	58.00	58.72	3.267	5.000	0.3433	27.53	60.33	65.80	12.24
LO 65 57	73.87	26.97	52.00	59.15	2.300	3.000	0.2133	26.70	67.30	51.15	12.30
LO 55 58	74.37	28.73	60.67	58.33	2.767	4.333	0.2500	29.10	77.20	47.27	12.26
LO T4 59	74.90	28.30	46.67	58.80	1.667	1.000	0.3733	16.17	52.67	51.26	11.96
LO Ma 60	74.77	27.40	64.00	55.33	7.407	5.000	0.7733	40.00	69.67	52.39	12.16
LO Ka 61	74.77	29.63	47.33	58.02	3.667	5.000	0.3600	33.43	76.33	45.41	12.44
LO 82 62	73.00	25.70	55.33	59.88	4.267	5.000	0.3700	36.07	71.67	65.07	12.15
LO 85 63	74.03	21.60	62.00	61.03	3.933	5.000	0.8467	51.93	67.00	66.65	12.06
LO In 64	74.23	24.27	58.67	58.37	4.367	5.000	0.4633	40.27	70.30	60.53	12.15
LO 86 65	75.00	23.87	41.33	59.65	2.433	3.333	0.3700	27.53	59.00	60.37	12.14
LO 57 66	73.60	25.77	55.33	56.03	7.407	5.000	0.3767	29.83	60.67	54.28	12.18
Mean	78.58	22.69	77.53	61.77	2.537	3.069	0.5858	32.12	58.00	69.34	11.65

4.6 Conclusion for the 1997 results

The mixograph development time showed discrimination in both main effects (environment and genotypes) as well as interaction, and seems to be an important factor. This shows the significant sensitivity of this parameter, and thus the need of identifying both genotypes and environments with optimum mixing time. In sites where the interaction is more, selection of genotypes, which will result in desirable mixing time, is necessary. Most of the parameters, which discriminated the genotypes, were those associated with high protein content and quality. However, except for loaf volume at 12% protein which was more genetically controlled and which will therefore give a good response on selection, other parameters showed environment interaction. Therefore for mixograph development time and point score, alveograph P/L ratio, alveograph strength and sedimentation in addition to identification of genotypes with medium to good values, identification of environments where these genotypes gives positive interactions will increase reliability of a good quality crop. Among the parameters, which discriminated between the environments, protein related ones were few; rather grain filling and hardness parameters were more responsible. In addition to mixograph development time as one of the protein related parameters, estimated loaf volume (at normal protein) was another. This calls for proper management to ensure high protein yield and selection of genotypes, which show good interaction for protein quality.

Flour colour was also largely influenced by environment and therefore the environments must be classified on their potential to give either of the three flour categories (cake, white bread and brown bread). Among the grain filling parameters, hectoliter mass was influenced by both environment and interaction. Therefore there is a need for improving grain filling conditions at each location, especially Loskop and identification of genotypes, which perform well in specific locations. However, for SKCS-diameter and thousand kernel mass which focuses much on individual wheat grain, it shows only the environments were responsible for the variation in these parameters. This again needs similar strategies as hectoliter mass and for locations like Loskop and to a lesser extent Barkly West where these parameters appeared to be low for most of the genotypes. There is probably a need to select genotypes with very short grain filling period so as to escape stress. Vitreous kernels, farinograph water absorption and environments and interaction also influenced hardness index. However, since these parameters proved to be influenced more by grain filling conditions and protein content (especially protein quality), both environment improvement (for grain filling and protein assimilation) and selection of genotypes, which perform well in specific locations, will be necessary. Moisture content for the environment showed mostly negative correlations with most of the parameters. This was mainly due to Loskop where moisture was high but lower values for most of the other parameters. Therefore careful inspection before harvesting to see if the grain moisture content is low at Loskop is necessary.

CHAPTER 5

RESULTS AND DISCUSSION FOR 1998 DATA

5.1 Quality parameters

The result shows that the magnitude of stress was somehow less compared to the previous year. As a result larger genotype and interaction effects were revealed for most of the parameters.

Flour yield

The ANOVA results are summarised in Table 5.1.1. Treatment, environment, genotypes, interaction, IPCA as well as residual were highly significant ($P < 0.001$). This implies different genotype performance, environmental conditions between locations as well as presence of specific interaction effects. However, non-significant block effect implies absence of variation for particular genotypes within locations. The significant residual also implies presence of noise effects. Compared to 1997 results, this year showed more interaction contribution to the variation followed by genotype and then environment. The environment contribution to the variation was 12.9% almost half that of 1997. Genotype contribution was 23.1%, and interaction contribution 36.7% showing a large effect for both genotype and environment. Out of this variation IPCA captured 50.5%.

Table 5.1.1 Analysis of variance results for flour yield in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	474.6	2.271			
Treatment	69	345.2	5.002	5.584	0.000	
Environment (E)	6	61.4	10.235	11.424	0.000	12.9
Block	14	16.5	1.181	1.318	0.206	
Genotype (G)	9	109.4	12.150	13.562	0.000	23.1
G x E	54	174.4	3.230	3.605	0.000	36.7
IPCA	14	88.1	6.296	6.296	0.000	50.5
Residual	40	86.3	2.157	2.157	0.000	
Error	126	112.9	0.896			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = $(SS \text{ for Genotype, Environment or } G \times E / SS \text{ for total}) \times 100$

IPCA = $(SS \text{ for IPCA} / SS \text{ for } G \times E) \times 100$

The environment means ranged between 74.51 to 76.35 at Hopetown and BullHill respectively, with a grand mean of 75.56. This shows that all localities managed to reveal their potential and they were not very far from

the mean and recommended value 76.0%. However, the significant difference among locations was due to the fact that at BullHill and Koedoeskop more than half of the genotypes were above the recommended value and only two slightly below the mean, showing good potential for flour yield. Hopetown had only one genotype above the recommended value; most were below the mean, showing less potential. For other sites almost half of the genotypes were close to the mean and some above the recommended value. Genotype means (Appendix 2) ranged between 74.38 to 76.73 for Palmiet and Kariega respectively. Despite presence of interaction, genotype main effect was more pronounced and at least three groups were realised. Kariega, SST38, SST876 and Marico had higher means, close to the recommended value and they didn't show interaction. T4, Inia and SST822 were below the recommended value but close to the grand mean, whereas Palmiet, SST822 and SST57 were much below the mean, particularly Palmiet.

The AMMI biplot for genotype and environment means (Figure 5.1.1) shows very high environment interaction for Palmiet and SST825 and to a lesser extent for SST822 and SST825. Palmiet ranked last or second from last at five sites but it was almost at the middle at Prieska and Douglas. SST825 ranked last at four sites but it was second, third and sixth at Hopetown, BullHill and Koedoeskop respectively. SST822 ranked close to the middle in most of the sites but it was second from last at Prieska and Douglas. Therefore, Palmiet, SST825 and SST822 may not give reliable ranking at most of the locations. However, SST876, which ranked higher at most of the sites, ranked intermediate at BullHill and Hopetown. But this genotype together with others that showed stability with slight fluctuations, may give reliable ranking at most of the sites.

For the locations (Figure 5.1.1) high interaction was shown at Prieska, Hopetown, BullHill and to a lesser extent Koedoeskop and Douglas, with the other two sites being highly stable.

In summary, SST825 may be included as a reference at BullHill and Hopetown, but its results at these sites together with Palmiet and SST822 both at Prieska and Douglas should not be generalised to other sites. For the locations care must be taken at Prieska, Hopetown and to a lesser extent BullHill for genotypes with interaction. Other sites may give reliable ranking for most of the genotypes.

Table 5.1.2 Ranking of genotypes in each location for flour yield and environmental means in 1998.

Rank	Bullhill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	Kariega (77.77)	Kariega (76.56)	SST876 (76.60)	Kariega (76.04)	SST876 (76.88)	Kariega (76.82)	Kariega (77.17)
2	SST38 (77.19)	SST876 (76.34)	Marico (76.01)	SST825 (75.86)	Kariega (76.77)	SST876 (76.64)	SST38 (76.71)
3	SST825 (77.16)	SST38 (76.29)	SST38 (75.99)	SST38 (75.36)	SST38 (76.61)	SST38 (76.56)	SST876 (76.42)
4	SST822 (76.81)	Marico (75.91)	Kariega (75.96)	SST822 (75.23)	Marico (76.39)	Marico (76.21)	Marico (76.09)
5	SST876 (76.67)	T4 (75.51)	Palmiet (75.95)	SST876 (74.68)	T4 (75.97)	T4 (75.80)	SST822 (76.00)
6	Marico (76.41)	SST822 (75.08)	T4 (75.57)	Marico (74.47)	Palmiet (75.57)	Inia (75.31)	SST825 (75.95)
7	Inia (76.21)	Inia (75.05)	SST57 (74.98)	Inia (74.46)	SST57 (75.34)	SST822 (75.31)	T4 (75.71)
8	T4 (76.04)	SST57 (74.85)	Inia (74.50)	T4 (74.11)	Inia (75.28)	SST57 (75.15)	Inia (75.63)
9	SST57 (75.32)	Palmiet (74.63)	SST822 (73.96)	SST57 (73.37)	SST822 (75.08)	Palmiet (74.99)	SST57 (75.02)
10	Palmiet (73.87)	SST825 (74.45)	SST825 (72.38)	Palmiet (71.57)	SST825 (74.09)	SST825 (74.63)	Palmiet (74.06)
Mean	76.35	75.47	75.19	74.51	75.80	75.74	75.88

Grand mean = 75.56 LSD (0.05): treatment = 0.314 , environment = 0.992

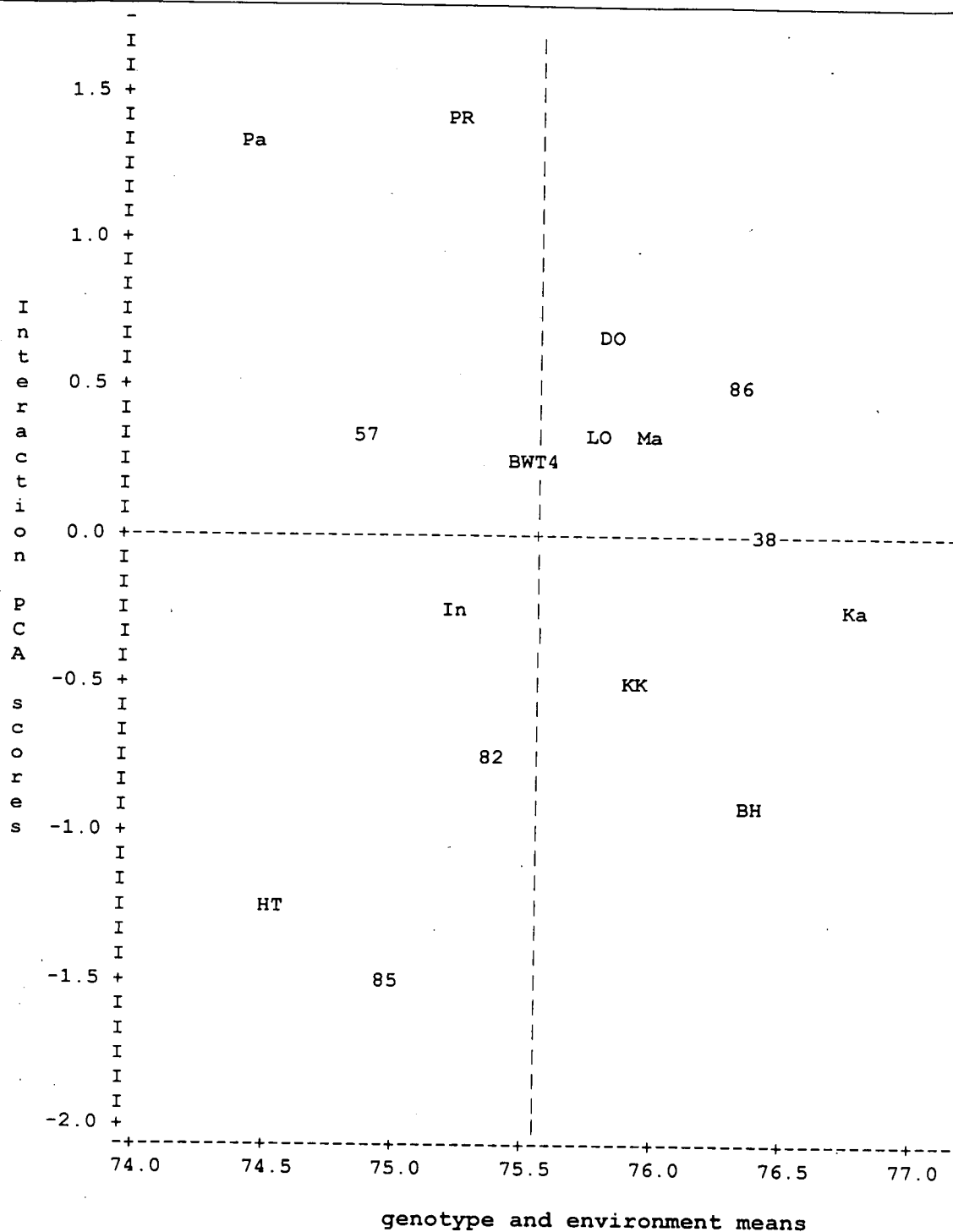


Figure 5.1.1 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariëga, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for flour yield in 1998.

Hectoliter mass

The analysis of variance results (Table 5.1.3) shows that, treatment, main sources of variation, interaction as well as IPCA were highly significant ($P < 0.001$). The residual and block effects were significant at ($p < 0.05$) and ($p < 0.01$) respectively, implying presence of slight noise effect and particular genotype variation within locations. The environment contribution to the variation was 54.6%, slightly lower than that of 1997, but higher than other sources of variation showing much influence of environment on this parameter. The genotype contribution to the variation was 11.9%, close to that of 1997, showing less genetic influence on this parameter. The contribution of interaction to the variation was 16.6%, slightly higher than that of the genotypes, showing interaction to have more influence than environment. Out of this the IPCA captured 59.2% of variation.

Table 5.1.3 Analysis of variance results for hectoliter mass in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	1180.4	5.65			
Treatment	69	980.9	14.22	11.46	0.000	
Environment (E)	6	645.0	07.50	86.64	0.000	54.6
Block	14	43.1	3.08	2.48	0.004	
Genotype (G)	9	140.0	15.56	12.54	0.000	11.9
G x E	54	195.9	3.63	2.92	0.000	16.6
IPCA	14	116.0	8.29	6.68	0.000	59.2
Residual	40	79.9	2.00	1.61	0.025	
Error	126	56.3	1.24			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = $(SS \text{ for Genotype, Environment or } G \times E / SS \text{ for total}) \times 100$

IPCA = $(SS \text{ for IPCA} / SS \text{ for } G \times E) \times 100$

However, as mentioned earlier it seems the stress effects were less, as the environment means ranged between $76.15\text{kg}/\text{hl}^{-1}$ to $81.38\text{kg}/\text{hl}^{-1}$ at BullHill and Prieska respectively, with a grand mean of $77.89\text{kg}/\text{hl}^{-1}$. Therefore all sites managed to be above the recommended value of $76\text{kg}/\text{hl}^{-1}$ and the observed difference among locations was mainly due to interaction effects with some genotypes. From environmental main effect, Prieska and Douglas (especially Prieska) showed very high means and far above the grand mean. Loskop and Koedoeskop were close to the grand mean, whereas Hopetown, Barkly West and BullHill were far below the mean especially Barkly West and BullHill. The genotype means (Appendix 2) ranged between $76.68\text{kg}/\text{hl}^{-1}$ to $79.05\text{kg}/\text{hl}^{-1}$ for SST57 and SST38 respectively. Apart from interaction effects, genotype main effects showed at least three groups. SST38, Inia, SST876 and SST822 had higher means and showed good

performance at most of the sites. Also these genotypes together with SST825 showed adaptation to high potential areas. SST825, Palmiet, T4 and Kariega had means close to the grand mean, with Palmiet, T4 and Kariega together with Marico showing adaptation to lower potential areas. SST57 and Marico had means very far below the grand mean and ranked very low at most of the sites. Therefore these two genotypes together with Kariega, have low potential for hectoliter mass.

The AMMI biplot for genotype and environment means (Figure 5.1.2) showed high environment interaction for SST825 and Marico and to a lesser extent SST876 and SST57. SST825 ranked first at Hopetown and intermediate at Prieska and Douglas, but it ranked very low at other sites. Marico and SST57 ranked last or second from last at most of the locations, except Koedoeskop and Barkly West. SST876 ranked intermediate to higher at most of the sites except Koedoeskop where it ranked very low. Therefore these genotypes may not give reliable ranking at all sites and care must be taken where the interaction is positive or negative not to be generalised to other sites. However, other genotypes showed stability and may give reliable rank at most of the locations (Table 5.1.4).

The locations (Figure 5.1.2) showed high genotype interaction at Hopetown and to a lesser extent Koedoeskop and Barkly West. Koedoeskop contrast more with other sites as SST825 and SST57 ranked first and close to the middle at this site, but they ranked lower at other locations. Both Palmiet and Marico were responsible for interaction at Koedoeskop and Barkly West as they ranked slightly higher compared to other sites. Other sites showed stability with Prieska and Douglas having higher and BullHill low mean values.

In summary, SST825 may be included as a reference at Hopetown, Prieska and Douglas. Results of SST825 and SST57 should not be generalised to other sites. Values of Marico and SST876 realised at Koedoeskop will probably not be realised at other sites; due to environment interaction. However, other genotypes may give reliable ranking at most of the locations. For the locations only Koedoeskop and Hopetown interacted with genotypes, but other sites especially Prieska and Douglas may give reliable ranking for most of the genotypes.

Table 5.1.4 Ranking of genotypes in each location for hectoliter mass and environmental means in 1998.

Rank	Bullhill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	Inia (77.43)	Inia (77.73)	SST38 (82.65)	SST825 (79.65)	SST38 (80.42)	Inia (78.38)	Inia (78.91)
2	SST38 (77.20)	SST38 (77.11)	SST876 (82.41)	SST876 (79.55)	Inia (80.39)	SST38 (79.14)	SST38 (78.12)
3	SST876 (76.65)	SST822 (76.73)	Inia (82.41)	SST38 (78.73)	SST876 (80.05)	SST876 (78.59)	SST822 (77.84)
4	SST822 (76.60)	Palmiet (76.38)	SST822 (81.79)	SST822 (76.98)	SST822 (79.68)	SST822 (78.55)	Palmiet (77.59)
5	Palmiet (76.01)	SST876 (76.31)	SST825 (81.69)	Inia (76.90)	SST825 (79.23)	Palmiet (77.97)	Marico (77.51)
6	T4 (75.92)	T4 (76.21)	Palmiet (80.91)	SST57 (76.76)	Palmiet (78.93)	T4 (77.87)	T4 (77.38)
7	Kariega (75.84)	Marico (76.15)	T4 (80.91)	Kariega (75.51)	T4 (78.89)	Kariega (77.80)	Kariega (77.27)
8	SST825 (75.69)	Kariega (76.11)	Kariega (80.86)	T4 (75.45)	Kariega (78.83)	SST825 (77.63)	SST876 (77.20)
9	Marico (75.42)	SST825 (75.15)	SST57 (80.32)	Palmiet (75.13)	Marico (78.10)	Marico (77.39)	SST825 (75.95)
10	SST57 (74.77)	SST57 (74.60)	Marico (79.89)	Marico (72.64)	SST57 (78.06)	SST57 (76.71)	SST57 (75.57)
Mean	76.15	76.25	81.38	76.73	79.26	78.10	77.33

Grand mean = 37.99 LSD (0.05): treatment = 0.369 , environment = 1.167

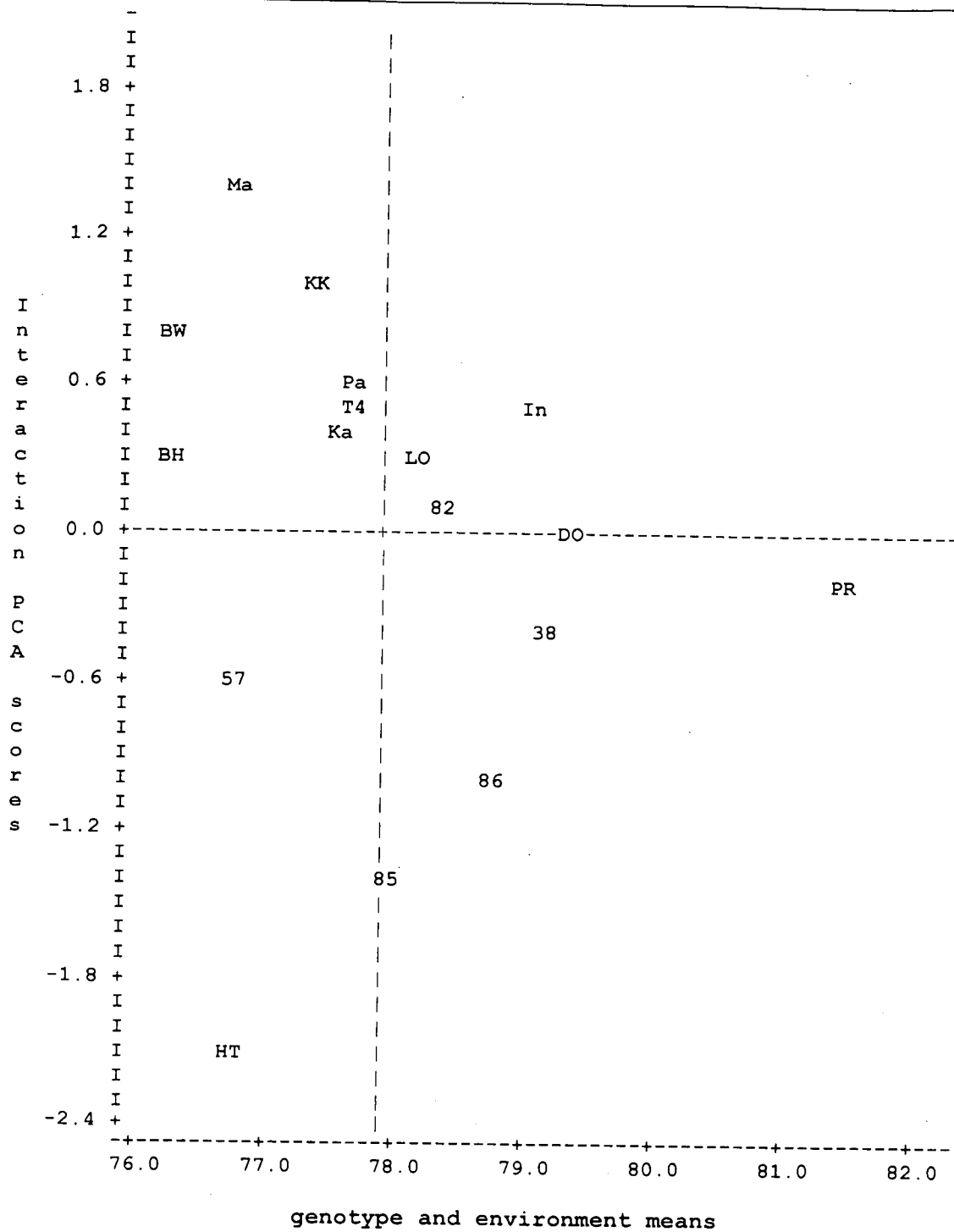


Figure 5.1.2 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) At seven localities BH = Bullhill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for hectoliter mass in 1998.

Thousand kernel mass

The ANOVA results (Table 5.1.5) show highly significant variations for treatment, environments, genotypes, interaction, IPCA, block effect as well as residual. This implies different genotype performance, variation in environmental conditions between and within locations as well as presence of specific interaction effect. The significant block effect and residual indicates presence of variations for particular genotypes within locations and presence of noise effects respectively. Compared to the 1997 results, the range between the lower and higher values were decreased due to a slight increase in lower value and a large decrease in the higher value. The environment contribution to the variation was 26.0%, much lower than that of 1997. The genotype contribution to the variation was 35.3%, which was higher than both environment and interaction contribution and thus signifies genetic effect for this parameter. The interaction contribution to the variation was 19.1% showing main effects to have more influence. Out of this the IPCA captured 42.4% of the variation.

Table 5.1.5 Analysis of variance results for thousand kernel mass in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	3480	16.65			
Treatment	69	2796	40.52	11.07	0.000	
Environment (E)	6	904	150.66	41.14	0.000	26.0
Block	14	223	15.93	4.35	0.000	
Genotype (G)	9	1228	136.48	37.27	0.000	35.3
G x E	54	664	12.29	3.36	0.000	19.1
IPCA	14	282	20.13	5.50	0.000	42.4
Residual	40	382	9.54	2.61	0.000	
Error	126	461	3.66			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 5.1.6) ranged between 35.56 g to 40.89 g at Barkly West and Prieska respectively, with a grand mean of 37.99g. Environmental main effects show Prieska, BullHill and Douglas to be far above the mean, especially the former two. More than half of the genotypes were above the recommended value of 40 g. Other sites like Loskop, Hopetown, Koedoeskop and Barkly West had means below the grand mean and only three genotypes were close to the recommended value. Therefore in connection to the hectoliter mass it shows Prieska and Douglas as having good grain filling conditions compared to other sites (Tables 5.1.4 and 5.1.6). The genotype means (Appendix 2) ranged between 33.28g to 41.16g for SST57 and Inia respectively. Genotype main effect show Inia, SST825, Káriegá and SST822 to

have a mean far above the grand mean and close to the recommended value. SST38, SST876, Palmiet and Marico were slightly below the recommended value but close to the grand mean, whereas T4 and SST57 were far below the mean. T4 and SST57 seem to have low genetic potential for this parameter.

The AMMI biplot for genotype and environment means (Figure 5.1.3) showed slight interaction for Kariega, Palmiet, Marico, SST38 and SST825. Kariega ranked higher at BullHill, Barkly West and Loskop but it was close to the middle for the other sites. Palmiet and Marico ranked above and at the middle at Barkly West and Loskop but ranked low at other sites. Both SST825 and SST38 ranked higher and close to middle in most of the sites except Barkly West and Loskop where they ranked close to middle and very low respectively. This shows that much of the interaction effects were at Barkly West, Loskop and to a lesser extent BullHill. Other genotypes showed stability but genotype main effect (different genetic potential) caused large variation around the mean. However, apart from T4 and SST57, which showed very low values, Kariega, Palmiet and Marico also showed negative interaction compared to others in Prieska, Douglas and Hopetown (Table 5.1.6).

Locations (Figure 5.1.3) showed high genotype interaction at Barkly West and Hopetown and to a lesser extent Loskop. Therefore ranking of some of the genotypes, which show interaction, may not be reliable. Other sites showed stability and may give reliable ranking except at BullHill where the result of Kariega looks similar to Barkly West and Loskop but not other sites.

Therefore in summary, for the genotypes, Kariega may be taken as a reference at BullHill, Barkly West and Loskop. The performance of Kariega, Palmiet, Marico, SST825 and SST38 at Barkly West and Loskop will probably be much poorer at other locations. Other genotypes may give reliable ranking at most of the locations and Inia, SST825, SST38 and SST822 seems to have higher genetic potential for this parameter. Prieska, Douglas, Koedoeskop and to a lesser extent BullHill and Hopetown may give reliable ranking for most genotypes but for the other two sites care must be taken for genotypes showing interaction.

Table 5.1.6 Ranking of genotypes in each location for thousand kernel mass (g) and environmental means in 1998.

Rank	Bullhill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	Inia (43.49)	Kariega (39.93)	Inia (44.77)	Inia (40.70)	Inia (42.87)	Kariega (40.66)	Inia (39.19)
2	Kariega (42.82)	Inia (37.17)	SST825 (44.04)	SST825 (40.28)	SST825 (42.05)	Inia (39.95)	SST825 (38.16)
3	SST825 (42.25)	Palmiet (37.16)	SST822 (43.05)	SST38 (39.26)	SST822 (41.21)	SST822 (38.67)	SST822 (37.64)
4	SST822 (42.07)	Marico (37.04)	SST38 (42.81)	SST822 (38.83)	SST38 (40.74)	SST825 (38.43)	Kariega (37.42)
5	SST876 (40.93)	SST822 (36.12)	SST876 (42.24)	SST876 (38.20)	SST876 (40.34)	Palmiet (38.11)	SST38 (36.70)
6	SST38 (40.63)	SST825 (35.25)	Kariega (41.46)	Kariega (35.89)	Kariega (40.08)	Marico (37.95)	SST876 (36.64)
7	Palmiet (40.41)	SST876 (34.55)	Palmiet (39.33)	Palmiet (33.92)	Palmiet (37.89)	SST876 (37.36)	Palmiet (35.13)
8	Marico (40.22)	T4 (33.38)	Marico (39.08)	Marico (33.64)	Marico (37.66)	SST38 (36.61)	Marico (34.92)
9	T4 (37.08)	SST38 (33.12)	T4 (36.35)	T4 (31.13)	T4 (34.84)	T4 (34.60)	T4 (31.95)
10	SST57 (36.06)	SST57 (31.82)	SST57 (35.73)	SST57 (30.76)	SST57 (34.15)	SST57 (33.36)	SST57 (31.09)
Mean	40.60	35.56	40.89	36.26	39.18	37.57	35.88

Grand mean = 37.99 LSD (0.05): treatment = 0.634 , environment = 2.004

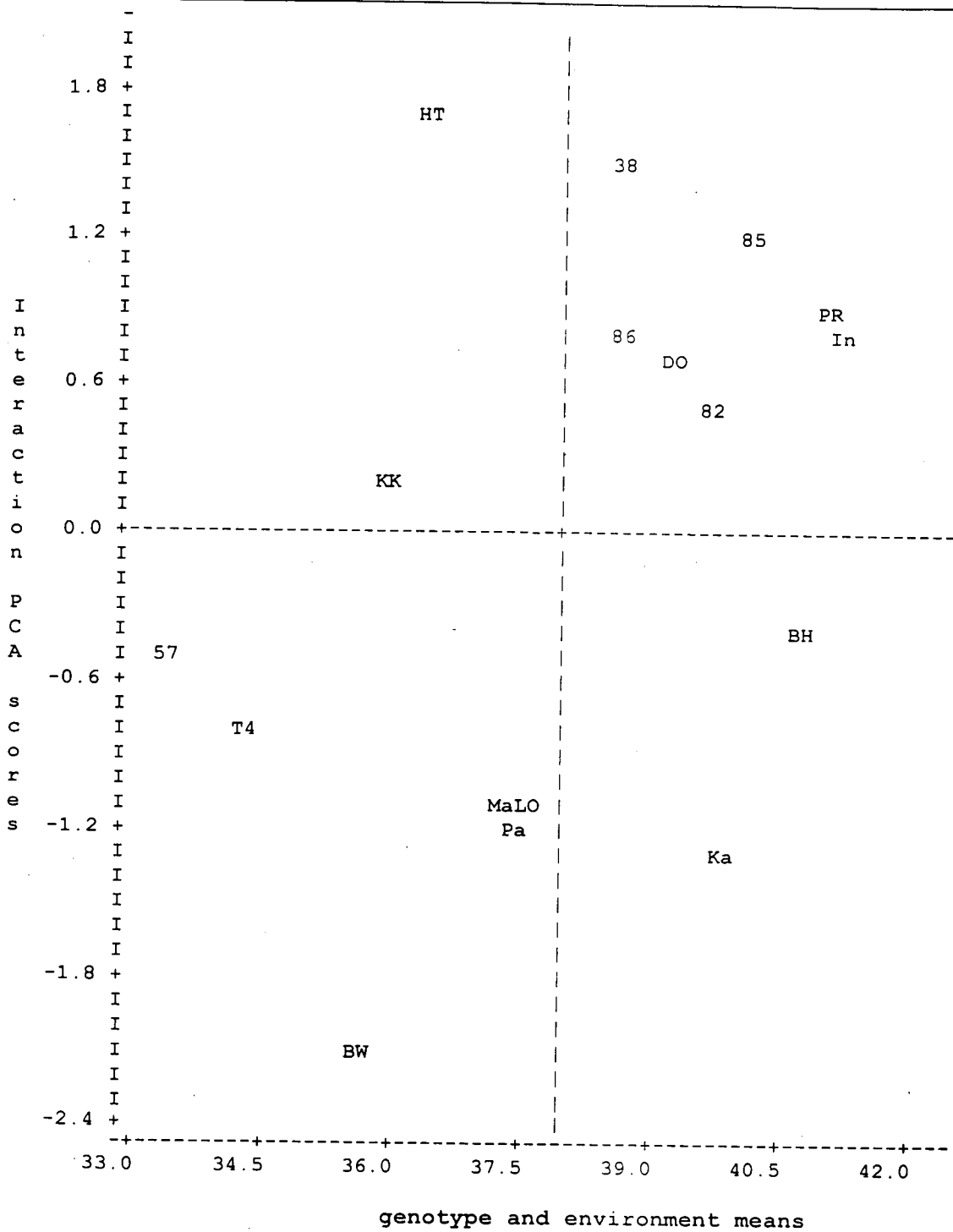


Figure 5.1.3 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for thousand kernel mass in 1998.

Single kernel characterisation system – diameter

Analysis of variance results (Table 5.1.7) show highly significant F-values for treatment, environments, genotypes, interaction, IPCA, block effect as well as residual. This indicates different genotype performance, varying environmental conditions between and within locations as well as presence of specific interaction effects. The significant block effect and residual indicates presence of variations for particular genotypes within locations and presence of noise effects respectively. The environment contribution to the variation was 16.7%, much lower compared to that of genotype and interaction and thus there was less environmental influence on this parameter. The genotype contribution to the variation was 38.5%, higher than environment and interaction and thus showing more genotype influence. The interaction also made a large contribution (21.5%) to the variation, and it was much higher compared to that of 1997. Out of this the IPCA captured 45.5% of variation. Taking into account that the ranges between the lower and higher value were not so high for both main effects, then it shows that interaction was largely responsible for the realised variation.

Table 5.1.7 Analysis of variance results for SKCS – diameter in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	9.453	0.045			
Treatment	69	7.254	0.105	8.09	0.000	
Environment (E)	6	1.578	0.263	20.25	0.000	16.7
Block	14	0.562	0.040	3.09	0.001	
Genotype (G)	9	3.640	0.404	31.14	0.000	38.5
G x E	54	2.036	0.038	2.90	0.000	21.5
IPCA	14	0.926	0.066	5.09	0.000	45.5
Residual	40	1.110	0.028	2.14	0.001	
Error	126	1.636	0.013			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 5.1.8) ranged between 2.46 mm to 2.73 mm at Koedoeskop and BullHill respectively with a grand mean of 2.59 mm. The environment main effect was less compared to interaction and only BullHill and Prieska were far above and Koedoeskop below the mean respectively, with other sites almost equal or very close to the mean. The genotype means ranged between 2.37 mm to 2.82 mm for SST57 and SST825 respectively (Appendix 2). As it was for environment, the genotype effect seems to be largely due to their difference in interaction effects, at various sites. However, at least three groups were

realised. They were SST825 and Inia with means above the grand mean; other genotypes were close to the mean, whereas Marico, T4 and SST57 were below the mean.

The AMMI biplot for genotype and environment means (Figure 5.1.4) showed high interaction for Palmiet, SST876 and Kariega. Palmiet ranked first at most of the sites except Barkly West and Loskop where it ranked third and this indicates wide adaptability for this genotype. Palmiet ranked intermediate, and Kariega above intermediate at most sites except for Prieska and Douglas where they both ranked low. Kariega ranked last at Hopetown. SST876 on the other hand ranked second at Hopetown, slightly higher at Prieska and Douglas but it was close to the middle and lower at other sites. Other genotypes showed stability with T4 and SST57 being lower (similar to kernel mass ranking). However, as it was for kernel mass, the main observation is that some of the genotypes like, SST825, Inia, SST822 and SST876 show good interaction with high potential areas and others like Kariega, Palmiet and Marico interact with poor potential areas. SST38 showed the same adaptation to all sites (Table 5.1.8).

The locations (Figure 5.1.4) showed high interaction at Hopetown and to a lesser extent Prieska, Barkly West and Loskop. For the first two sites it was mainly due to SST876 and for Loskop and Barkly West Kariega and Palmiet ranked higher compared to other sites. Other sites were stable, with Koedoeskop having a slightly lower mean value.

Therefore in summary, for the genotypes, performance of SST876, Palmiet and Kariega at Hopetown, Prieska and Douglas will probably not be repeated at other sites. Other genotypes may give reliable ranking at most of the locations and SST825 and Inia may be taken as references at all sites. For the locations, care must be taken at Barkly West, Hopetown and Loskop where some of the genotypes showed negative interactions. Other sites may give reliable ranking and particularly Prieska, BullHill and Douglas where higher values were also realised.

Table 5.1.8 Ranking of genotypes in each location for SKCS – diameter(mm) and environmental means in 1998.

Rank	Bullhill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	SST825 (2.91)	Inia (2.70)	SST825 (3.04)	SST825 (2.93)	SST825 (2.86)	Inia (2.75)	SST825 (2.62)
2	Inia (2.89)	Kariega (2.69)	Inia (2.85)	SST876 (2.71)	Inia (2.74)	Kariega (2.73)	Inia (2.61)
3	Kariega (2.81)	SST825 (2.66)	SST876 (2.82)	Inia (2.68)	SST822 (2.67)	SST825 (2.72)	Kariega (2.56)
4	SST822 (2.78)	Palmiet (2.61)	SST822 (2.81)	SST822 (2.66)	SST876 (2.66)	Palmiet (2.66)	SST822 (2.50)
5	Palmiet (2.72)	SST822 (2.57)	SST38 (2.70)	SST38 (2.53)	Kariega (2.60)	SST822 (2.63)	Palmiet (2.48)
6	SST876 (2.71)	SST38 (2.52)	Kariega (2.66)	Kariega (2.44)	SST38 (2.58)	SST38 (2.58)	SST38 (2.44)
7	SST38 (2.71)	Marico (2.48)	Palmiet (2.53)	T4 (2.34)	Palmiet (2.49)	SST876 (2.54)	SST876 (2.43)
8	Marico (2.62)	SST876 (2.48)	T4 (2.53)	Marico (2.29)	Marico (2.43)	Marico (2.53)	Marico (2.37)
9	T4 (2.59)	T4 (2.42)	Marico (2.50)	SST57 (2.29)	T4 (2.43)	T4 (2.47)	T4 (2.32)
10	SST57 (2.52)	SST57 (2.34)	SST57 (2.47)	Palmiet (2.29)	SST57 (2.36)	SST57 (2.40)	SST57 (2.25)
Mean	2.73	2.55	2.69	2.52	2.58	2.60	2.46

Grand mean = 2.59 LSD (0.05) : treatment = 0.034 , environment = 0.119

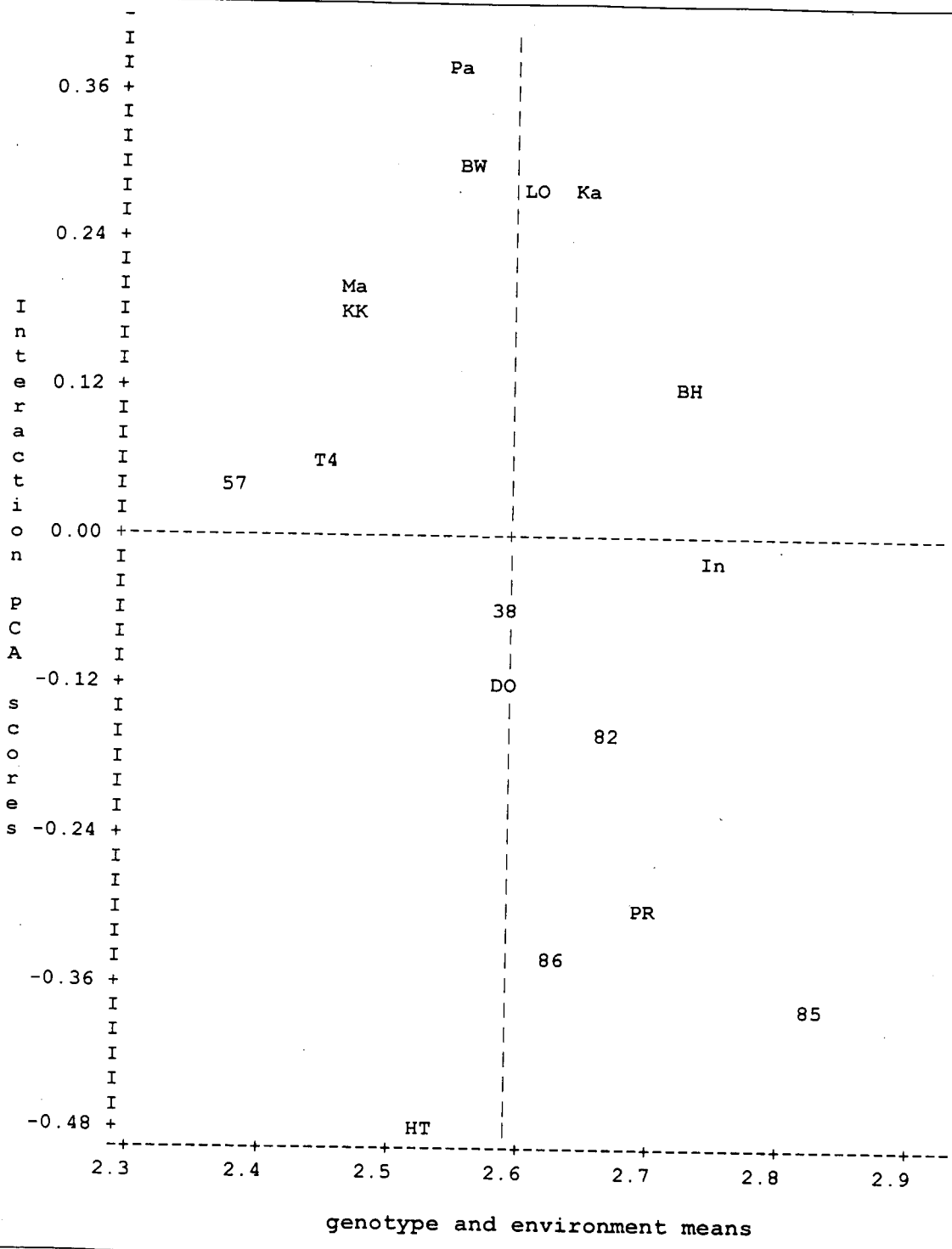


Figure 5.1.4 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for SKCS - diameter in 1998.

Breakflour yield

The results for analysis of variance (Table 5.1.9) shows that, both treatments, main sources of variation, interaction, IPCA as well as residual were highly significant ($P < 0.001$). This implies different genotype performance, environmental conditions between locations as well as presence of specific interaction effects. However, non-significant block effect implies absence of variation for particular genotypes within locations. The significant residual also indicates presence of noise effects. The environment contribution to the variation was 21.2%, less than both genotype and interaction and the value was almost half that of 1997. This again reveals less stress effects during the 1998 cropping season. Genotype contribution to the variation was 41.8%, much higher than both environment and interaction effects and it was not much different from that of 1997. This shows more genetic contribution to the variation in this parameter. The contribution of interaction to the variation was 28.8%, slightly higher than the environment contribution. Out of this the IPCA captured 49.2% of the variation.

Table 5.1.9 Analysis of variance results for breakflour yield in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	877.6	4.20			
Treatment	69	805.1	11.67	23.04	0.000	
Environment (E)	6	185.7	30.96	61.13	0.000	21.2
Block	14	8.8	0.63	1.23	0.259	
Genotype (G)	9	366.8	40.75	80.48	0.000	41.8
G x E	54	252.6	4.68	9.24	0.000	28.8
IPCA	14	124.4	8.89	17.55	0.000	49.2
Residual	40	128.2	3.20	6.33	0.000	
Error	126	63.8	0.51			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = $(SS \text{ for Genotype, Environment or } G \times E / SS \text{ for total}) \times 100$

IPCA = $(SS \text{ for IPCA} / SS \text{ for } G \times E) \times 100$

The environment means (Table 5.1.10) ranged between 21.75 to 24.17 at Prieska and Barkly West respectively with a grand mean of 23.18. The environment main effect showed at least two main groups. Barkly West, Loskop, Hopetown and Bullhill had higher mean values, above the grand mean; whereas Koedoeskop, Douglas and Prieska had mean values below the grand mean particularly Douglas and Prieska. However, apart from Koedoeskop, which seemed to have adverse conditions like those of Loskop in 1997; for other sites higher and lower breakflour yields were realised from sites with lower and higher grain filling, respectively, as revealed by hectoliter and particularly kernel mass (Tables 5.1.4 and 5.1.6). This is from

the well-known negative association between high yield and protein content. High yield results in low protein content consequently reducing the strength of starch – protein interactions that cause endosperm hardness. Therefore under low grain filling conditions and thus low yields, endosperm hardness increases and this results in higher breakflour yield. The genotype means ranged between 20.48 to 25.06 for SST825 and T4 respectively (Appendix 2). The genotype main effect showed at least three groups. T4 and Kariega had means far above the mean whereas SST876 and SST825 were far below the grand mean. Other genotypes were closer to the mean except again Marico and SST38, which deviated from the mean. Again, as it was for the environments higher breakflour yields were realised from genotypes with less grain filling ability and vice versa. Genotypes like Inia, SST822 and to a lesser extent SST38, Palmiet and Kariega show potential for both grain filling ability and breakflour yield, but Palmiet and Kariega show interaction with the environment and may give low values in some locations.

The AMMI biplot for genotype and environment means (Figure 5.1.5) showed high interaction for only Palmiet and to a lesser extent Kariega. Palmiet showed a different trend in each location. It was first, second and third at Douglas, Barkly West and Prieska respectively, close to the middle at BullHill and Hopetown but last and second from last at Loskop and Koedoeskop respectively. Kariega ranked high at most of the sites except Douglas where it was slightly below the middle. Of the two cultivars, Kariega seems to give more reliable ranking than Palmiet at most of the sites. Other genotypes showed stability and may give reliable ranking at most of the sites.

Location means (Figure 5.1.5) showed slight interaction at Loskop and Douglas. At Loskop, Kariega ranked first and had the highest mean value but Palmiet ranked last. However, at Douglas Palmiet ranked first with a slightly higher mean, but Kariega was slightly below the middle. Other locations show stability and may give reliable ranking, particularly Barkly West, Hopetown and BullHill, which also showed higher mean values.

In summary, most genotypes gave reliable ranking at most of the sites. Kariega may be included as a reference at Douglas, and Palmiet at Barkly West and Douglas, but it cannot be used at other sites. Also it is better to crosscheck breakflour yield with other grain filling parameters to see if they are also optimum. This is due to the fact that despite T4 showing high breakflour yield at most of the sites, it had medium to very low hectoliter mass and kernel mass and diameter. Most of the locations may give reliable ranking except Loskop and Douglas where care needs to be taken for Kariega and especially Palmiet.

Table 5.1.10 Ranking of genotypes in each location for breakflour yield and environmental means in 1998.

Rank	Bullhill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	T4 (25.54)	T4 (25.80)	T4 (23.43)	T4 (25.63)	Palmiet (24.26)	Kariega (28.39)	Kariega (25.10)
2	Kariega (25.45)	Palmiet (25.40)	Kariega (22.81)	Kariega (25.18)	T4 (23.44)	T4 (26.76)	T4 (24.79)
3	Marico (24.45)	Kariega (25.06)	Palmiet (22.70)	Marico (24.73)	Marico (22.93)	Marico (24.78)	Marico (23.50)
4	SST822 (24.06)	Marico (25.05)	Marico (22.62)	Palmiet (24.46)	SST822 (22.55)	SST57 (24.68)	SST822 (23.11)
5	SST57 (23.92)	SST822 (24.67)	SST822 (22.23)	SST822 (24.34)	Inia (22.35)	SST38 (24.55)	SST57 (23.07)
6	Palmiet (23.40)	SST57 (24.35)	SST57 (21.95)	SST57 (24.11)	Kariega (22.24)	SST822 (24.38)	SST38 (22.30)
7	Inia (23.38)	Inia (24.27)	Inia (21.78)	Inia (23.82)	SST57 (22.12)	Inia (22.95)	Inia (22.25)
8	SST38 (23.09)	SST38 (23.09)	SST38 (20.75)	SST38 (22.98)	SST38 (20.63)	SST876 (22.52)	Palmiet (21.61)
9	SST876 (22.14)	SST876 (22.72)	SST876 (20.29)	SST876 (22.41)	SST876 (20.59)	SST825 (22.06)	SST876 (21.20)
10	SST825 (20.96)	SST825 (21.26)	SST825 (18.88)	SST825 (21.07)	SST825 (18.93)	Palmiet (20.06)	SST825 (20.18)
Mean	23.63	24.17	21.75	23.87	22.00	24.11	22.71

Grand mean = 23.18 LSD (0.05): treatment = 0.237, environment = 0.748

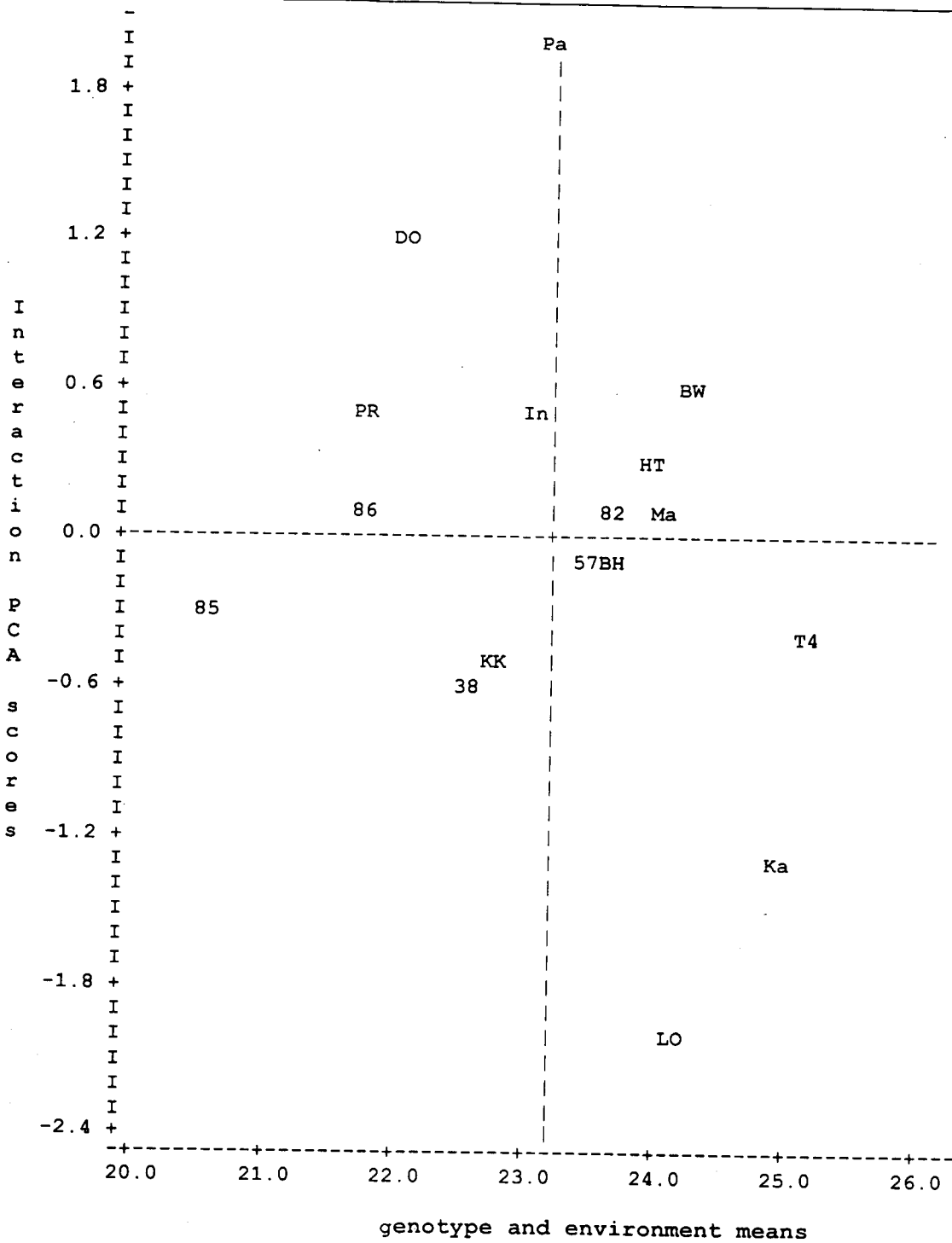


Figure 5.1.5 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities (57BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for breakflour yield in 1998.

Vitreous kernels

Analysis of variance results (Table 5.1.11) show highly significant variations for treatment, environments, genotypes, interaction, IPCA as well as block effect. This implies different genotype performance, varying environmental conditions between and within locations as well as presence of specific interaction effects. However, the residual was significant at $p < 0.05$, implying presence of slight noise effect. The significant block effect implies presence of variations for particular genotypes within locations. The contribution of environment to the variation in this parameter was 62%, which was very high, compared to the contribution of genotype and interaction. It was similar to that of 1997 and this indicates larger influence of environmental conditions on this parameter. The genotype contribution to the variation was 6.6%, very low, and it was less even than that of 1997 indicating smaller genetic influence to the variation in this parameter, particularly under optimal environments. The contribution of interaction was 14%, slightly higher than that of genotype and the IPCA captured 49.5% of this. This implies that, in addition to environment, the interaction was also responsible for the variation in kernel vitreousness.

Table 5.1.11 Analysis of variance results for vitreous kernels in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	40018	191.5			
Treatment	69	33051	479.0	11.56	0.000	
Environment (E)	6	24819	4136.5	99.82	0.000	62.0
Block	14	1746	124.7	3.01	0.001	
Genotype (G)	9	2643	293.7	7.09	0.000	6.6
G x E	54	5590	103.5	2.50	0.000	14.0
IPCA	14	2769	197.8	4.77	0.000	49.5
Residual	40	2821	70.5	1.70	0.014	
Error	126	5221	41.4			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 5.1.12) ranged between 44.19 to 82.67 at BullHill and Loskop respectively with a mean of 65.07 and at least three groups of locations were realised. Loskop and Prieska were much higher than the mean. At other sites (except Hopetown which was much lower), means were close to the grand mean with Douglas being slightly higher and similar to Prieska. However, BullHill seemed to have adverse conditions, which led to very low values being realised for most of the genotypes. For other sites vitreous kernels were more associated with

protein content and optimum grain filling. At Loskop genotypes had very high protein content, while at Prieska and Douglas the protein content was lower, but grain filling was better. The genotype means (Appendix 2) ranged between 58.82 for Palmiet to 69.33 for Marico and SST825 with genotype main effect showing at least three groups. Marico, SST825, Kariega and SST57 were far above the mean, Inia, SST38 and SST57 much closer to the mean and SST822, T4 and particularly Palmiet were far below the mean. However, as it was for environments, higher and lower values were associated with high protein content and/or higher grain filling ability by most of the genotypes. Nevertheless this was not true for Kariega and particularly Marico, despite having low protein content and lower kernel mass, vitreous kernels were higher. This shows in addition to environmental influence on this parameter, genotype effect may also be revealed and that is why there is hard and soft wheat.

The AMMI biplot for genotype and environment means (Figure 5.1.6) shows high environment interaction for Inia, Palmiet and SST822 and to a lesser extent SST876, SST57, SST825 and Kariega. Inia ranked first and second at BullHill and Barkly West respectively but it was intermediate at other sites except Prieska and Koedoeskop where it was last. Palmiet and SST822 showed similar trends as they ranked lower with Palmiet being last at most of the sites, but they were intermediate at Prieska and Koedoeskop. SST876 ranked above the middle at Bullhill and Barkly West but it was lower in other sites and next from last at Prieska and Koedoeskop. SST57 was first at Barkly West, second at Bullhill and Hopetown but close to the middle at other sites. SST825 and Kariega showed similar trends as they ranked intermediate to lower at Barkly West and Bullhill respectively but higher at other sites. These two genotypes together with Marico, SST38 and T4, which were stable, may give reliable ranking at most of the sites (Table 5.1.12).

The locations (Figure 5.1.6) showed high interaction at Hopetown, Prieska, Koedoeskop and to a lesser extent Barkly West. However, Hopetown contrasts more with other sites as it had very low means and had less potential compared to other sites. This again reveals the occurrence of different interaction effects between genotypes and environments for the quality parameters in different locations and seasons. This is due to the fact that for 1997 Loskop showed much contrast to other sites for both vitreous kernel and hardness index but for 1998 it was Hopetown, which showed the contrast. Both SST822 and Palmiet were responsible for interaction at Prieska and Koedoeskop, whereas at BullHill and Barkly West it was Inia, SST876 and SST57. Therefore in summary, for the genotypes, Kariega, SST825, Marico, SST38 and T4 may give reliable ranking at most of the sites. For others, care must be taken where they show interaction such as Inia, SST57 and SST876, which may be included as references at BullHill and Barkly West but they will probably not perform well at other sites. For the locations BullHill, Prieska, Koedoeskop and Barkly West gave unstable results across years, but other sites may give reliable ranking especially Douglas, which gave higher values for both years, compared to Loskop, which was higher only in 1998.

Table 5.1. 12 Ranking of genotypes in each location for vitreous kernels and environmental means in 1998.

Rank	Bullhill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	Inia (53.58)	SST57 (71.54)	SST825 (79.93)	Marico (66.71)	Marico (72.11)	SST825 (87.32)	SST825 (68.18)
2	SST57 (52.55)	Inia (71.24)	Kariega (79.25)	SST57 (66.29)	SST825 (72.08)	Marico (86.97)	Kariega (67.54)
3	SST876 (49.17)	Marico (69.24)	Marico (76.82)	SST825 (66.09)	Kariega (71.70)	Kariega (86.91)	Marico (65.49)
4	Marico (47.99)	SST876 (67.94)	SST822 (76.43)	Kariega (65.77)	SST57 (70.66)	SST57 (84.82)	SST822 (64.16)
5	SST38 (45.88)	SST825 (67.11)	Palmiet (73.33)	Inia (64.38)	Inia (68.13)	Inia (81.87)	Palmiet (61.03)
6	SST825 (44.62)	Kariega (66.94)	SST57 (69.68)	SST876 (62.42)	SST38 (67.19)	SST38 (81.73)	SST57 (59.13)
7	Kariega (44.56)	SST38 (66.07)	SST38 (69.25)	SST38 (62.27)	SST876 (66.68)	SST876 (80.78)	SST38 (58.28)
8	T4 (40.39)	T4 (61.34)	T4 (67.72)	T4 (58.47)	SST822 (64.79)	SST822 (80.50)	T4 (56.49)
9	SST822 (33.34)	SST822 (57.33)	SST876 (65.15)	SST822 (58.12)	T4 (63.74)	T4 (78.51)	SST876 (54.67)
10	Palmiet (29.87)	Palmiet (53.93)	Inia (63.73)	Palmiet (54.81)	Palmiet (61.52)	Palmiet (77.25)	Inia (53.69)
Mean	44.19	65.27	72.13	62.53	67.86	82.67	60.87

Grand mean = 65.07 LSD (0.05) : treatment = 2.132 , environment = 6.741

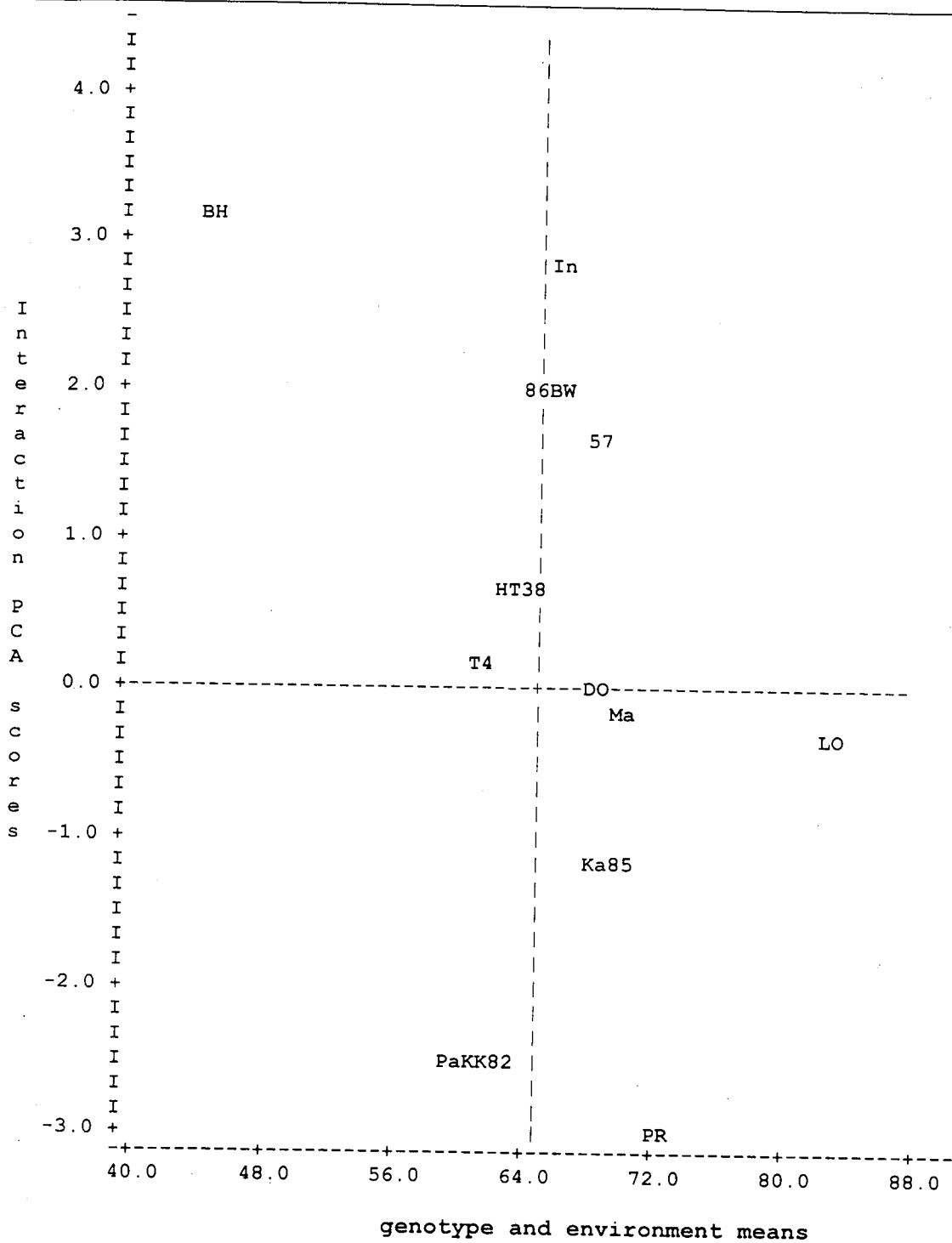


Figure 5.1.6 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for vitreous kernels in 1998.

Single kernel characterisation system – hardness index

The ANOVA results (Table 5.1.13) show highly significant F-values for treatment, environments, genotypes, interaction as well as IPCA. This implies different genotype performance, varying environmental conditions as well as presence of specific interaction effects. Block effect and residual were significant at $p < 0.05$ and $p < 0.01$ respectively. This indicates presence of variations for particular genotypes within locations and slight noise effect. The environment contribution to the variation was 40.3%, slightly lower to that of 1997 but it was also lower than that of vitreous kernels, showing more genetic influence for this parameter. Both genotype and interaction had similar contributions to the variation, which was 26.5%. The IPCA captured 67.2% of the interaction.

Table 5.1.13 Analysis of variance results for SKCS – hardness index in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	9904	47.4			
Treatment	69	8121	117.7	10.15	0.000	
Environment (E)	6	3994	665.7	57.41	0.000	40.3
Block	14	321	22.9	1.98	0.024	
Genotype (G)	9	1506	167.3	14.43	0.000	26.5
G x E	54	2621	48.5	4.19	0.000	26.5
IPCA	14	1762	125.9	10.85	0.000	67.2
Residual	40	859	21.5	1.85	0.005	
Error	126	1461	11.6			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = $(SS \text{ for Genotype, Environment or } G \times E / SS \text{ for total}) \times 100$

IPCA = $(SS \text{ for IPCA} / SS \text{ for } G \times E) \times 100$

The environment means (Table 5.1.14) ranged between 53.26 to 65.93 at Barkly West and Prieska respectively with a mean of 59.17. Apart from Loskop, which showed more contrast to others due to interaction, the environmental main effect was higher resulting in three groups. Prieska, Douglas and Koedoeskop were above the mean with Prieska being much higher. Hopetown and Loskop were lower but close to the mean, whereas BullHill and Barkly West were far below the mean. Compared to vitreous kernels which were influenced by protein content, for hardness index grain filling seems to be important together with optimum conditions for protein and starch assimilation. That is why sites like Prieska and Douglas ranked higher while Loskop with higher protein ranked much lower. The genotype means (Appendix 2) ranged between 54.71 to 63.41 for Karioga and SST825 respectively and genotype main effect showed at least two

groups. SST825, SST822, SST57, T4, Palmiet and Marico were above the mean with SST825 ranking first at all sites showing more stability for this parameter. SST876, SST38, Inia and Kariega were below the mean with Inia and Kariega being much lower and thus contrasting with others, especially Kariega. However, Kariega ranked low at most of the sites and at Barkly West and Loskop it was last with very low mean values, especially Loskop. On the other hand, Inia was last at five sites and only at Loskop it was above middle. This indicates the parameter to be highly heritable and Inia and Kariega seem to be genetically poor as Kariega ranked lower also in 1997. Other genotypes like SST825, SST822 and Palmiet seem to have genetical potential for this parameter. However, SST822 and Palmiet together with other genotypes which showed medium potential were to some extent influenced by environment especially grain filling conditions.

The AMMI biplot for genotype and environment means (Figure 5.1.7) show environment interaction for Kariega and Inia. Some cultivars showed very slight interactions like SST876 which ranked intermediate, SST822 second and Palmiet third at Barkly West and Loskop. T4 and ranked second and Marico fourth at Prieska, Hopetown and Douglas. They were higher than other genotypes except for SST825 and SST57. This shows adaptation to lower potential environments for SST876, Palmiet and SST822, and to higher potential environments for Marico and T4. All except Kariega and Inia were stable, like SST825, SST57 and SST38, as they were not far from the mean. Kariega ranked sixth at Prieska and seventh at Douglas and Koedoeskop, which proved positive interaction compared to those sites where it ranked very low (Table 5.1.14).

Locations (Figure 5.1.7) showed a highly negative genotype interaction at Loskop. This was due to T4 and Marico, which ranked very low at this site compared to others and also Kariega had the lowest mean. Other sites proved to be stable with BullHill and Barkly West having lower means.

In summary, SST825, SST822, Palmiet and Marico seem to have good genetic potential for hardness index. All genotypes may give reliable ranking at most of the sites except Loskop where the results of Inia, Kariega, Marico and T4 should not be generalised to other sites. For the locations Prieska, Douglas, Koedoeskop and Hopetown may give higher means and more reliable ranking than Loskop, which showed more interactions. However, Barkly West and BullHill had much lower means though the ranking was not much different from the former four sites. This may be due to higher humidity, as according to Charles *et al.* (1996) wheat grown in more humid environments were softer, producing more break - and patent flours and probably lower levels of damaged starch than those grown in drier environments.

Table 5.1.14 Ranking of genotypes in each location for SKCS – hardness index and environmental means in 1998.

Rank	Bullhill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	SST825 (57.91)	SST825 (58.30)	SST825 (68.99)	SST825 (61.79)	SST825 (66.55)	SST825 (65.59)	SST825 (64.74)
2	SST57 (56.33)	SST822 (56.28)	T4 (68.83)	T4 (60.68)	T4 (66.30)	SST822 (64.16)	T4 (64.33)
3	T4 (56.32)	Palmiet (55.41)	SST57 (68.48)	SST57 (60.57)	SST57 (65.98)	Palmiet (63.00)	SST57 (64.05)
4	SST822 (55.63)	SST57 (54.67)	Marico (67.64)	Marico (59.49)	Marico (65.12)	Inia (62.81)	Marico (63.14)
5	Marico (55.13)	T4 (53.98)	SST822 (66.57)	SST822 (59.46)	SST822 (64.15)	SST876 (61.69)	SST822 (62.35)
6	Palmiet (54.88)	SST876 (53.34)	Kariega (66.08)	Palmiet (58.74)	Palmiet (63.46)	SST57 (57.26)	Palmiet (61.66)
7	SST38 (52.62)	Marico (52.78)	Palmiet (65.89)	SST38 (56.84)	Kariega (63.43)	T4 (55.00)	Kariega (61.24)
8	SST876 (52.48)	SST38 (51.09)	SST38 (64.70)	Kariega (56.65)	SST38 (62.21)	SST38 (53.98)	SST38 (60.28)
9	Kariega (51.66)	Inia (51.07)	SST876 (63.32)	SST876 (56.28)	SST876 (60.90)	Marico (53.77)	SST876 (59.12)
10	Inia (48.74)	Kariega (45.65)	Inia (58.80)	Inia (52.28)	Inia (56.43)	Kariega (38.27)	Inia (54.74)
Mean	54.17	53.26	65.93	58.28	63.45	57.55	61.57

Grand mean = 59.17 LSD (0.05) : treatment = 1.128 , environment = 3.568

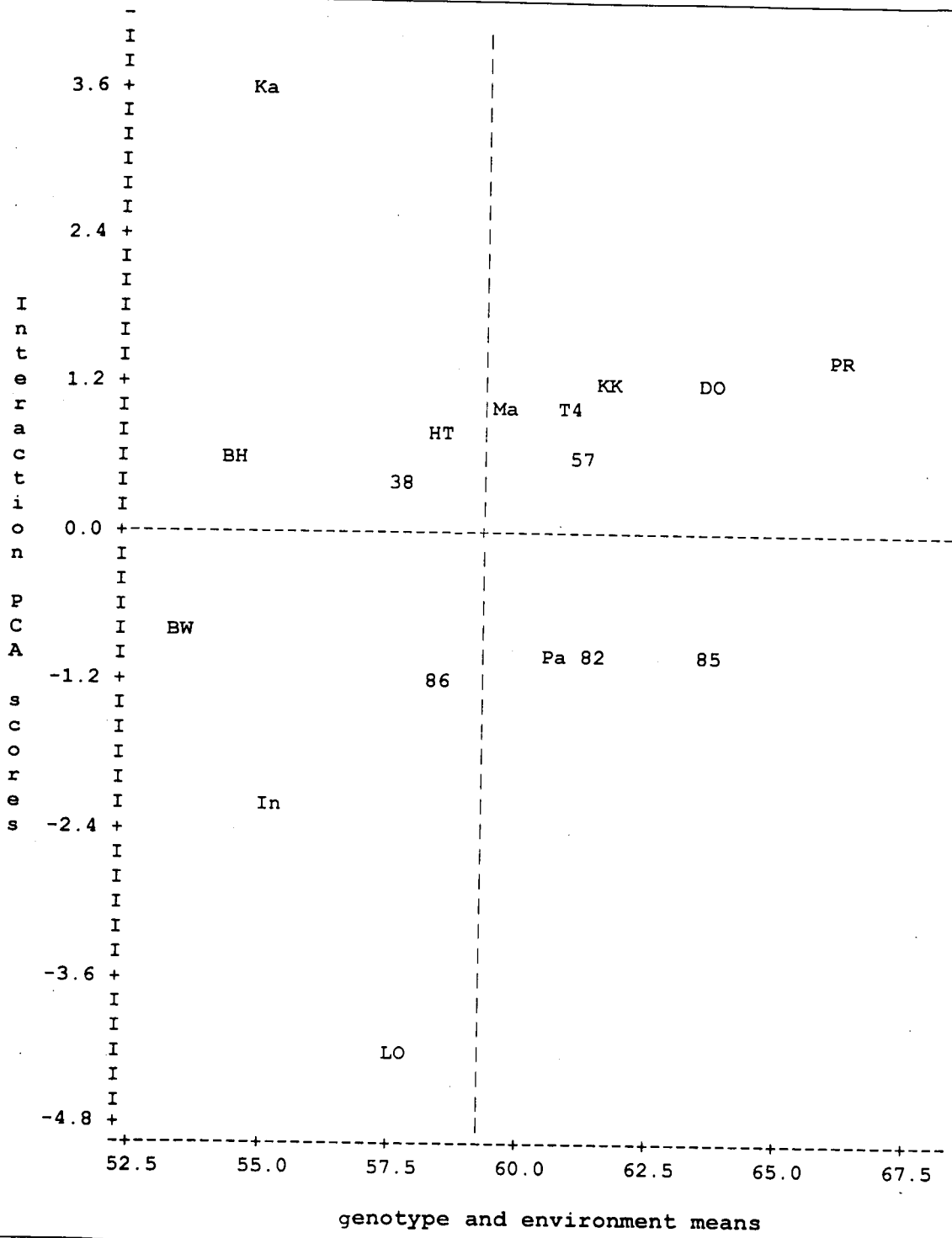


Figure 5.1.7 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for SKCS - hardness index in 1998.

Single kernel characterisation system – weight

The results were similar to those of thousand kernel mass especially genotype contribution. The analysis of variance results (Table 5.1.15) show highly significant variations ($p < 0.001$) for treatment, environments, genotypes, interaction, IPCA, block effect as well as residual. This implies different genotype performance, variation in environmental conditions between and within locations as well as presence of specific interaction effect. The significant block effect and residual indicates presence of variations for particular genotypes within locations and presence of noise respectively. The contribution of environment to the variation was 19.6%, which was slightly lower than interaction contribution but much lower than genotype contribution. This shows less environmental influence for this parameter under favourable conditions. However, under adverse conditions as it was in 1997, both genotype and interaction effects tended to be less and environmental effect increases. Genotype and interaction contributions to the variation were 35.0% and 22.7% respectively. From the interaction effect the IPCA explained 45.4% of the variation.

Table 5.1.15 Analysis of variance results for single kernel characterisation system – weight in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	3519	16.84			
Treatment	69	2720	39.42	8.42	0.000	
Environment (E)	6	690	114.94	24.54	0.000	19.6
Block	14	209	14.91	3.18	0.001	
Genotype (G)	9	1231	136.82	29.21	0.000	35.0
G x E	54	799	14.80	3.16	0.000	22.7
IPCA	14	363	25.92	5.53	0.000	45.4
Residual	40	436	10.91	2.33	0.000	
Error	126	590	4.68			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 5.1.16) ranged between 33.61 g to 38.87 g at Koedoeskop and Bullhill respectively with a grand mean of 36.2 g, and three groups of environments were realised. Prieska and BullHill had higher means far above the grand mean whereas Douglas and Loskop were very close and slightly higher than the mean. Barkly West, Hopetown and particularly Koedoeskop were below the mean. However, compared to thousand-kernel mass, the environment main effect was similar and Prieska, BullHill, Douglas and Loskop seemed to have better grain filling conditions. Nevertheless this parameter seems to reveal the interaction effects. The genotype means ranged between 31.68 g to 39.74 g for SST57 and Inia

respectively (Appendix 2). Genotype main effect showed three groups; Inia, SST825, SST822 and Kariega were above the mean, particularly SST825. SST876, SST38, Marico and Palmiet were close to the mean with T4 and SST57 being far below the mean. However, higher weights were shown by genotypes with higher grain filling ability, especially in high potential areas.

The AMMI biplot for genotype and environment means (Figure 5.1.8) showed slightly higher environment interaction for Palmiet and to a lesser extent Kariega, SST876 and SST825. Palmiet and Kariega ranked higher at Barkly West, BullHill and Loskop and Kariega also ranked higher at Koedoeskop. However, both ranked lower in other sites particularly Palmiet. SST825, and SST876 ranked higher at Prieska, Hopetown, Douglas and Koedoeskop but SST825 was close to middle and SST876 much lower at other sites. Nevertheless the two genotypes together with Inia and SST822, which were stable, show adaptation to high potential areas. Other genotypes showed stability also but T4 and SST57 seem to have less genetic potential for this parameter (Table 5.1.16).

The sites (Figure 5.1.8) show high environment interaction at Hopetown and to a lesser extent Prieska, Barkly West, Loskop and BullHill. At Prieska and Barkly West it was due to SST825 and SST876 which ranked higher while Palmiet ranked very low. At the other three sites interaction was due to Palmiet and Kariega which ranked higher than at other sites. Douglas and Koedoeskop proved to be stable and therefore may give reliable ranking for most of the genotypes.

In summary, SST825, Inia, SST822 and to a lesser extent Kariega showed good potential and wide adaptability for this parameter. Kariega and Palmiet may be included as references at Barkly West, Loskop and BullHill. However, Kariega, Palmiet and SST876 (which ranked lower) will probably not perform well at other sites. For the locations, reliable ranking and higher means may be achieved at Prieska, Douglas and BullHill. For other sites, care should be taken for interaction effects and low mean values realised at Koedoeskop.

Table 5.1.16 Ranking of genotypes in each location for single kernel characterisation system – weight (g) and environmental means in 1998.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	Inia (41.75)	Kariega (38.20)	SST825 (42.78)	SST825 (39.90)	Inia (40.40)	Kariega (39.69)	Inia (36.90)
2	Kariega (41.69)	Inia (37.79)	Inia (42.75)	Inia (39.32)	SST825 (39.72)	Inia (39.28)	SST825 (35.53)
3	SST825 (39.83)	Palmiet (36.25)	SST822 (41.34)	SST876 (38.24)	SST822 (38.80)	Palmiet (37.73)	Kariega (35.53)
4	SST822 (39.81)	SST822 (35.80)	SST876 (41.11)	SST822 (38.06)	SST876 (38.04)	SST822 (37.29)	SST822 (35.11)
5	Palmiet (39.60)	SST825 (35.67)	SST38 (38.76)	SST38 (34.98)	Kariega (37.39)	SST825 (37.17)	SST876 (33.84)
6	SST38 (39.00)	SST38 (35.16)	Kariega (38.08)	Kariega (33.34)	SST38 (36.85)	SST38 (36.65)	SST38 (33.79)
7	Marico (38.76)	Marico (35.15)	Marico (36.30)	Marico (31.88)	Marico (35.19)	Marico (36.64)	Palmiet (33.04)
8	SST876 (33.97)	SST876 (33.97)	T4 (34.67)	T4 (30.63)	Palmiet (34.40)	SST876 (35.47)	Marico (32.92)
9	T4 (35.80)	T4 (32.06)	Palmiet (34.58)	SST57 (29.98)	T4 (33.08)	T4 (33.55)	T4 (30.34)
10	SST57 (34.33)	SST57 (30.52)	SST57 (33.83)	Palmiet (29.45)	SST57 (32.02)	SST57 (32.01)	SST57 (29.05)
Mean	38.87	35.06	38.42	34.58	36.59	36.55	33.61

Grand mean = 36.24 LSD (0.05) : treatment = 0.717 , environment = 2.266

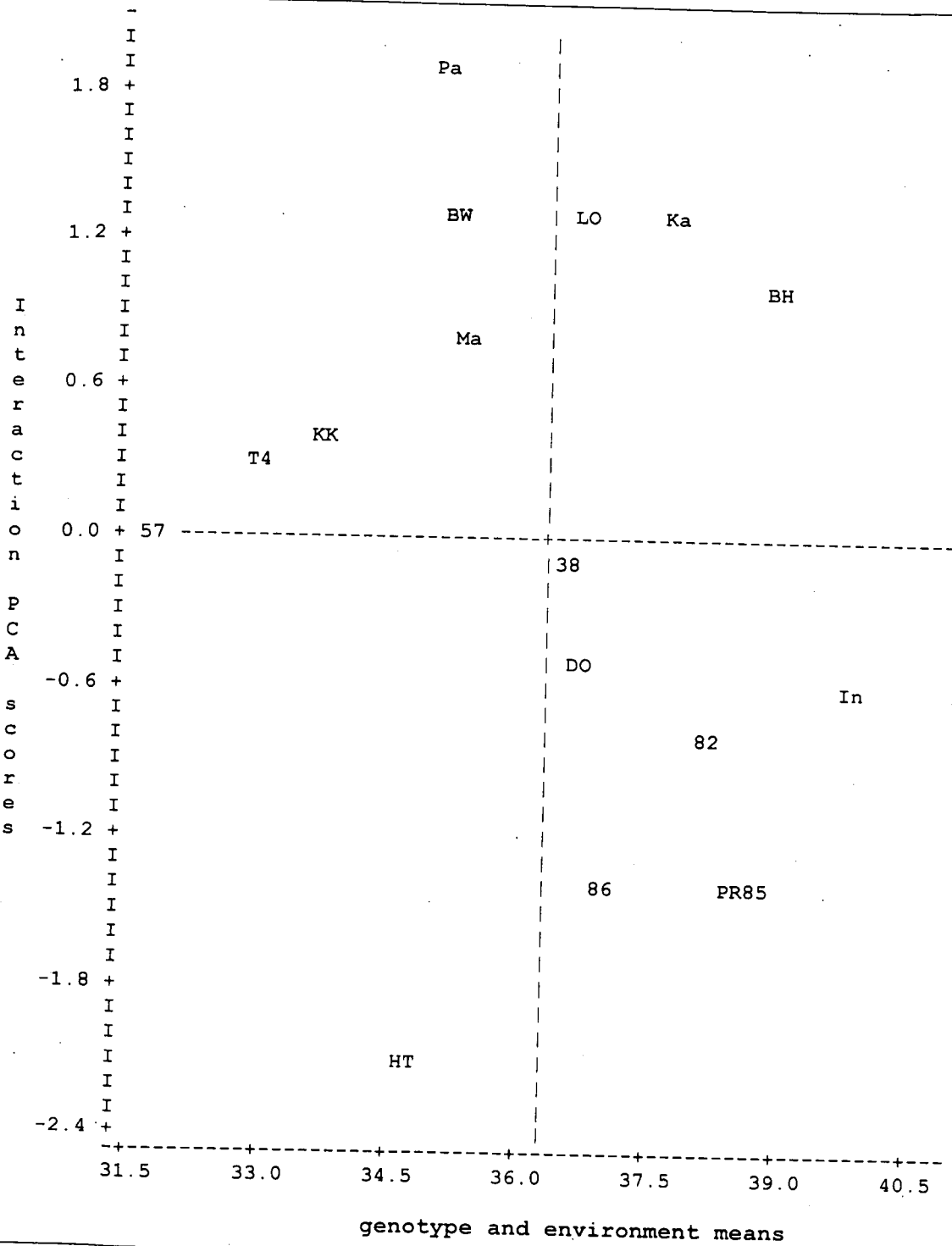


Figure 5.1.8 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Koedoeskop and KK = Koedoeskop) for single kernel characterisation system - weight in 1998.

Grain protein content – LECO

The ANOVA results (Table 5.1.17) show highly significant variations for treatment, environments, genotypes, interaction, IPCA as well as residual. The block effect was significant at $p < 0.05$, which shows that there were slight variations for particular genotypes even within locations. The significant residual implies noise effect and that is why the IPCA1 explained a smaller percentage (37.7) of the interaction effect. The contribution of environment to the variation was very high (88.7%) and thus very low genotype and interaction effects were found. The genotype contribution to the variation was only 1.9% showing less genetic influence compared to environment. The contribution of interaction was also only 4.6% showing less influence.

Table 5.1.17 Analysis of variance results for grain protein content – LECO in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	721.8	3.45			
Treatment	69	687.0	9.96	44.66	0.000	
Environment (E)	6	640.5	106.75	478.81	0.000	88.7
Block	14	6.7	0.48	2.14	0.014	
Genotype (G)	9	13.6	1.51	6.79	0.000	1.9
G x E	54	32.9	0.61	2.73	0.000	4.6
IPCA	14	12.4	0.88	3.96	0.000	37.7
Residual	40	20.5	0.51	2.30	0.000	
Error	126	28.1	0.22			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 5.1.18) ranged between 12.17% to 17.40% at Prieska and Loskop respectively with a grand mean of 13.22. The environment main effect showed that Loskop contrasted more with other sites by having a higher mean, followed by Barkly West, which was slightly above the mean. Other sites were all below the mean and similar to each other. Due to the negative association between yield and protein content, protein content was less and higher at Prieska and Loskop where grain filling was higher and lower respectively. For Loskop, it seems the warmer conditions accelerate the mineralisation of nitrogen. This is according to Smika and Greb (1973), who reported that higher soil temperatures have shown to favour the mineralisation and uptake of nitrogen. Nevertheless the warmer conditions may reduce biomass production (in terms of tillering) and grain filling due to limited photosynthesis. This reduces nitrogen translocation to and demand from other plant parts (vegetative part). Consequently more nitrogen is accumulated to the grains and thus higher protein content realised at this site. The genotype means ranged

between 12.69% to 13.58% for T4 and Inia respectively (Appendix 2). Though the range was small, at least three groups were realised. Inia and SST38 had higher means. Palmiet had a value far above the grand mean, and T4 a value far below the grand mean. Other genotypes were closer to the grand mean.

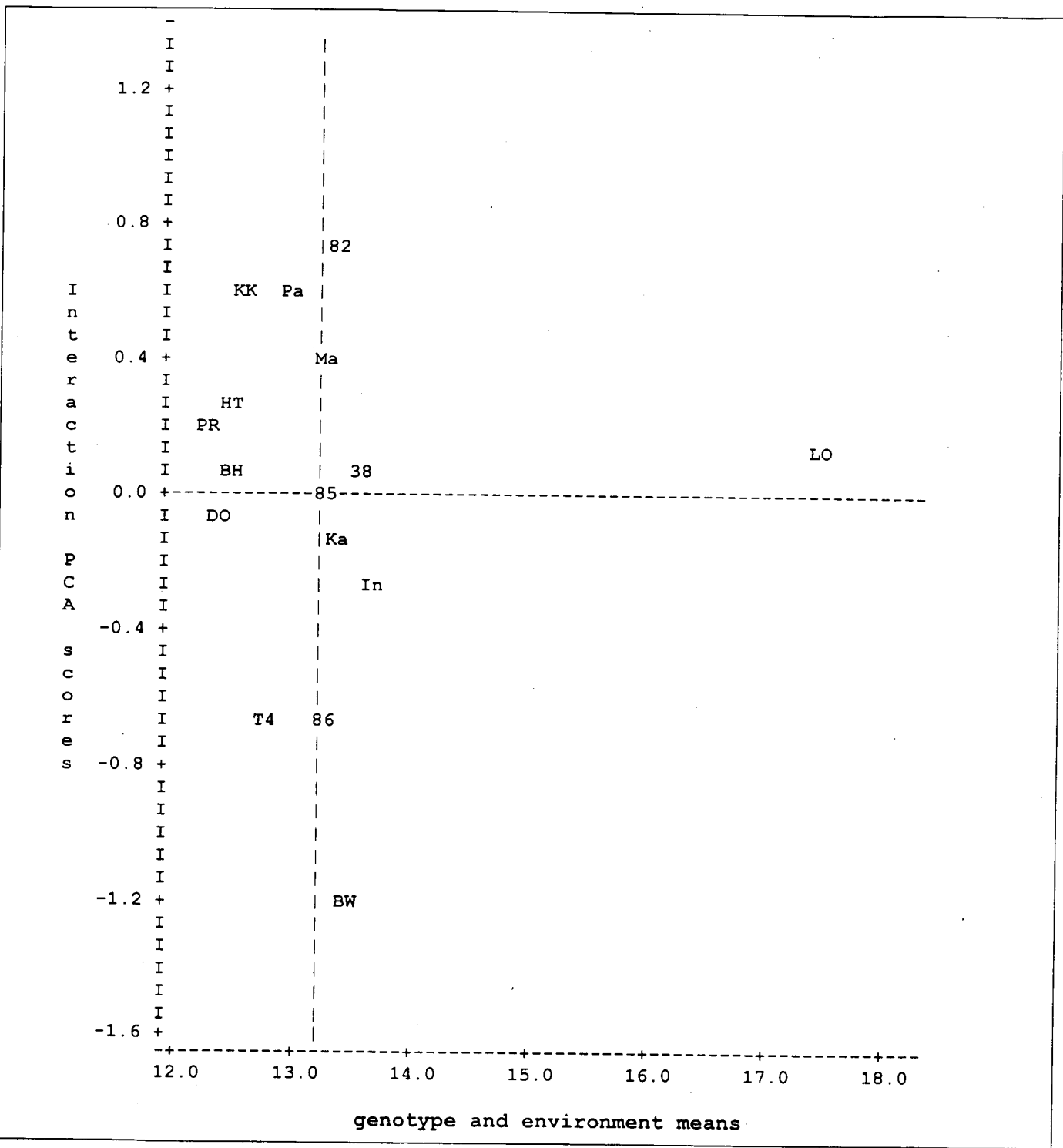
The AMMI biplot for genotype and environment means (Figure 5.1.9) shows some environment interaction for T4, SST876 and SST822. All the interactions were realised at Barkly West with T4 and SST876 ranking higher and SST822 lower, but it was the other way round for other sites. Other genotypes showed stability and thus reliable ranking at most of the sites (Table 5.1.18). The sites showed slightly higher environment interaction at Barkly West and to a lesser extent Koedoeskop. The interaction at Barkly West was due to T4 and SST876 whereas at Koedoeskop it was due to SST822, which ranked first and Palmiet, which ranked slightly higher compared to other sites. However, the interaction effect and high protein content at Barkly West and Loskop respectively caused the two sites to contrast with others.

In summary, only T4, SST876 and SST822, may not perform well at Barkly West, but most of them may give reliable ranks at most of the sites. Also Inia and SST38 seem to have good genetic potential and more stability for this parameter. For the locations, most of them may give reliable ranking except Barkly West. Loskop needs management practices to reduce nitrogen level and to produce genotypes with low nitrogen yield.

Table 5.1.18 Ranking of genotypes in each location for grain protein content – LECO and environmental means in 1998.

Rank	Bullhill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	Inia (12.66)	SST38 (13.44)	Kariega (11.39)	Inia (11.95)	SST38 (11.80)	Kariega (18.33)	Inia (13.10)
2	SST38 (11.88)	Kariega (13.37)	SST38 (11.33)	SST38 (11.94)	Kariega (11.68)	SST38 (17.98)	SST57 (12.04)
3	Marico (11.74)	SST825 (13.03)	SST825 (10.99)	Kariega (11.70)	Inia (11.50)	SST825 (17.77)	Marico (11.90)
4	SST57 (11.73)	Inia (13.02)	SST876 (10.80)	Marico (11.52)	SST825 (11.37)	SST876 (17.37)	SST38 (11.89)
5	SST822 (11.58)	SST876 (12.94)	SST822 (10.77)	SST822 (11.51)	SST822 (11.31)	SST822 (17.29)	SST822 (11.66)
6	SST876 (11.50)	SST822 (12.94)	Marico (10.63)	SST876 (11.49)	SST876 (11.31)	Marico (17.02)	Palmiet (11.61)
7	Palmiet (11.34)	Marico (12.86)	Inia (10.59)	SST825 (11.45)	Marico (11.26)	T4 (16.98)	SST876 (11.56)
8	Kariega (11.31)	SST57 (12.43)	T4 (10.26)	SST57 (11.24)	SST57 (10.88)	Inia (16.52)	SST825 (11.16)
9	SST825 (11.23)	T4 (12.34)	SST57 (10.09)	Palmiet (10.94)	T4 (10.69)	SST57 (16.23)	Kariega (11.15)
10	T4 (10.66)	Palmiet (12.18)	Palmiet (9.88)	T4 (10.80)	Palmiet (10.61)	Palmiet (16.10)	T4 (10.63)
Mean	11.56	12.86	10.67	11.45	11.24	17.16	11.67

Grand mean = 13.22 LSD (0.05): treatment = 0.155 , environment = 0.491



NB: There are three distinct groups of environments: (i) Loskop, (ii) BarkWes and (iii) the others

Figure 5.1.9 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) At seven localities BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for grain Protein content - LECO in 1998.

Grain protein content – FL

The ANOVA results (Table 5.1.19) show significant variation ($p < 0.001$) for both treatment, environments, genotypes, interaction as well as the IPCA. However, the residual was significant at ($p < 0.01$), showing presence of noise effect. The significant block effect ($p < 0.05$) indicates presence of slight variations for particular genotypes within locations. The contribution of environment to the variation was also high (88.0%), almost similar to the LECO method. The contributions of genotype and interaction to the variation were 2.1% and 4.4% respectively. Again it was much lower and almost similar to the former method and the IPCA explained 37.8% of the interaction effect.

Table 5.1.19 Analysis of variance for the grain protein content, FL – method in 1998.

Source	Df	SS	MS	F-value	Pr>F	SS%
Total	209	571.0	2.73			
Treatment	69	539.6	7.82	37.57	0.000	
Environment (E)	6	502.2	83.70	402.18	0.000	88.0
Block	14	5.2	0.37	1.79	0.040	
Genotype (G)	9	12.0	1.33	6.40	0.000	2.1
G x E	54	25.4	0.47	2.26	0.000	4.4
IPCA	14	9.6	0.69	3.29	0.000	37.8
Residual	40	15.8	0.39	1.90	0.004	
Error	126	26.2	0.21			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 5.1.20) ranged between 11.53% to 16.19% at Bullhill and Loskop respectively with a grand mean of 12.49%. However, as it was for the previous method, Loskop contrasted with other sites due to a mean far above the grand mean. Barkly West was the second closest to the mean and other sites were below the mean. A similar trend was observed as for the former parameter, whereby higher and lower protein contents were realised from low and high grain filling environments respectively. Genotype means (Appendix 2) ranged between 12.01% to 12.82% for T4 and SST38 respectively. Although all genotypes had means between 12.0% and 13.0%, there were small differences. SST38 and Inia still had higher means and Palmiet and T4 lower with T4 being much far below the grand mean. Other genotypes were closer to the grand mean but compared to the former method SST57 was below the mean probably due to lower values realised at BullHill and Prieska.

Table 5.1.20 Ranking of genotypes in each location for the grain protein content, FL – method and environmental means in 1998.

Rank	Bullhill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	SST38 (11.86)	SST825 (13.05)	SST822 (12.06)	SST822 (12.11)	SST38 (12.15)	Inia (16.57)	SST822 (12.50)
2	Inia (11.82)	Inia (13.02)	SST38 (12.00)	SST38 (12.03)	Inia (12.10)	SST38 (16.48)	SST38 (12.38)
3	SST822 (11.69)	SST876 (13.01)	Marico (11.89)	Marico (11.94)	SST822 (12.00)	SST825 (16.47)	Marico (12.32)
4	Kariega (11.64)	SST38 (12.82)	Inia (11.87)	Inia (11.89)	Kariega (11.92)	SST876 (16.38)	Inia (12.23)
5	SST825 (11.59)	Kariega (12.77)	Kariega (11.72)	Kariega (11.75)	Marico (11.86)	Kariega (16.35)	Kariega (12.09)
6	Marico (11.55)	T4 (12.68)	SST57 (11.59)	SST57 (11.62)	SST825 (11.86)	SST57 (16.02)	SST57 (11.97)
7	SST876 (11.45)	SST57 (12.32)	SST825 (11.55)	SST825 (11.56)	SST876 (11.72)	T4 (16.00)	SST825 (11.89)
8	SST57 (11.43)	Palmiet (12.08)	Palmiet (11.40)	Palmiet (11.44)	SST57 (11.72)	SST822 (15.98)	Palmiet (11.79)
9	Palmiet (11.22)	SST822 (12.00)	SST876 (11.37)	SST876 (11.39)	Palmiet (11.52)	Marico (15.90)	SST876 (11.70)
10	T4 (11.03)	Marico (11.97)	T4 (10.92)	T4 (10.39)	T4 (11.29)	Palmiet (15.79)	T4 (11.24)
Mean	11.53	12.57	11.64	11.67	11.81	16.19	12.01

Grand mean = 12.49 LSD (0.05): treatment = 0.152 , environment = 0.48

The AMMI biplot for genotype and environment means (Figure 5.1.10) showed high environment interaction for SST822 and to a lesser extent T4, SST876, Marico and SST825. SST822 and Marico ranked higher at Prieska, Hopetown and Koedoeskop but intermediate at other sites and very low at Barkly West and Loskop. T4 ranked last in five sites but it was below the middle at Barkly West and Loskop. SST825 and SST876 ranked higher at Barkly West and Loskop, close to middle at Bullhill and Douglas but SST876 was much lower at Prieska, Hopetown and Koedoeskop. Other genotypes showed stability, with Palmiet and SST57 being unstable.

The sites (Figure 5.1.10) showed high genotype interaction at Barkly West and to a lesser extent Loskop, Koedoeskop, Hopetown and Prieska. At Barkly West and Loskop T4, SST876 and SST825 were responsible for the interaction and at Koedoeskop, Hopetown and Prieska it was due to SST822 and Marico. There were no interaction effects at Douglas and Bullhill, and these sites may give reliable ranking for most of the genotypes.

In summary, SST38, Inia and Kariega seem to have good genetic potential and Palmiet and T4 poor potential for protein content. SST825 and SST876 showed positive and T4, SST822 and Marico negative environment interactions at Barkly West and Loskop. Therefore the results of these genotypes at the two sites should not be generalised to other sites. Other genotypes seemed to be less influenced by environments and thus may give reliable ranking at most of the sites. For the locations, reliable ranking (stable protein results) were expected at Douglas and Bullhill. For other sites particularly Barkly West and Loskop care is needed for genotypes showing environment interactions.

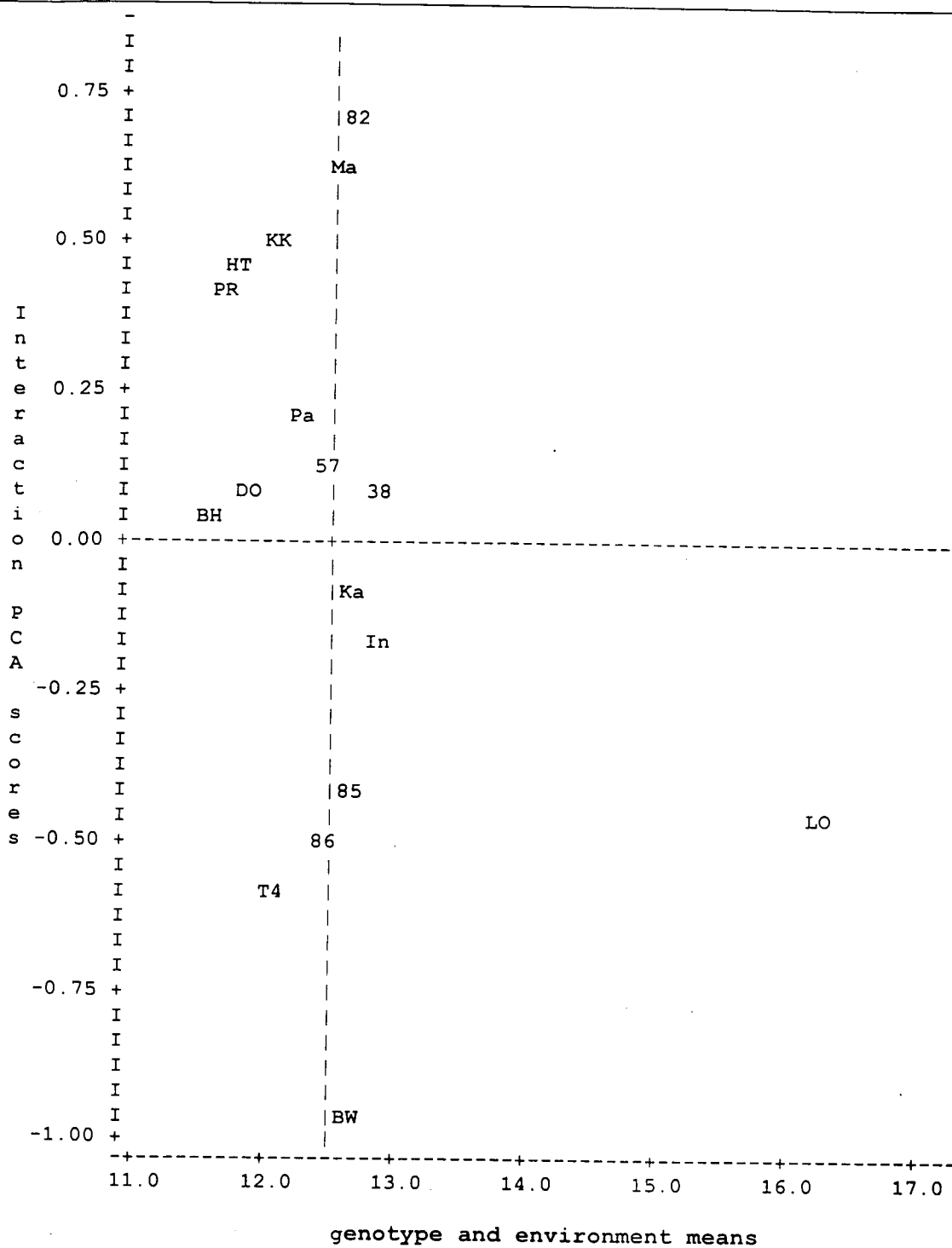


Figure 5.1.10 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for grain Protein content - FL in 1998.

Grain protein content – WH

The ANOVA results (Table 5.1.21) showed significant variation ($p < 0.001$) for both treatment, environments, genotypes, interaction as well as the IPCA. However, the residual was significant only at ($p < 0.05$), showing less noise effect and the block effect was not significant. Compared to the former two methods, the contribution of genotype and interaction was a bit higher but not at a significant level and thus environment was still dominating as the main source of variation. This shows that although the variation among genotypes and interaction effects were significant, their contribution to total variation was less compared to environments. The respective contributions of environments, genotypes and interactions to the total variation were 84.4%, 3.5% and 5.4% and the IPCA captured 44.1% of the interaction effects.

Table 5.1.21 Analysis of variance for the grain protein content WH - method in 1998.

Source	Df	SS	MS	F-value	Pr>F	SS%
Total	209	648.3	3.10			
Treatment	69	604.2	8.76	29.09	0.000	
Environment (E)	6	546.9	91.15	302.82	0.000	84.4
Block	14	6.1	0.44	1.46	0.137	
Genotype (G)	9	22.4	2.49	8.27	0.000	3.5
G x E	54	34.9	0.65	2.15	0.000	5.4
IPCA	14	15.4	1.10	3.65	0.000	44.1
Residual	40	19.5	0.49	1.62	0.023	
Error	126	37.9	0.30			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 5.1.22) ranged between 10.54 to 15.66 at Bullhill and Loskop respectively with a grand mean of 11.82. The environment main effect showed four groups. Loskop had the highest mean far above the grand mean followed by Barkly West, which was just above the mean. Douglas, Koedoeskop, Prieska and Hopetown were below the mean and more than half of the genotypes had means above 11.0. However, Bullhill was much lower than the mean and only two genotypes had means above 11.0, showing less potential for protein content. The genotype means ranged between 11.27 to 12.46 for T4 and SST38 respectively (Appendix 2). The genotype main effect again shows three groups. SST38, Inia and Kariega were above the mean with SST38 being far above the mean and it ranked high at most of the locations. Palmiet and T4 were below the mean, particularly T4 in most of the locations. Others were very close or almost equal to the mean. Only those with interactions showed higher or lower ranks in some locations (Table 5.1.22).

The AMMI biplot for genotype and environment means (Figure 5.1.11) shows high environment interaction for SST822 and SST876 and to a lesser extent Marico and T4. SST822 ranked very low at BullHill, Loskop and last at Barkly West but it was intermediate to higher at other sites showing less adaptation in low potential areas. However, it was the reverse for SST876 which ranked intermediate to higher at these three sites but much lower at other sites and thus showing higher adaptation in low potential areas. Marico was intermediate at most of the locations but much higher at Prieska much lower at Barkly West, showing some interaction. T4 was last in other sites except Barkly West where it was close to the middle and thus showing less potential for this parameter. Other genotypes showed stability and therefore may give predictable ranking at most of the sites.

The sites (Figure 5.1.11) show high genotype interaction at Barkly West and to a lesser extent Prieska. The two sites showed opposite interaction effects, whereby SST876 ranked higher and Marico and SST822 lower at Barkly West but it was the reverse at Prieska. SST822 also ranked lower at Loskop while at other sites it showed less interaction effects. However, due to more interaction effects realised at Barkly West and very high protein contents at Loskop, the two sites showed large contrast to other locations.

In summary, first of all this method seems to be more precise compared to the former two as it doesn't exaggerate the values and may be close to optimum. For the genotypes, SST38, Inia and Kariaga seem to have higher genetic potential and may be taken as references in most of the locations. Most of the other genotypes showed intermediate potential and ranked higher or lower in some locations due to interaction effects. Palmiet and T4 seem to have less genetic potential for this characteristic. Considering interaction effects, SST876 may also be included as a reference for high protein content at Barkly West where it ranked higher. The performance of SST876, Marico and SST822 will not be the same at all localities, as Marico and SST876 ranked lower at Barkly West, and SST822 ranked lower at at Loskop and BullHill also. The results are therefore environment specific. However, most of the genotypes may give predictable ranking at most of the locations. For the locations, predictable ranking may be achieved at Douglas, Prieska, Koedoeskop and Hopetown. Barkly West needs care for genotypes showing interaction with this site. However, the very high and low protein contents realised at Loskop and BullHill respectively need management practices for bringing the protein to optimum level, and selection of genotypes with specific nitrogen yields may be important.

Table 5.1.22 Ranking of genotypes in each location for the grain protein content WH – method and environmental means in 1998.

Rank	Bullhill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	SST38 (11.14)	Inia (12.78)	SST38 (11.92)	SST38 (11.78)	SST38 (11.98)	SST38 (16.26)	SST38 (11.85)
2	Inia (11.00)	SST876 (12.68)	SST822 (11.83)	Inia (11.36)	Inia (11.65)	Inia (16.12)	SST822 (11.53)
3	Kariega (10.79)	Kariega (12.41)	Marico (11.36)	SST822 (11.32)	Kariega (11.49)	Kariega (15.91)	Inia (11.34)
4	SST825 (10.58)	SST38 (12.31)	Inia (11.22)	Kariega (11.23)	SST822 (11.42)	SST825 (15.70)	Marico (11.24)
5	SST876 (10.57)	SST825 (12.22)	Kariega (11.17)	Marico (11.13)	Marico (11.31)	SST876 (15.68)	Kariega (11.23)
6	Marico (10.40)	T4 (11.90)	SST57 (11.04)	SST825 (11.00)	SST825 (11.27)	Marico (15.54)	SST57 (11.01)
7	SST57 (10.38)	SST57 (11.68)	Palmiet (10.94)	SST57 (10.96)	SST57 (11.17)	SST57 (15.50)	SST825(11.00)
8	SST822 (10.33)	Marico (11.39)	SST825 (10.93)	Palmiet (10.80)	SST876 (11.11)	SST822 (15.47)	Palmiet (10.87)
9	Palmiet (10.15)	Palmiet (11.31)	SST876 (10.49)	SST876 (10.78)	Palmiet (11.00)	Palmiet (15.28)	SST876 (10.71)
10	T4 (10.07)	SST822 (10.73)	T4 (10.24)	T4 (10.41)	T4 (10.70)	T4 (15.18)	T4 (10.37)
Mean	10.54	11.94	11.11	11.08	11.31	15.66	11.12

Garnd mean = 11.82 LSD (0.05) : treatment = 0.181 , environment = 0.574

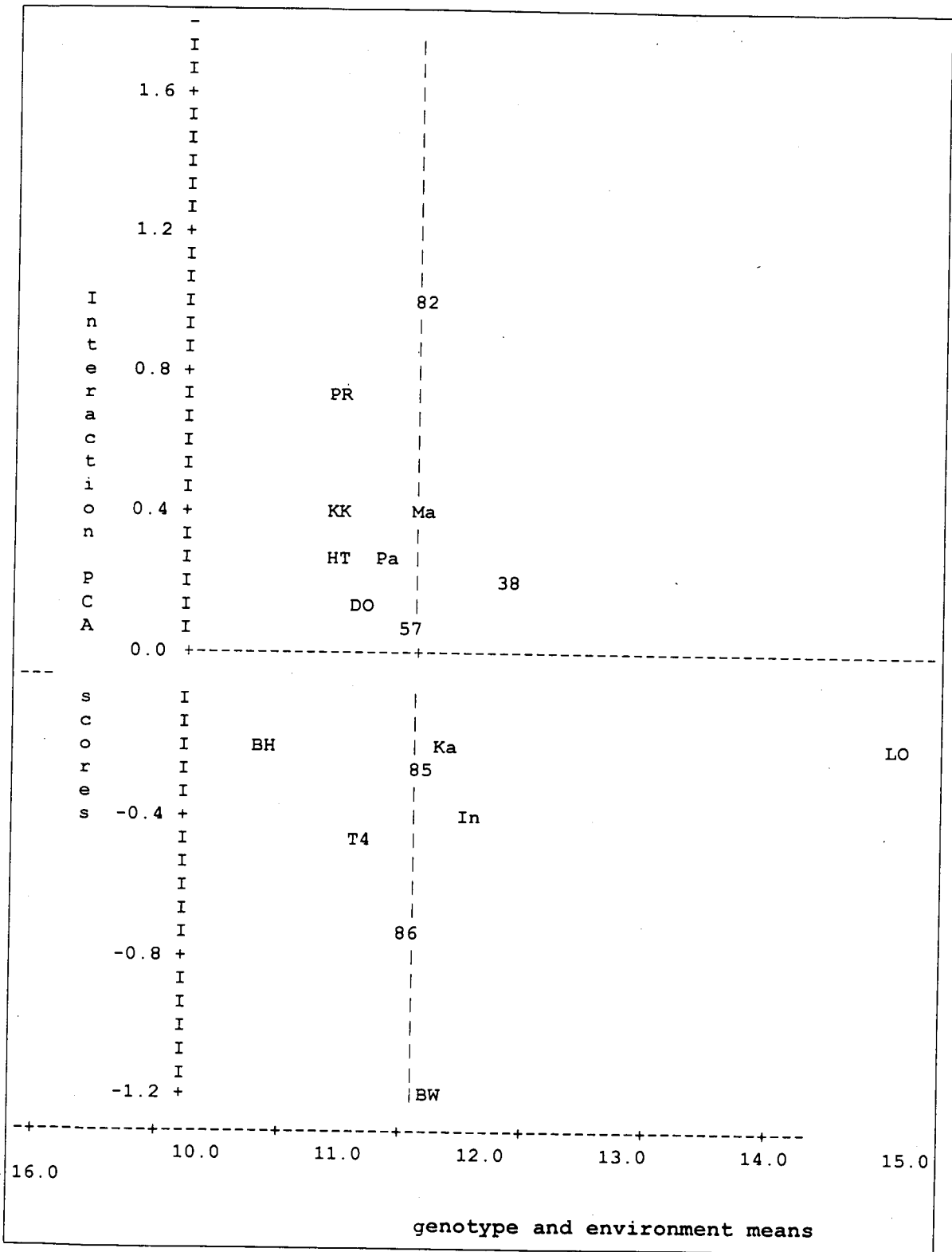


Figure 5.1.11 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) At seven localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for grain Protein content - WH in 1998.

Flour protein content – LECO

The analysis of variance (Table 5.1.23) shows significant variation ($p < 0.001$) for treatment, main sources of variation, interaction, IPCA as well as residual. The significance of residual indicates presence of noise due to other IPCA – axes and that is why the interaction percentage captured by IPCA1 was not so high. The block effect was not significant and this implies absence of variations for particular genotypes within locations. As it was for the grain methods, although genotypes and interaction effects were significant, the environment made a larger contribution to the total variation than the genotype and environment interaction. The contributions to the variation for environments, genotypes and interactions were 83.7%, 2.0% and 7.0% respectively with IPCA explaining 34.8% of the interaction.

Table 5.1.23 Analysis of variance for flour protein content using LECO - method in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	1051.4	5.03			
Treatment	69	981.1	14.22	29.68	0.000	
Environment (E)	6	879.5	146.58	306.02	0.000	83.7
Block	14	10.0	0.71	1.49	0.125	
Genotype (G)	9	27.5	3.06	6.39	0.000	2.6
G x E	54	74.1	1.37	2.86	0.000	7.0
IPCA	14	25.8	1.84	3.84	0.000	34.8
Residual	40	48.3	1.21	2.52	0.000	
Error	126	60.4	0.48			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 5.1.24) ranged between 10.67 to 17.16 at Prieska and Loskop respectively, with a grand mean of 12.37. The environment main effect as it was for the grain methods showed four groups. Loskop was still leading with a mean far above the grand mean followed by Barkly West which was closer to the mean. Other genotypes were below the mean but close to it, except Prieska, which was below the mean. General observations show that the sites with less and higher grain filling had higher and low protein contents respectively. The genotype means ranged between 11.77 to 12.90 for T4 and SST38 respectively (Appendix 2). The genotype main effect shows at least three groups and compared to grain methods the difference within each group is not high. SST38, Inia and Kariaga had means much higher than the grand mean but interaction effect was more pronounced in this group. SST822, SST876, Marico and

SST825 were just above the mean whereas SST57, Palmiet and T4 were below the mean with Palmiet and T4 being very low. As in the case of grain methods, the first group showed high genetic potential, and the third group low genetic potential for this parameter, unless it was influenced by interaction effects.

The AMMI biplot for genotype and environment means (Figure 5.1.12) shows high environment interaction for Inia and Kariega and to a lesser extent SST57 and SST825. Inia ranked above the middle at other locations except Prieska and Loskop where it ranked much lower. Kariega ranked very high at four sites but it was very low at BullHill and Koedoeskop. SST825 ranked above the middle at three sites but it was intermediate at Hopetown, Koedoeskop and very low at BullHill. SST57 ranked very low in five locations but it was above the middle to very high at BullHill and Koedoeskop respectively. Other genotypes showed stability and may give reliable ranking at most of the locations, particularly SST38, SST822, SST876 and Marico.

The locations (Figure 5.1.12) show high environment interaction at Loskop and Koedoeskop and to a lesser extent BullHill and Prieska. For Loskop and Prieska it was due to Kariega, SST825 and T4, which ranked higher and Inia and SST57 lower compared to other sites. For Koedoeskop and BullHill interaction was due to Inia, which had higher mean values with SST57 and Palmiet ranking higher and SST825 and Kariega lower compared to other sites. Other sites showed less interaction effects and may give reliable ranking for protein content for most of the genotypes.

In conclusion, SST38, Inia and Kariega showed high and SST822, SST876, Marico and SST825 intermediate genetic potential for protein content. Most of these genotypes are expected to rank higher at most of the sites unless interaction occurs. Other genotypes particularly Palmiet and T4 shows less potential and ranked lower at most locations. Considering interaction effects, SST57 may give promising results at Koedoeskop and Bullhill but together with SST825 and Kariega which ranked lower at these sites, their results should not be generalised to other sites. The same applies to the results of Inia at Loskop and Prieska. Other genotypes (except the above four) are therefore expected to give predictable ranking at most of the locations. For the locations, predictable rankings for the genotypes are expected at Barkly- West, Douglas and Hopetown but other sites need care due to interactions realised with certain genotypes. Also management practices at Prieska and Loskop to manipulate nitrogen yield coupled with selection of genotypes with high and low nitrogen yields respectively are important.

Table 5.1.24 Ranking of genotypes in each location for the flour protein content (%) LECO - method and environmental means in 1998.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	Inia (12.66)	SST38 (13.44)	Kariega (11.39)	Inia (11.95)	SST38 (11.80)	Kariega (18.33)	Inia (13.10)
2	SST38 (11.88)	Kariega (13.37)	SST38 (11.33)	SST38 (11.94)	Kariega (11.68)	SST38 (17.98)	SST57 (12.04)
3	Marico (11.74)	SST825 (13.03)	SST825 (10.99)	Kariega (11.70)	Inia (11.50)	SST825 (17.77)	Marico (11.90)
4	SST57 (11.73)	Inia (13.02)	SST876 (10.80)	Marico (11.52)	SST825 (11.37)	SST876 (17.37)	SST38 (11.89)
5	SST822 (11.58)	SST876 (12.94)	SST822 (10.77)	SST822 (11.51)	SST822 (11.31)	SST822 (17.29)	SST822 (11.66)
6	SST876 (11.50)	SST822 (12.94)	Marico (10.63)	SST876 (11.49)	SST876 (11.31)	Marico (17.02)	Palmiet (11.61)
7	Palmiet (11.34)	Marico (12.86)	Inia (10.59)	SST825 (11.45)	Marico (11.26)	T4 (16.98)	SST876 (11.56)
8	Kariega (11.31)	SST57 (12.43)	T4 (10.26)	SST57 (11.24)	SST57 (10.88)	Inia (16.52)	SST825 (11.16)
9	SST825 (11.23)	T4 (12.34)	SST57 (10.09)	Palmiet (10.94)	T4 (10.69)	SST57 (16.23)	Kariega (11.15)
10	T4 (10.66)	Palmiet (12.18)	Palmiet (9.88)	T4 (10.80)	Palmiet (10.61)	Palmiet (16.10)	T4 (10.63)
Mean	11.56	12.86	10.67	11.45	11.24	17.16	11.67

Grand mean = 12.37 LSD (0.05) : treatment = 0.230 , environment = 0.726

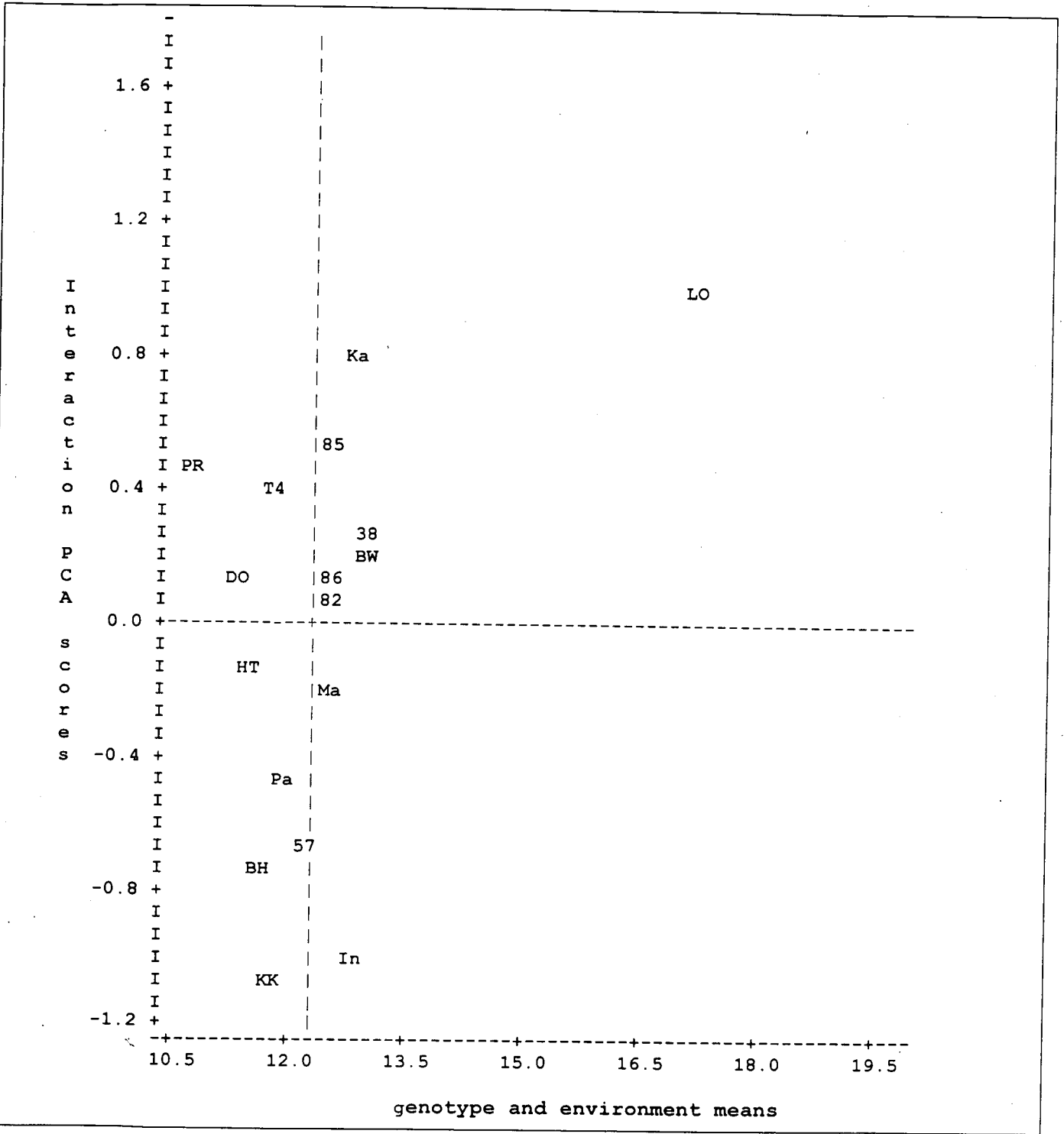


Figure 5.1.12 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for flour protein content LECO - method in 1998.

Flour protein content – NIR

The ANOVA results (Table 5.1.25) show significant variation ($p < 0.001$) for only treatment and main effects. The interaction was significant at $p < 0.05$ and the IPCA at $p < 0.01$. This indicates less interaction effects and more influence by the main effects in the variation of protein content. However, the residual and block were not significant, implying absence of noise and variation for certain genotypes within locations. Compared to the former protein method (LECO) and grain methods, this method shows reduced environment contribution and a slight increase in genotype and interaction contribution to the variation. The respective contributions to the total variation were 69.4%, 5.5% and 9.4% for environment, genotype and interaction respectively. The IPCA captured 41.0% of the interaction effect.

Table 5.1.25 Analysis of variance results for flour protein content NIR – method in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	811.7	3.88			
Treatment	69	684.4	9.92	10.62	0.000	
Environment (E)	6	563.4	93.89	100.55	0.000	69.4
Block	14	9.7	0.69	0.74	0.727	
Genotype (G)	9	44.6	4.96	5.31	0.000	5.5
G x E	54	76.4	1.41	1.51	0.030	9.4
IPCA	14	31.3	2.24	2.40	0.005	41.0
Residual	40	45.0	1.13	1.21	0.218	
Error	126	117.7	0.93			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 5.1.26) ranged between 11.05% to 15.91% at BullHill and Loskop respectively with a grand mean of 12.0%. The environment main effect shows at least three groups. As for the former method, Loskop had the highest mean, far above grand mean followed by Barkly West just above the mean. Other locations had values very close to mean values. Compared to the LECO-method, however, this method seems to neglect minor differences among locations. That is why Prieska, which was lower with the LECO-method, was similar to BullHill and Douglas with this method. This is also affected by kernel mass whereby these three sites had higher kernel mass than other sites. The genotype means ranged between 11.08 to 12.62 for T4 and SST38 respectively (Appendix 2). Genotype main effect showed three groups and as it was for environments, minor differences were reduced. SST38 and SST876 maintained their rank and together with SST876, SST825 and SST57 had values higher than the

grand mean. SST822, Kariega and Marico were close to the mean, whereas Palmiet and particularly T4 were far below the mean. The method also revealed the potential of some genotypes like SST57, which ranked lower at most of the sites with the former method but it was intermediate to higher with this method (Table 5.1.26).

The AMMI biplot for genotype and environment means (Figure 5.1.13) shows small environment interactions for SST825, SST822, Inia and Kariega. The former two ranked higher at Loskop but was intermediate to very low at other sites. Inia was intermediate to very high at most of the sites and Kariega was third at Barkly West but intermediate to very low at other sites. Other genotypes showed stability with most of them ranking intermediate to higher at most of the locations. However, Palmiet and T4 ranked last at most of the sites proving to have low genetic potential for this trait.

Locations (Figure 5.1.13) showed very high interaction at Loskop, which made this site contrast more with others. The genotypes responsible were SST825, SST822 and Palmiet, which ranked higher at this site compared to others. Barkly West also showed some interaction due to Kariega. Other sites, particularly BullHill, Koedoeskop, Hopetown and Douglas showed fewer interactions and thus may give reliable rank for most of the genotypes.

In summary we can say this method seems to be more efficient to determine protein content due to reduced environment effects, minor differences among locations and genotypes and also the values were not so high. SST38 was very stable for protein content at most of the sites and this genotype also seems to have good protein quality due to its higher rank for loaf volume. This was followed by Inia, which was intermediate to higher at most of the locations but it showed environment interaction at Barkly West. Nevertheless, considering loaf volume, the protein quality for this genotype seems to be influenced by warmer environments as it ranked very low at Loskop, Koedoeskop and BullHill. Other genotypes except Palmiet and T4, showed intermediate stability with SST825 and SST822 showing positive and negative environment interactions at Loskop and Barkly West respectively.

However, considering loaf volume and aspects of protein quality, SST822 and SST57 proved to be stable in quality, despite having low protein content. This is due to the fact that the two genotypes showed intermediate loaf volumes at most of the sites (Table 5.1.32). The quality parameters for Kariega, Marico, SST876 and SST825 seem to be more sensitive to environment effects. Regardless of having high or low protein content, Kariega and Marico had intermediate loaf volumes at Barkly West, Prieska, Hopetown and Douglas but much lower at BullHill, Loskop and Koedoeskop. On the other hand SST876 and SST825 had intermediate loaf volumes at BullHill, Loskop and Koedoeskop but much lower at Barkly West, Prieska, Hopetown and Douglas.

Table 5.1.26 Ranking of genotypes at each location for the flour protein content NIR – method (%) and environmental means in 1998.

Rank	Bullhill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	SST38 (11.67)	SST38 (13.02)	SST38 (11.79)	SST38 (11.91)	SST38 (11.81)	SST825 (17.48)	SST38 (11.95)
2	Inia (11.44)	SST57 (12.89)	SST57 (11.54)	Inia (11.78)	SST57 (11.52)	Inia (17.41)	Inia (11.70)
3	SST825 (11.35)	Kariega (12.73)	SST876 (11.43)	SST825 (11.70)	SST876 (11.46)	SST822 (17.11)	SST876 (11.62)
4	SST876 (11.33)	SST876 (12.63)	Kariega (11.30)	SST876 (11.59)	Inia (11.34)	SST38 (16.18)	SST825 (11.60)
5	SST57 (11.29)	Marico (12.21)	Inia (11.20)	SST57 (11.49)	Kariega (11.25)	SST876 (15.96)	SST57 (11.58)
6	SST822 (11.08)	Inia (12.10)	SST825 (11.07)	SST822 (11.43)	SST825 (11.23)	Palmiet (15.79)	SST822 (11.34)
7	Kariega (10.95)	SST825 (11.93)	Marico (10.95)	Kariega (11.13)	SST822 (10.97)	SST57 (15.26)	Kariega (11.25)
8	Marico (10.80)	T4 (11.72)	SST822 (10.82)	Marico (11.03)	Marico (10.97)	Marico (15.18)	Marico (11.09)
9	Palmiet (10.41)	SST822 (11.71)	T4 (10.38)	Palmiet (10.71)	Palmiet (10.41)	Kariega (14.55)	Palmiet (10.67)
10	T4 (10.14)	Palmiet (11.34)	Palmiet (10.31)	T4 (10.35)	T4 (10.37)	T4 (14.17)	T4 (10.43)
Mean	11.05	12.23	11.08	11.31	11.13	15.91	11.32

Grand mean = 12.0 LSD (0.05) : treatment = 0.319 , environment = 1.01

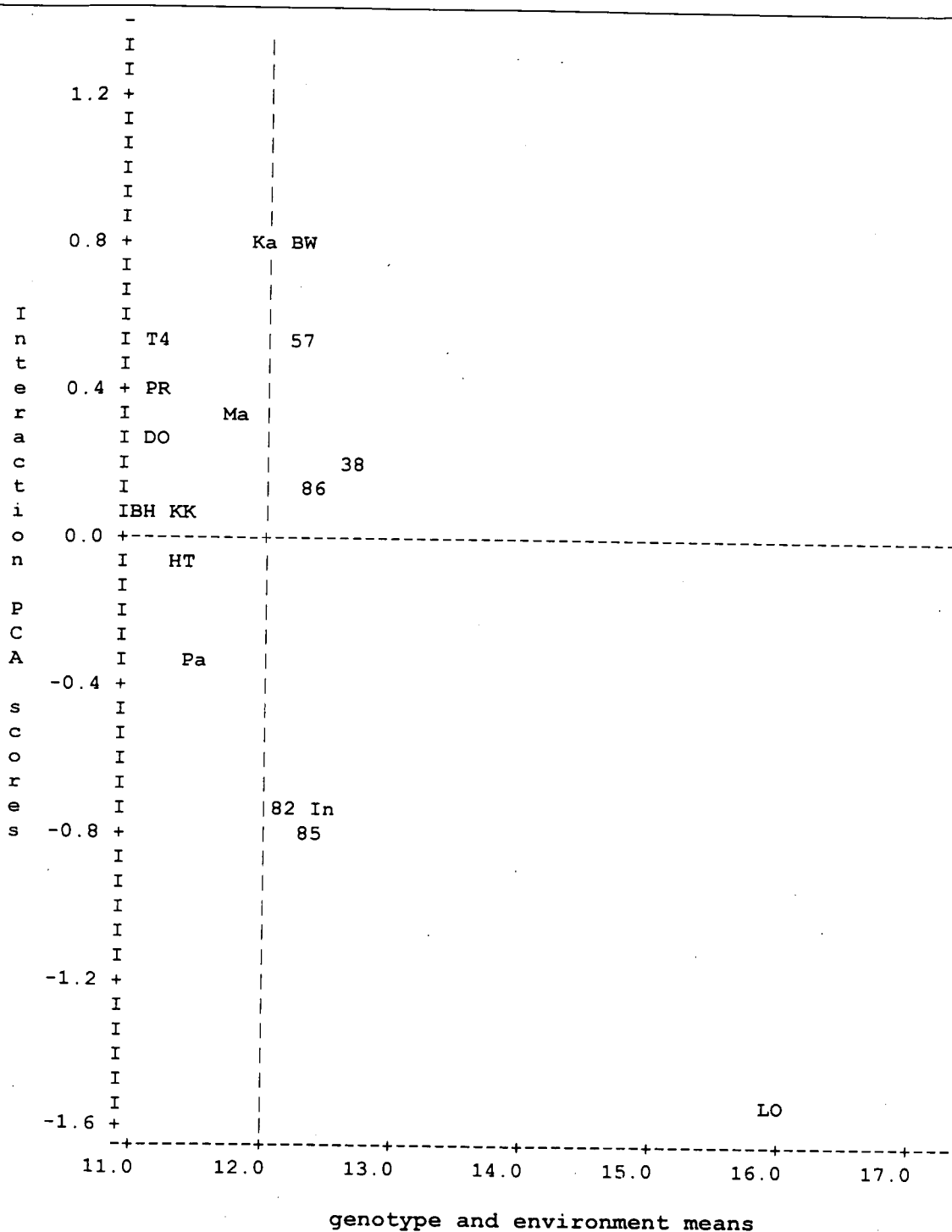


Figure 5.1.13 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for flour protein content NIR - method in 1998.

However, despite Palmiet showing less potential for protein content together with T4, it ranked first for loaf volume at BullHill, Loskop and Koedoeskop. This shows environment interaction with these sites probably in terms of protein quality. This indicates that high protein content by itself is not a sufficient indication of good quality. There is a need to verify protein related parameters also, to make sure that they are at optimum level. For the locations, care should be taken at Barkly West and particularly Loskop for genotypes showing interaction. Most of the other sites may give reliable ranking for most of the genotypes. Management practices to manipulate nitrogen yield are necessary at BullHill, Prieska, Douglas and Loskop. Again considering protein quality, BullHill, Loskop and Koedoeskop need separate strategies in terms of genotypes which show positive interaction with environments in these sites. Barkly West, Prieska, Hopetown and Douglas also needs similar strategies.

Farinograph water absorption

The analysis of variance (Table 5.1.27) shows significant variation ($p < 0.001$) for treatments, environments, genotypes, interaction, IPCA as well as residual. The block effect was not significant. The significant residual implies presence of noise and that is why the percentage of interaction captured by the IPCA was 36.2%, which is not so high. The respective contributions to the total variation for environments, genotypes and interaction were 55.9%, 23.7% and 10.6%. This shows that most of the variations was associated with environments and then genotypes.

Table 5.1.27 Analysis of variance results for farinograph water absorption in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	1494.9	7.15			
Treatment	69	1347.8	19.53	19.81	0.000	
Environment (E)	6	835.2	139.20	141.17	0.000	55.9
Block	14	22.8	1.63	1.65	0.074	
Genotype (G)	9	353.6	39.29	39.85	0.000	23.7
G x E	54	159.0	2.94	2.99	0.000	10.6
IPCA	14	57.5	4.11	4.17	0.000	36.2
Residual	40	101.5	2.54	2.57	0.000	
Error	126	124.2	0.99			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = $(SS \text{ for Genotype, Environment or } G \times E / SS \text{ for total}) \times 100$

IPCA = $(SS \text{ for IPCA} / SS \text{ for } G \times E) \times 100$

The higher environment effect is from the fact that protein content and grain filling which were more susceptible to environmental effects are associated with flour water absorption. This may be seen from

Tables 5.1.10 and 5.1.12 where, because of low protein content at Prieska, breakflour yield and vitreous kernels were lower than at Loskop where protein was high. Wheat grains with higher protein and good grain filling tend to be harder, resulting in more breakflour which in turn increases flour water absorption capacity. That is why genotype effect was also higher as genotypes differ in protein assimilation, grain filling, and consequently hardness. The smaller interaction effects indicate the parameter to be more influenced by environment and then genotype.

The environment means (Table 5.1.28) ranged between 59.67 to 66.80 at Koedoeskop and Loskop respectively with the grand mean being 62.38. The environment main effect showed three groups of sites. Loskop had the highest mean, far above the grand mean. Prieska, Hopetown, BullHill and Barkly West were very close or similar to the grand mean, whereas Koedoeskop was far below the mean. It was due to ideal or optimum environments realised in this year compared to those of 1997, which made Loskop have higher grain filling which, in addition to its higher protein resulted in higher water absorption. However, with a site like Koedoeskop being in the warmer areas, protein (especially quality) might have been affected. This effect together with reduced grain filling realised at this site resulted in lower water absorption compared to other sites. Very poor results may have been realised if this site was included in 1997, which had more adverse environmental conditions. The genotype means ranged between 59.89 to 64.40 for SST57 and SST825 respectively (Appendix 2). Genotype main effect also showed three groups. SST825 and SST822 had higher mean values, far above the grand mean and ranked very high in most of the locations. Other genotypes were closer to the mean except Marico and SST57, which were far below the mean and showed contrast with other genotypes. It is true that good absorption capacity is influenced by both grain filling and protein content and may be revealed by loaf volume. This is proved by higher hectoliter mass and loaf volume at Prieska, Hopetown and Douglas (Tables 5.1.4 and 5.1.32). However, Palmiet, Marico, T4 and SST57 showed lower grain filling at most of the locations. Because Marico and SST57 were not very low in protein content, and their absorptions proved to be low at most of the sites, still the loaf volumes were intermediate to higher, particularly that of SST57. On the other hand, Palmiet and T4 had low to very low grain filling respectively and showed low protein contents at most of the sites. Consequently although they showed intermediate to high water absorption, this may be due to problems in milling such as bran contamination. This is from the fact that the two genotypes had very low loaf volumes at most of the sites except some environment interactions showed by Palmiet. Also since SST825 had higher grain filling in most of the sites than SST38, it also showed higher water absorptions. However, since SST825 had lower protein content than SST38 in most of the sites, SST38 and SST825 had higher and lower loaf volumes respectively at most of the sites. This again confirms the importance of high protein content in addition to high water absorption capacities for wheat flour.

Table 7 5.1.28 Ranking of genotypes in each location for farinograph water absorption and environmental means in 1998.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	SST825 (63.71)	SST825 (63.66)	SST822 (65.11)	SST825 (63.89)	SST825 (64.11)	SST825 (68.97)	SST825 (61.55)
2	SST822 (62.92)	SST822 (62.88)	SST825 (64.90)	Kariega (62.93)	SST822 (63.47)	SST822 (68.59)	SST822 (60.65)
3	T4 (62.50)	T4 (62.44)	SST38 (63.71)	T4 (62.91)	T4 (62.82)	T4 (67.57)	T4 (60.38)
4	Kariega (62.01)	Kariega (61.93)	T4 (63.25)	SST822 (62.58)	Palmiet (62.26)	SST38 (67.10)	Kariega (59.98)
5	Palmiet (61.99)	Palmiet (61.92)	SST876 (63.02)	Palmiet (62.54)	SST876 (62.24)	SST876 (67.09)	Palmiet (59.89)
6	Inia (61.87)	Inia (61.81)	Inia (62.86)	Inia (62.15)	Inia (62.23)	Inia (67.04)	Inia (59.72)
7	SST876 (61.85)	SST876 (61.79)	Palmiet (62.45)	SST876 (62.03)	Kariega (62.16)	Palmiet (66.94)	SST876 (59.68)
8	SST38 (61.37)	SST38 (61.33)	Kariega (61.73)	Marico (61.80)	SST38 (61.95)	Kariega (66.65)	SST38 (59.09)
9	Marico (60.11)	Marico (60.00)	SST57 (58.84)	SST38 (60.96)	Marico (60.01)	Marico (64.11)	Marico (58.23)
10	SST57 (59.46)	SST57 (59.38)	Marico (58.32)	SST57 (60.56)	SST57 (59.56)	SST57 (63.96)	SST57 (57.47)
Mean	61.78	61.71	62.42	62.24	62.08	66.80	59.67

Grand mean = 62.39 LSD (0.05) : treatment = 0.33 , environment = 1.042

The AMMI biplot for genotype and environment means (Figure 5.1.14) shows environment interaction for SST38 and Marico. SST38 ranked lower at most of the sites except Prieska and Loskop where it had environment interaction and ranked above the middle. On the other hand Marico showed negative environment interactions and ranked last or second from last except at Hopetown where it was third from last. Other genotypes showed stability for water absorption at most of the sites. However, although SST822 and Kariega showed slightly higher or lower ranking in some sites, the values were not so far from the mean to show significant interaction.

At Prieska positive environment interaction was shown, and at Hopetown negative interaction was shown (Figure 5.1.14). At Prieska most of the genotypes had higher mean values and SST38 ranked higher due to environment interaction. In Hopetown although Marico ranked a bit higher, SST822 and SST876 which were higher at most of the locations, were lower at this site. SST38 also ranked much lower. Other locations showed fewer interactions and may give reliable ranking for most of the genotypes, particularly Douglas, BullHill and Barkly West.

In conclusion we can say most of the genotypes proved to be stable in water absorption at most of the locations except SST38 which had environment interactions at Prieska and Loskop. Nevertheless despite a genotype showing higher or low absorption capacity there is a need to crosscheck if the grain filling and protein content were also higher (optimum). This is from the fact that the two parameters are necessary to ensure that the realised absorption is optimum and the three parameters together have a large influence on loaf volume. For the locations however, environment interactions were shown by SST38 at Prieska, Loskop and also at Hopetown together with SST822 and Marico. However, most of the genotypes showed predictable rank and had means within the expected range of 60.0 to 63.0 (South African recommendation) at most of the sites except Loskop and Koedoeskop. This shows that the two sites both need management practices and genotype selection for higher grain filling. For Loskop again low environment and genotype nitrogen yields are important.

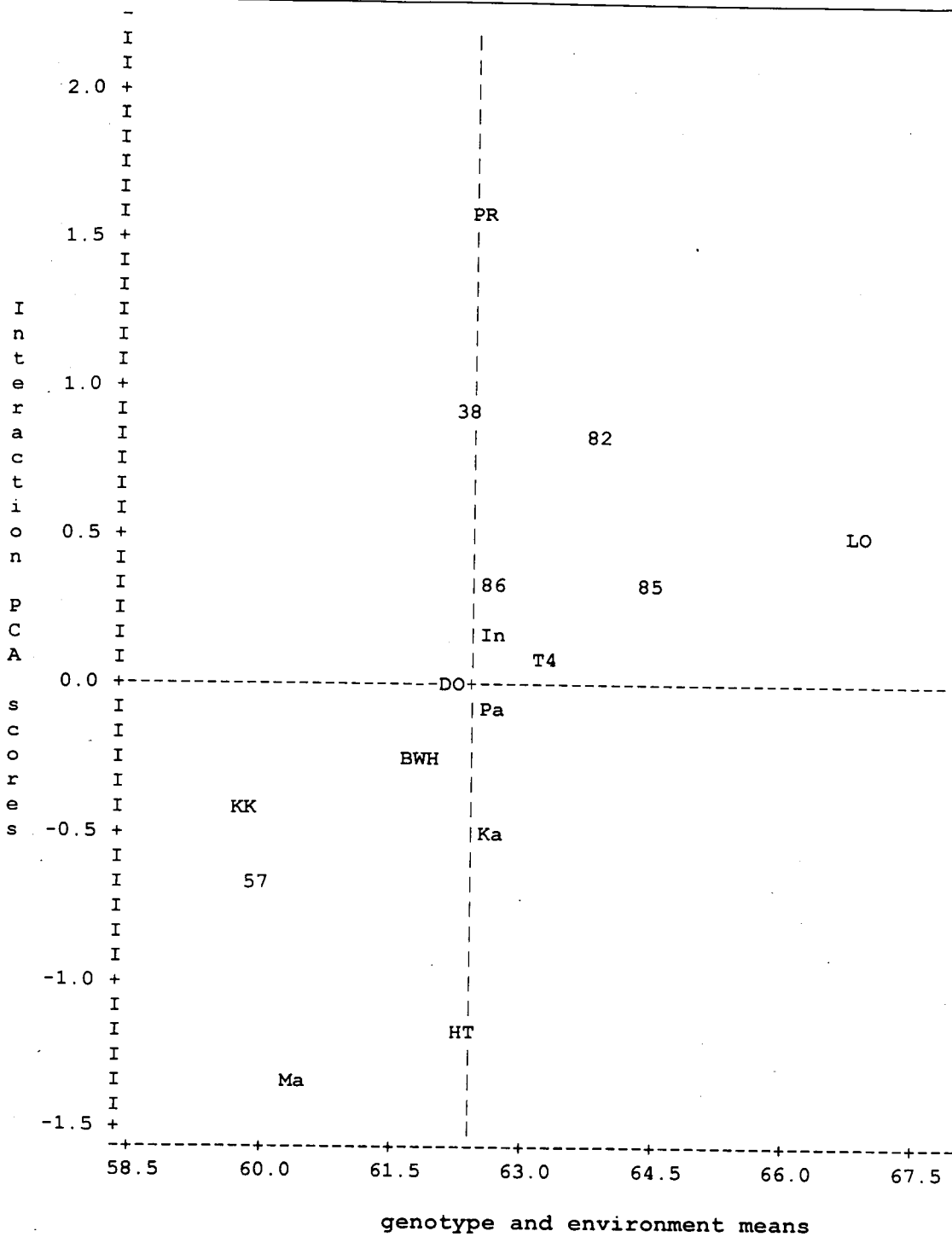


Figure 5.1.14 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for farinograph water absorption in 1998.

Sodium dodecyl sulphate (SDS) – sedimentation

The ANOVA results (Table 5.1.29) show significant variation for, treatment, environments, genotypes, interaction, IPCA as well as residual which again indicates presence of noise. The highly significant variation indicates different genotype performance as well as varying environment and interaction effects in various locations for this parameter. The block effect was not significant and this shows that there were no variations for genotypes within locations. High SDS values being associated with high protein, and they may differ depending on quality aspects. Sontag–Stroh *et al.* (1996) reported that significant interaction between the allelic variants of HMW glutenins and low molecular weight (LMW) gluten proteins affected the SDS–sedimentation volume. The heritability of the parameter is also high and that is why environmental influence was low in both years. According to János (1998) the SDS–sedimentation volumes of different cultivars are considered to be a relatively stable quality feature, not very sensitive to environmental effects. Also with more conducive environments as it was for 1998, the environment effects tend to decrease and both genotype and interaction effects increase. The respective contribution to the variation made by environments, genotypes and interactions were 7.0%, 66.5% and 14.0% respectively. The IPCA captured 49.3% variation of the interaction effect.

Table 5.1.29 Analysis of variance results for sodium dodecyl sulphate sedimentation in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	18128	86.7			
Treatment	69	15869	230.0	14.82	0.000	
Environment (E)	6	1274	212.4	13.68	0.000	7.0
Block	14	303	21.7	1.40	0.164	
Genotype (G)	9	12061	1340.1	86.34	0.000	66.5
G x E	54	2534	46.9	3.02	0.000	14.0
IPCA	14	1248	89.2	5.74	0.000	49.3
Residual	40	1285	32.1	2.07	0.001	
Error	126	1956	15.5			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E /SS for total) x 100

IPCA = (SS for IPCA/SS for G x E) x 100

The environment means ranged between 75.37 to 84.30 (Table 5.1.30) at Prieska and Loskop respectively with the grand mean being 78.92. However, although all sites managed to be above the recommended value (≥ 70.0), slight differences were found. Loskop had a mean above the grand mean, other sites were almost equal to the mean and Prieska was lower than the mean. Another observation is that this parameter was influenced by the environment variation between locations more than between years as the pattern of variation between sites was similar. This is from the fact that, although in 1997 non of the locations attained the recommended value, the environment main effect was similar to that of 1998, with Prieska being lower, Loskop higher and other sites intermediate. The genotype means ranged between 63.95 to 88.76 for T4 and Kariega respectively (Appendix 2) and three genotype groups were realised. Kariega, Marico, SST38, Inia and SST822 had means above the grand mean and they ranked higher at most of the sites (Table 5.1.30). SST825, SST876 and SST57 had means closer and a bit lower than the mean and they ranked just below the middle at most of the sites. However, Palmiet and T4 had lower means, far below the mean and contrasted with other genotypes. This was from the fact that other genotypes were above the recommended value at all sites. Palmiet and T4 showed optimum values at Loskop and Koedoeskop and BullHill (Palmiet), but for the other sites they were much lower than the recommended value.

The AMMI biplot for genotype and environment means (Figure 5.1.15) shows very small environment interactions for Palmiet, T4, SST876 and SST38. Palmiet had higher mean values at BullHill than at other sites, although it was still ranking relatively low. SST876 was higher at this site but it was below the middle in other sites and SST38 also ranked lower at this site but it was at the middle to higher at other locations. T4 on the other hand was last at four sites but second from last at Barkly West, Prieska and Hopetown thus showing small positive interaction. Other genotypes showed very high stability and maintained their rank at almost all sites.

The sites (Figure 5.1.15) showed high genotype interaction at BullHill and to a lesser extent Koedoeskop. At BullHill this was due to SST38 and SST876 which had environment interaction and ranked lower and higher respectively compared to other sites. SST38 also ranked at the middle at Koedoeskop thus showing environment interaction.

Table 5.1.30 Ranking of genotypes in each location for sodium dodecyl sulphate sedimentation and environmental means in 1998.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	Inia (88.11)	Kariega (89.66)	Kariega (87.25)	Kariega (89.91)	Kariega (89.04)	Kariega (94.77)	Kariega (86.58)
2	Marico (85.76)	Marico (86.87)	Marico (84.05)	Marico (87.15)	Marico (86.68)	Marico (92.60)	Marico (86.22)
3	Kariega (84.13)	SST38 (84.59)	SST38 (82.27)	SST38 (84.84)	SST38 (83.89)	SST38 (89.58)	Inia (85.74)
4	SST876 (82.82)	Inia (82.90)	Inia (79.50)	Inia (83.23)	Inia (83.33)	Inia (89.52)	SST822 (81.79)
5	SST822 (82.29)	SST822 (81.25)	SST822 (78.23)	SST822 (81.55)	SST822 (81.27)	SST822 (87.28)	SST38 (81.02)
6	SST825 (81.04)	SST825 (77.68)	SST825 (74.46)	SST825 (78.00)	SST825 (77.93)	SST825 (84.05)	SST825 (79.50)
7	SST38 (78.15)	SST57 (74.88)	SST57 (72.03)	SST57 (75.17)	SST876 (74.78)	SST876 (81.14)	SST876 (78.83)
8	Palmiet (77.16)	SST876 (74.01)	SST876 (70.27)	SST876 (74.36)	SST57 (74.72)	SST57 (80.66)	SST57 (74.43)
9	SST57 (74.11)	T4 (66.18)	T4 (64.28)	T4 (66.40)	Palmiet (66.40)	Palmiet (72.89)	Palmiet (71.81)
10	T4 (55.18)	Palmiet (65.33)	Palmiet (61.32)	Palmiet (65.71)	T4 (65.03)	T4 (70.52)	T4 (60.09)
Mean	78.87	78.33	75.37	78.63	78.31	84.30	78.60

Grand mean = 78.92 LSD (0.05) : treatment = 1.304 , environment = 4.125

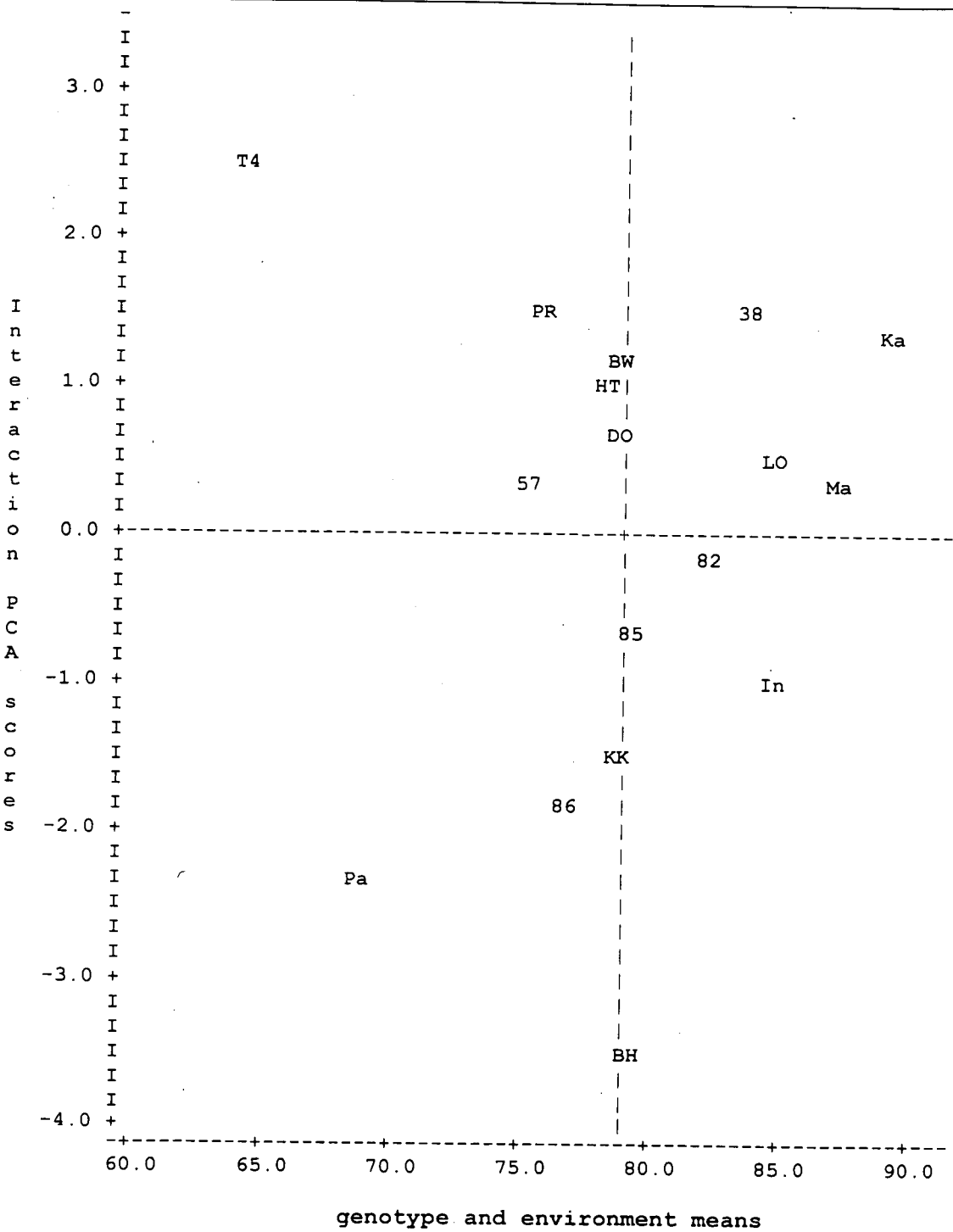


Figure 5.1.15 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for sodium dodecyl sulphate sedimentation in 1998.

In conclusion we can say, that the parameter showed high heritability and was not influenced by environment change such as between years as the sites maintained their rank. Therefore it is a good parameter for showing the potential of both genotypes and locations. For the genotypes, most of them were stable for this parameter and may give reliable ranking at most of the sites except SST38 and SST876 which had environment interaction particularly at BullHill. Therefore care should be taken for these genotypes at this site. Palmiet and T4 seemed to have low genetic potential for this parameter, especially T4. However, Palmiet had means just above the recommended value at Loskop and Koedoeskop and much higher at BullHill. Despite it ranking low it showed specific interaction with these sites as it also ranked first for loaf volume. For the locations, only BullHill needs care due to some environment interaction with certain genotypes but most of the sites are expected to give reliable ranking for most of the genotypes. However, in sites where higher yields were realised like Prieska, there is a need for management practices to increase nitrogen yield and thus increase protein content. This is from the fact that apart from protein quality which is more cultivar specific, sedimentation values tend to increase with increase in protein content.

Loaf volume at 12% protein content

The results for analysis of variance (Table 5.1.31) show significant variation ($p < 0.001$) for treatment, environments, genotypes, interaction, IPCA as well as residual. This implies different genotype performance, varying environment and interaction effects as well as presence of noise. Compared to other parameters, the effects of environments, genotypes and interactions on loaf volume were much the same and environment effect was a bit higher. The cause of similar effects for the three sources of variation is due to the fact that protein content and quality as well as endosperm starch content are important to realise a desirable loaf volume. Protein quality (gluten composition) is more genotype specific, but interaction and environment effects may interfere and modify the final quality. This may be mainly due to alteration of glutenin-to-gliadin ratios. According to Robert *et al.* (1996), flour protein concentration and the percentage of protein present as gliadin and non-gluten proteins was found to be most sensitive to environmental fluctuations. Protein and endosperm starch contents are more influenced by environment but the final contents again will depend on genotype potential and its interaction with the environment. The respective contributions to the total variation by environment, genotype and interaction were 39.7%, 27.6% and 20.2% respectively. From the interaction effect, the IPCA captured 53.7%. For 1997 the interaction effect was higher, followed by genotype and then environment effects. This shows genotype effect to be more stable for this parameter. With adverse environmental conditions the interaction effect was high as only genotypes with good genetic potential managed to show high values. However, with optimal environmental conditions, most of the genotypes even with less potential may show higher values and this cause environmental effects to be high.

Table 5.1.31 Analysis of variance results for loaf volume at 12% protein content in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	09	1290812	6176			
Treatment	69	1129948	16376	14.89	0.000	
Environment (E)	6	512628	85438	77.68	0.000	39.7
Block	14	22275	1591	1.45	0.141	
Genotype (G)	9	356727	39636	36.04	0.000	27.6
G x E	54	260593	4826	4.38	0.000	20.2
IPCA	14	140025	10002	9.09	0.000	53.7
Residual	40	120568	3014	2.74	0.000	
Error	126	138589	1100			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means ranged between 810.8 to 959.0 at Loskop and Hopetown respectively, with a grand mean of 928.7 (Table 5.1.32). Environment main effect showed two major groups. Loskop performed below the mean, while most of the other sites had averages above the mean, and Barkly West was equal to the mean. The higher mean values at Hopetown for both years implies that most of the genotypes performed well at this site suggesting reliability of results from this site. On the other hand the results from Loskop seems not to be reliable as the site was intermediate in 1997 but very low in 1998 indicating poor performance for most of the genotypes.

The genotype means (Appendix 2) ranged between 823.4 to 972.3 for T4 and SST38 respectively. Genotype main effect showed three groups. SST38, Inia, SST822, Kariega and SST57 had means much higher than the grand mean and ranked intermediate to higher in most of the sites. However, due to negative environment interactions at BullHill, Loskop and Koedoeskop SST822, Kariega and Inia were below the middle. SST825, SST876 and Marico had means very close to the grand mean and ranked close and below the middle at most of the locations. Palmiet and T4, on the other hand, ranked very low or last at most of the sites. However, Palmiet showed high positive environment interactions at BullHill, Loskop and Koedoeskop and ranked first at all three sites. This implies that there is a need for identification of which environments, genotypes and interaction effects may result in optimum loaf volumes due to strong effects of all three sources of variation.

The AMMI biplot for genotype and environment means (Figure 5.1.16) showed very high environment interaction for Palmiet and to a lesser extent SST876 and Inia. SST876 and Palmiet showed negative interactions as they ranked very low at Barkly West, Prieska, Hopetown and Douglas where Inia ranked second and thus showed positive environment interaction. Nevertheless, for other sites, Palmiet was first, SST876 intermediate and Inia much lower. Other genotypes showed stability and thus had similar rankings at most of the sites. From the same AMMI biplot the genotypes showed high negative and positive environment interactions at Koedoeskop, BullHill, Loskop and Prieska respectively. For Koedoeskop, BullHill and Loskop, with the exception of SST38 and SST57, most of the genotypes, which ranked intermediate to higher at other sites, were intermediate to lower at these sites. At Prieska, genotype ranking was similar to that of most of the sites (like Douglas, Hopetown and Barkly West). However, SST38, Inia and SST822 had higher means than at other sites and thus showed positive environment interaction with this site. Other sites showed absence of interaction and thus may give reliable ranking for most of the genotypes.

In conclusion we can say that SST38, SST822, SST57, Kariega and SST825 showed wide adaptability for loaf volume and may give intermediate to higher ranking at most of the locations. Considering interaction effects, Marico and Inia had intermediate to higher means respectively at Barkly West, Prieska, Hopetown and Douglas and together with SST38, SST822, SST57, Kariega and SST825 are expected to give good results at these sites. However, at BullHill, Koedoeskop and Loskop, Palmiet and SST876 ranked first and intermediate respectively. The two genotypes are therefore, also expected to give good results at these sites. For the locations, BullHill, Loskop and Koedoeskop more environment interactions were shown for genotypes and care should be taken for Inia, Marico and Palmiet, which ranked very low and high respectively, not to be generalised to other sites. Nevertheless other sites showed less and/or positive environment interactions with some of the genotypes which indicates that these genotypes should perform well in any of these environments. However, for Loskop which showed much contrast with other sites, cultivars will have to be used which are adapted to that particular environment.

Table 5.1.32 Ranking of genotypes in each location for loaf volume at 12% protein content and environmental means in 1998.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	Palmiet (997)	SST38 (980)	SST38 (1027)	SST38 (1015)	SST38 (1000)	Palmiet (841)	Palmiet (995.0)
2	SST57 (979)	Inia (968)	Inia (1016)	Inia (1003)	Inia (989)	SST38 (833)	SST57 (976.8)
3	SST38 (977)	SST822 (961)	SST822 (1004)	SST822 (995)	SST822 (979)	SST57 (832)	SST38 (974.3)
4	SST876 (973)	Kariega (956)	Kariega (997)	Kariega (990)	Kariega (973)	SST825 (825)	SST876 (970.8)
5	SST825 (972)	SST57 (945)	SST57 (970)	SST57 (976)	SST57 (952)	SST876 (824)	SST825 (969.6)
6	SST822 (963)	Marico (933)	Marico (969)	Marico (966)	Marico (947)	SST822 (819)	SST822 (960.6)
7	Kariega (962)	SST825 (932)	SST825 (954)	SST825 (962)	SST825 (937)	Kariega (818)	Kariega (960.1)
8	Inia (960)	SST876 (915)	SST876 (927)	SST876 (944)	SST876 (915)	Inia (817)	Inia (957.6)
9	Marico (948)	Palmiet (858)	T4 (866)	Palmiet (880)	T4 (843)	Marico (804)	Marico (946.3)
10	T4 (838)	T4 (827)	Palmiet (826)	T4 (861)	Palmiet (831)	T4 (694)	T4 (835.9)
Mean	956.8	927.6	955.7	959.0	936.6	810.8	954.7

Grand mean = 928.74 LSD (0.05) : treatment = 10.988 , environment = 34.747

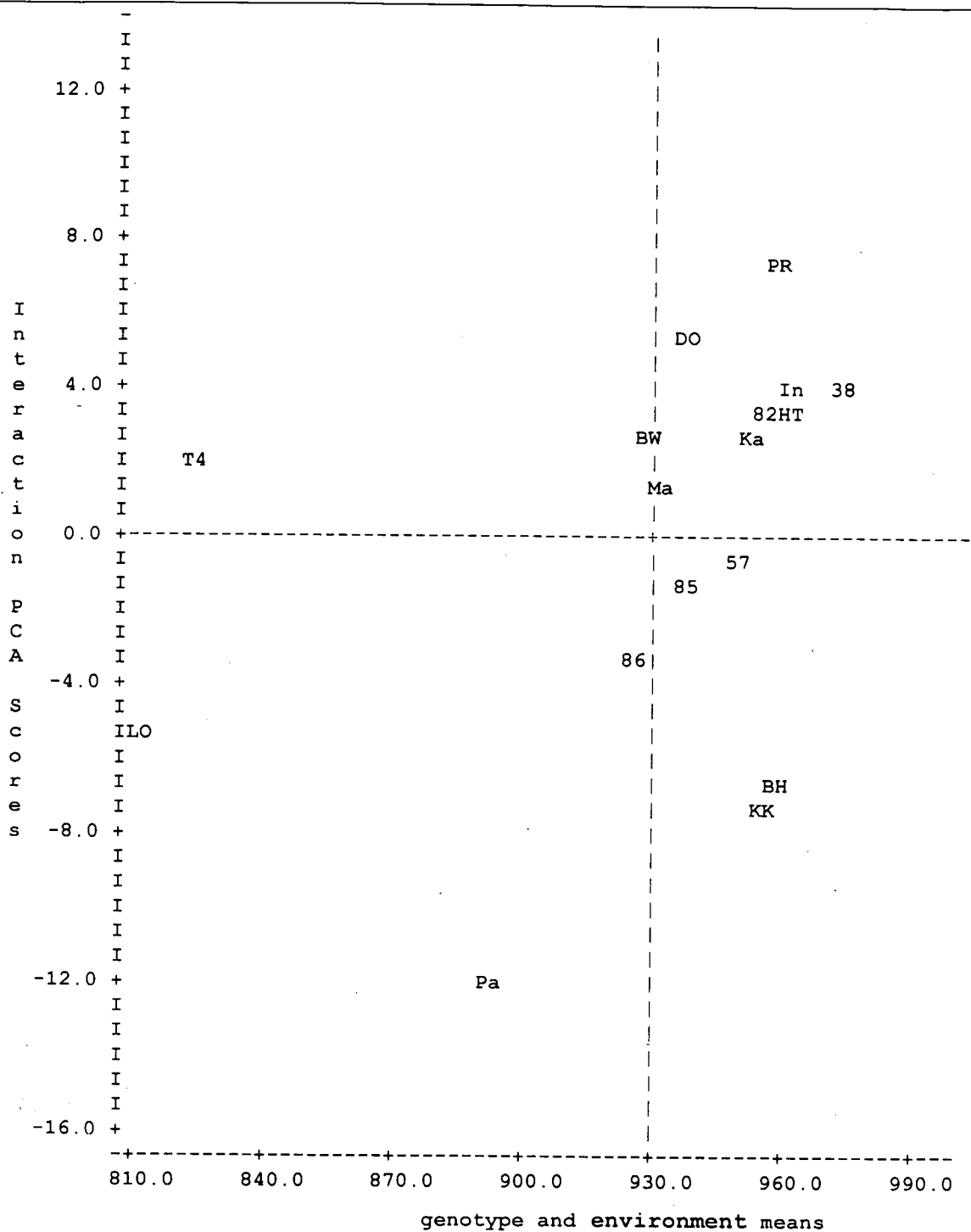


Figure 5.1.16 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedkop) for loaf volume at 12% protein content in 1998.

Loaf volume point score

The ANOVA results (Table 5.1.33) as it was for loaf volume, shows significant variation ($p < 0.001$) for treatment, environment, genotype, interaction, IPCA as well as residual. The non-significant block effect implies lack of variation for particular genotypes within locations. The contributions of environment, genotype and interaction to the variation were 12.15, 22.0% and 36.2% respectively. This shows genotype and interaction to contribute almost twice and thrice the variation than that of environment. This is due to the fact that protein quality (in addition to content) and endosperm starch content (not affected by α -amylase activities) are more important to realise higher loaf volume with good crumb and internal structure. However, protein quality and α -amylase activity are more genotype specific and genotype x environment interaction also plays as big a role as environment. The highly significant residual implies presence of noise and this was revealed by the smaller percentage (47.7) of the interaction effect captured by the IPCA.

Table 5.1.33 Analysis of variance results for loaf volume point score in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	10227	48.93			
Treatment	69	7189	104.19	4.793	0.000	
Environment (E)	6	1233	205.49	9.454	0.000	12.1
Block	14	299	21.38	0.983	0.474	
Genotype (G)	9	2253	250.33	11.517	0.000	22.0
G x E	54	3703	68.58	3.155	0.000	36.2
IPCA	14	1766	126.13	5.803	0.000	47.7
Residual	40	1937	48.44	2.228	0.000	
Error	126	2739	21.74			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)

and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 5.1.34) ranged between 83.96 to 90.00 at Loskop and Hopetown respectively with a grand mean of 86.676. The environment main effect showed three groups; with Hopetown and Koedoeskop having means much higher than the grand mean. Barkly West and Bull Hill had means equal and a bit higher than the mean respectively. Loskop, Prieska and Douglas were slightly below the mean and the interaction effect was more in this group. However, most of the genotypes had a falling number (a measure of α -amylase activity) close to and higher than the recommended value of 250s (Table 5.1.38)

Table 5.1.34 Ranking of genotypes in each location for loaf volume point score and environmental means in 1998.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	SST38 (92.26)	SST38 (90.00)	Inia (90.41)	SST57 (92.52)	Inia (95.05)	SST38 (87.52)	SST38 (93.19)
2	Inia (90.43)	SST57 (88.70)	SST38 (90.03)	SST38 (92.46)	SST38 (92.04)	SST57 (86.20)	SST57 (92.07)
3	SST876 (90.01)	SST876 (87.65)	SST876 (87.95)	Palmiet (92.21)	SST876 (90.17)	SST876 (85.18)	SST876 (90.82)
4	SST57 (89.92)	SST822 (87.08)	Kariega (87.53)	T4 (90.42)	Kariega (90.13)	SST822 (84.59)	SST822 (90.33)
5	Kariega (89.28)	Inia (86.93)	SST822 (86.16)	SST822 (89.99)	SST822 (87.44)	Inia (84.49)	Inia (89.90)
6	SST822 (89.00)	Kariega (86.74)	SST57 (85.81)	SST876 (89.98)	marico (86.40)	Kariega (84.27)	Kariega (89.88)
7	Marico (88.41)	Marico (86.60)	Marico (85.36)	Marico (89.66)	SST57 (85.60)	Marico (84.11)	Marico (89.87)
8	Palmiet (83.65)	Palmiet (85.03)	SST825 (79.15)	Kariega (88.85)	SST825 (78.79)	Palmiet (82.44)	Palmiet (88.85)
9	SST825 (83.38)	T4 (83.64)	Palmiet (74.90)	inia (87.79)	T4 (69.30)	T4 (81.06)	T4 (87.40)
10	T4 (82.57)	SST825 (82.23)	T4 (74.37)	SST825 (86.13)	Palmiet (69.17)	SST825 (79.72)	SST825 (85.61)
Mean	87.89	86.46	84.17	90.00	84.41	83.96	89.79

Grand mean = 86.67 LSD (0.05) : treatment = 1.545 , environment = 4.885

It seems that protein content close to ideal (12%) and quality (composition) had a large influence on baking quality. According to Finney *et al.* (1987), the protein composition is primarily responsible for the differences in loaf volume for cultivars (genotypes) with the same protein content. Hopetown and Koedoeskop had protein contents close to the ideal for most of the genotypes. However, at Prieska and Douglas most of the genotypes had protein contents much lower than the ideal value. At Loskop (warmer area), protein contents for all genotypes were much higher than the recommended value but with lower loaf volume scores. It seems therefore that this site was the cause of negative correlation (not significant) between protein content and loaf volume point score. Consequently the three sites (Loskop, Prieska and Douglas) showed much lower loaf volume scores. The genotype means ranged between 81.25 to 91.07 for T4 and SST38 respectively (Appendix 2). The genotype main effect also showed three groups; with SST38 ranking much higher than the mean. This genotype also ranked higher at all sites showing wide adaptability in loaf volume point score. Most of the other genotypes had values higher (not significantly) than the mean. However, Palmiet, T4 and SST825 had very low values (significantly lower than the grand mean) and ranked very low at most of the locations. As expected, higher mean values in genotypes for this characteristic was accompanied by high protein content and vice versa. The only exception was SST825.

The AMMI biplot for genotype and environment means (Figure 5.1.17) shows high environment interactions for Inia, Palmiet, T4 and to a lesser extent Kariega and high interaction effects occurred at Hopetown. Palmiet and T4, which ranked very low at other sites, were above average at this site, showing positive environment interaction. Nevertheless Inia and Kariega which ranked intermediate to very high at other sites, were second and third from last at this site, showing negative environment interactions. Other genotypes proved to be stable and thus may give reliable rank at most of the locations. The sites show high environment interaction at Douglas and to a lesser extent Prieska and Hopetown. Both Douglas and Prieska showed negative interaction as Palmiet and T4 had much lower mean values at these sites, particularly at Douglas. The same genotypes were higher at Hopetown as already mentioned earlier.

In summary SST38, SST57, ST876, Inia, SST822, Kariega and Marico ranked intermediate to higher at most of the sites and thus may give reliable rank at most of the locations. Nevertheless Marico ranked lower than others did and Kariega and Inia showed negative environment interactions at Hopetown and thus care must be taken not to use these genotypes in this environment. On the other hand, Palmiet, T4 and SST825 ranked very low at most of the sites except Palmiet and T4 which showed positive environment interactions at Hopetown and rank a bit higher. Therefore these three genotypes seem to have less potential for this character. For the locations, most gave reliable genotype ranking except Hopetown that showed positive and negative environment interactions with some genotypes. Also the very low mean values shown by Palmiet and T4 at Prieska and particularly at Douglas should not be generalised to other sites.

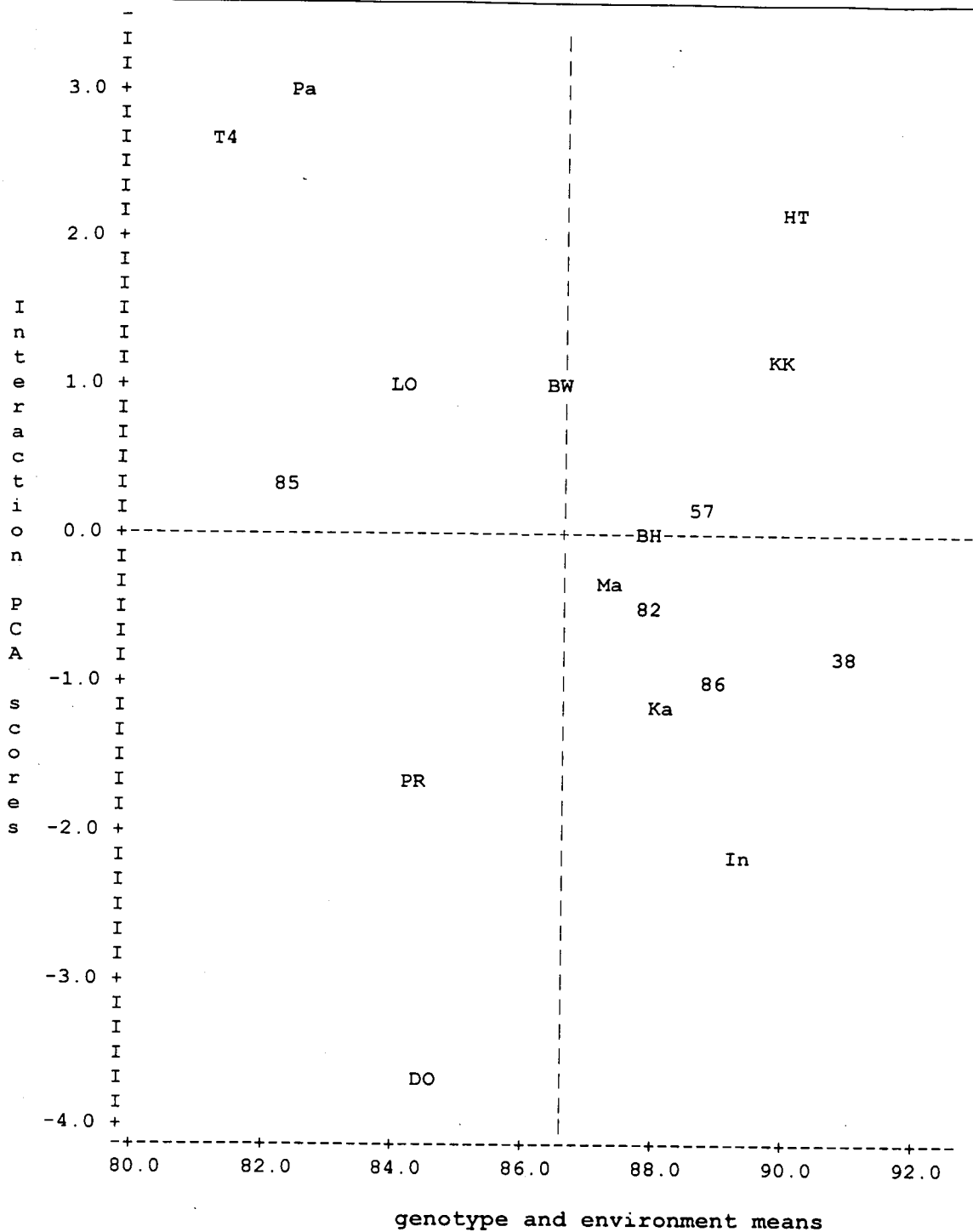


Figure 5.1.17 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for loaf volume point score in 1998.

Wet gluten content at 12% protein

Analysis of variance (Table 5.1.35) showed highly significant variations for treatment, environment, genotypes, interactions and the IPCA. However, the block effect was significant at $p < 0.05$, implying presence of slight variation for particular genotypes within locations. The non-significant residual implies absence of noise and thus most of the interaction effects were revealed by the IPCA1. When compared to other protein-related parameters already discussed, like loaf volume, sedimentation and loaf volume point score where environment, genotype and interaction showed much influence. However, for this parameter, environment effect was dominant as it was for the protein content, with genotypes and interactions having less significant effects. This is due to the fact that gluten content increases with increase in protein content. Also considering the constituents of gluten protein which are, high and low molecular weight glutenins (HMW-G and LMW-G) as well as gliadins. As mentioned earlier, according to Robert *et al.* (1996), gliadins are more susceptible to environmental variations and thus influence the final gluten content. Therefore the contributions of environments, genotypes and interactions to the variation were 75.6%, 5.1% and 8.7% and the IPCA captured 52.7% of the interaction effect. In 1997 the environment contribution was lower than that of genotype and interaction which was much higher. This implies that genotype and particularly interaction effects tends to increase with adverse growth conditions as only the genotypes with good potential (genetical and interaction) may have high values. Consequently the character seems to be less stable for the variations between years, compared to others like SDS-sedimentation which showed stability.

Table 5.1.35 Analysis of variance results for wet gluten content at 12% protein in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	7996	38.3			
Treatment	69	7145	103.6	18.32	0.000	
Environment (E)	6	6042	1007.0	178.13	0.000	75.6
Block	14	139	9.9	1.75	0.053	
Genotype (G)	9	409	45.5	8.04	0.000	5.1
G x E	54	694	12.9	2.27	0.000	8.7
IPCA	14	366	26.1	4.62	0.000	52.7
Residual	40	328	8.2	1.45	0.063	
Error	126	712	5.7			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = $(SS \text{ for Genotype, Environment or } G \times E / SS \text{ for total}) \times 100$

IPCA = $(SS \text{ for IPCA} / SS \text{ for } G \times E) \times 100$

The environmental means ranged between 31.92 to 48.34 at Koedoeskop and Loskop respectively, with a grand mean of 35.85 (Table 5.1.36). The environment main effect showed at least three groups. Loskop had the highest mean than the grand mean, followed by Barkly West. The two sites showed much contrast with others on the basis of main effect for Loskop and both Loskop and Barkly West for interaction. Other sites had less variation for means and they were lower than the mean (not significantly) except Koedoeskop. Therefore higher and lower gluten contents were realised from locations with higher and lower protein contents respectively. In contrast, loaf volume at Loskop had a lower mean value. It seems that higher gluten content is not desirable as it increases the percentages of low molecular weight glutenins and gliadins, which have low (or negative) influence on most of the parameters. According to Pomeranz (1988), although the HMW-glutenins make up only 10% of the total gluten and only 1% of the whole endosperm, they are nevertheless of fundamental significance in determining the rheological properties of the dough. Although Koedoeskop had a much lower mean for gluten content, it was among the sites which ranked higher for loaf volume. Therefore irrespective of gluten content being higher/lower, protein content closer to 12.0% is also important to confirm the environment's potential.

The genotype means ranged between 32.58 to 37.86 for Marico and SST876 respectively (Appendix 2). Though the range was not so high as for the environments, again three groups were realised. SST38 and SST876 had higher mean and ranked higher at most of the sites. Other genotypes were much closer to the mean, except Marico which was much lower and ranked last at most of the locations. However, concurrent to environments, it showed that for most of the genotypes, gluten contents between ± 30 to 40% are sufficient to give good results for other quality parameters such as loaf volume (Tables 5.1.32 and 5.1.36), (Glutomatic system). This will be fulfilled if the protein content is close to 12.0% and of good quality. This aspect of protein quality was revealed by genotypes like Palmiet, T4, SST825 and SST876 which, despite having intermediate to higher gluten contents, had very low loaf volumes. On the other hand, despite Marico having the lowest mean value, it had, together with Kariega, SST57, SST822, Inia and SST38 good protein qualities, particularly SST822, Inia and SST38. These genotypes ranked intermediate to higher for loaf volume.

The AMMI biplot for genotype and environment means (Figure 5.1.18) showed high environment interactions for SST825, SST876, SST38 and Marico and to a lesser extent Palmiet and SST822. SST822, SST38 and SST825 ranked lower at Barkly West and very high at Loskop, but it was the other way round at other sites. SST876 showed almost similar rank at most of the sites but it had higher means only at Barkly West and Loskop, showing negative environment interactions at most of the sites. This was also shown by Marico which ranked last at most of the locations with a mean gluten content close to 30%, but the higher mean at Loskop proved positive environment interaction. Values for Palmiet were much lower at Barkly West, Douglas and Loskop but intermediate at other sites and thus showing positive environment interaction. Other genotypes showed stability as they didn't vary much in rank and mean values at most of the sites.

The locations (Figure 5.1.18) showed high and negative environment interactions at Loskop and Barkly West. The genotypes responsible were SST38, SST822 and Palmiet which ranked lower at these two sites than at other sites. In conclusion therefore we can say, most of the genotypes had gluten content within an acceptable range irrespective of ranking higher or lower. However, considering loaf volume, protein content (close to 12.0%) and particularly protein quality (glutenin-to-gliadin ratios) was important for gluten content to have positive effects on other quality parameters such as loaf volume. Consequently, SST38, Inia, SST822, SST57, Kariega and Marico showed good potential for this parameter, with positive influence on other parameters more than other genotypes. Most of the locations had gluten content within the optimum range except Loskop that was very high due to high protein content realised at this site. Therefore, management practices and genotype selection, which will reduce nitrogen yield and thus protein content (closer to 12.0%) are important at this site. The higher protein content increases the percentages of LMW-glutenin and gliadins that are less important for most of the quality parameters, loaf volume in particular, as compared to HMW-glutenin. Payne *et al.* (1979,1981) demonstrated first that the HMW-glutenin subunits have an effect on bread making quality.

Table 5.1.36 Ranking of genotypes in each location for wet gluten content at 12% protein and environmental means in 1998.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	SST38 (36.49)	SST876 (42.22)	SST38 (36.51)	SST 38 (35.93)	SST38 (35.49)	SST876 (54.19)	SST38 (34.53)
2	SST822 (34.48)	SST825 (40.36)	SST822 (34.55)	SST822 (33.91)	SST876 (34.54)	SST825 (52.40)	SST876 (32.89)
3	SST876 (33.87)	T4 (38.35)	SST876 (34.06)	SST876 (33.26)	SST822 (33.91)	T4 (49.37)	SST822 (32.77)
4	Inia (33.71)	SST57 (37.73)	Inia (33.80)	Inia (33.13)	Inia (33.37)	SST57 (48.65)	Inia (32.13)
5	Palmiet (33.36)	Inia (37.63)	Palmiet (33.41)	Palmiet (32.80)	T4 (33.16)	Kariega (48.39)	T4 (31.82)
6	T4 (33.23)	Kariega (37.56)	T4 (33.35)	T4 (32.65)	Kariega (32.87)	Inia (48.30)	Kariega (31.59)
7	Kariega (33.09)	SST38 (37.53)	Kariega (33.19)	Kariega (32.51)	SST57 (32.81)	SST822 (47.78)	Palmiet (31.53)
8	SST57 (32.96)	SST822 (37.40)	SST57 (33.07)	SST57 (32.38)	Palmiet (32.58)	SST38 (47.36)	SST57 (31.50)
9	SST825 (31.73)	Palmiet (35.35)	SST825 (31.92)	Marico (31.15)	SST825 (32.46)	Palmiet (45.45)	SST825 (30.78)
10	Marico (31.70)	Marico (31.88)	Marico (31.71)	SST825 (31.12)	Marico (30.51)	Marico (41.47)	Marico (29.62)
Mean	33.46	37.60	33.56	32.88	33.17	48.34	31.92

Grand mean = 35.85 LSD (0.05): treatment = 0.791 , environment = 2.501

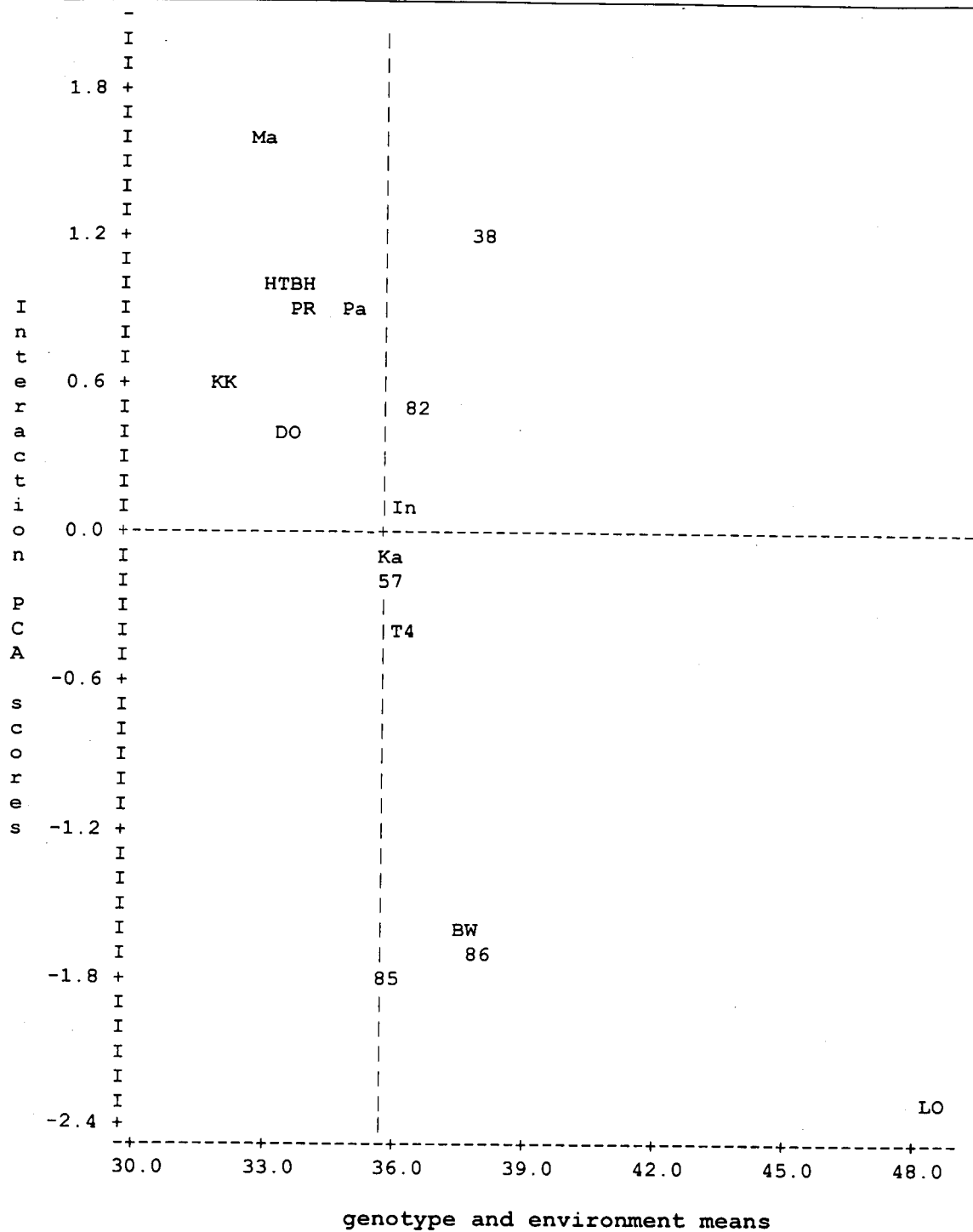


Figure 5.1.18 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for wet gluten content at 12% protein content in 1998.

Falling number

The analysis of variance (Table 5.1.37) shows highly significant variation ($p < 0.001$) for treatment, main effects, interactions as well as IPCA. The block and residual were non-significant, implying absence of genotype variations within locations and noise effect. Similar to the 1997 results, the interaction contribution to the variation was much higher followed the contribution by genotypes. The contribution of environment was not significant. The significant variations among locations were due to the extent to which environments interacts with genotypes, nevertheless environment had no influence on this parameter. Therefore the respective contributions to the variation for environment, genotype and interaction were 2.3%, 12.1% and 40.7% and the IPCA captured 61.2% of the interaction effect. The closeness of the values for both two years, implies that the parameter was stable and not much influenced by the environmental variations between years.

Table 5.1.37 Analysis of variance results for falling number in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	11888	535.3			
Treatment	69	61568	892.3	2.610	0.000	
Environment (E)	6	2543	423.9	1.240	0.291	2.3
Block	14	7242	517.3	1.513	0.115	
Genotype (G)	9	13519	1502.1	4.394	0.000	12.1
G x E	54	45506	842.7	2.465	0.000	40.7
IPCA	14	27852	1989.5	5.819	0.000	61.2
Residual	40	17654	441.3	1.291	0.145	
Error	126	43078	341.9			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 5.1.38) ranged between 267.9 s to 278.2 s at Prieska and Koedoeskop respectively with a grand mean of 273.8. All sites had means above the recommended value of 250.0 s and the main effect showed slight variation and only two groups of environments were realised. The environment means did not differ significantly from the mean, but Koedoeskop, BullHill, Loskop and Douglas performed above and Barkly West, Hopetown and Prieska below the mean. The genotype means (Appendix 2) ranged between 259.0 s to 290.9 s for Marico and SST822 respectively. However, genotype main effect was pronounced and about three groups were realised, though most were above the recommended value. SST822 had a higher mean, significantly higher than the grand mean, whereas Karioga and Marico had

much lower means (significantly in the case of Marico). Other genotypes had values closer to the mean. The higher and lower values for SST822 and Marico respectively were due to the higher and lower means they showed at Hopetown as a result of environment interaction. However, the differences from other genotypes were not so high at most of the locations.

The AMMI biplot for genotype and environment means (Figure 5.1.19) shows high environment interactions for SST822, Marico, SST38 and T4. SST822 ranked intermediate at Loskop, very high at other sites except BullHill where it was second from last, showing negative environment interaction. This phenomenon together with a very high means at Hopetown made it the most unstable. SST38 also showed negative environment interactions as it ranked very low at most of the sites except Hopetown, where it ranked second. T4 showed positive environment interactions at BullHill, Barkly West, Douglas and Loskop where it ranked high. It was also intermediate at other sites except Hopetown where it was second from last. Marico ranked higher only at BullHill but very low other sites (Table 5.1.38). Other genotypes were stable and are expected to give reliable rank at most of the locations.

The locations showed very high environment interactions with genotypes at Hopetown and BullHill with Hopetown showing much contrast with others. The genotypes responsible were SST822, SST38, Marico and T4. Therefore it seems there is a risk of higher humidity which may cause partial sprouting in some of the genotypes with less resistance, particularly at Hopetown and BullHill.

In conclusion we can say that SST38, Marico and Kariega ranked lower at most of the locations, showing less resistance to sprouting. However, at Hopetown, SST38 and BullHill, Marico and Kariega showed environment interaction and may perform well. Though SST822 and T4 ranked higher at most of the sites, they were very low at BullHill and Hopetown respectively. This shows negative environment interactions and they may not perform well at these sites. Other genotypes ranked intermediate to higher at most of the sites and thus may perform well at most of the locations. For these locations care must be taken at Hopetown and BullHill particularly for genotypes showing negative environment interactions such as SST822, T4 and for the much lower values shown by Kariega and Marico at Hopetown.

Table 5.1.38 Ranking of genotypes at each location for falling number and environmental means in 1998.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	T4 (291.8)	SST822 (280.7)	SST822 (287.4)	SST822 (346.5)	SST822 (284.5)	T4 (283.4)	SST822 (295.9)
2	Inia (283.8)	Inia (274.3)	Palmiet (272.6)	SST38 (297.3)	T4 (279.5)	Inia (281.1)	Palmiet (282.6)
3	SST825 (282.4)	T4 (274.0)	SST876 (271.9)	Palmiet (286.6)	Inia (279.4)	SST825 (280.1)	SST876 (282.1)
4	Marico (279.9)	SST876 (273.8)	Inia (270.1)	SST876 (280.9)	SST876 (278.6)	SST876 (278.7)	Inia (280.8)
5	SST57 (279.8)	Palmiet (273.7)	SST825 (269.5)	SST825 (266.5)	SST825 (278.5)	SST822 (278.7)	SST825 (280.1)
6	SST876 (277.5)	SST825 (273.4)	T4 (266.6)	Inia (266.0)	Palmiet (278.4)	Palmiet (277.9)	T4 (277.9)
7	Kariega (275.4)	SST57 (269.3)	SST38 (265.2)	SST57 (258.3)	SST57 (274.4)	SST57 (276.4)	SST57 (275.5)
8	Palmiet (275.1)	Kariega (263.9)	SST57 (264.7)	Kariega (250.3)	Kariega (269.1)	Kariega (271.4)	SST38 (274.6)
9	SST822 (262.3)	SST38 (263.1)	Kariega (259.0)	T4 (243.8)	SST38 (267.4)	Marico (270.0)	Kariega (269.8)
10	SST38 (256.6)	Marico (259.8)	Marico (251.6)	Marico (223.5)	Marico (265.4)	SST38 (264.8)	Marico (263.1)
Mean	276.5	270.6	267.9	272.0	275.5	276.3	278.2

Grand mean = 273.86 LSD (0.05): treatment = 6.126 , environment = 19.372

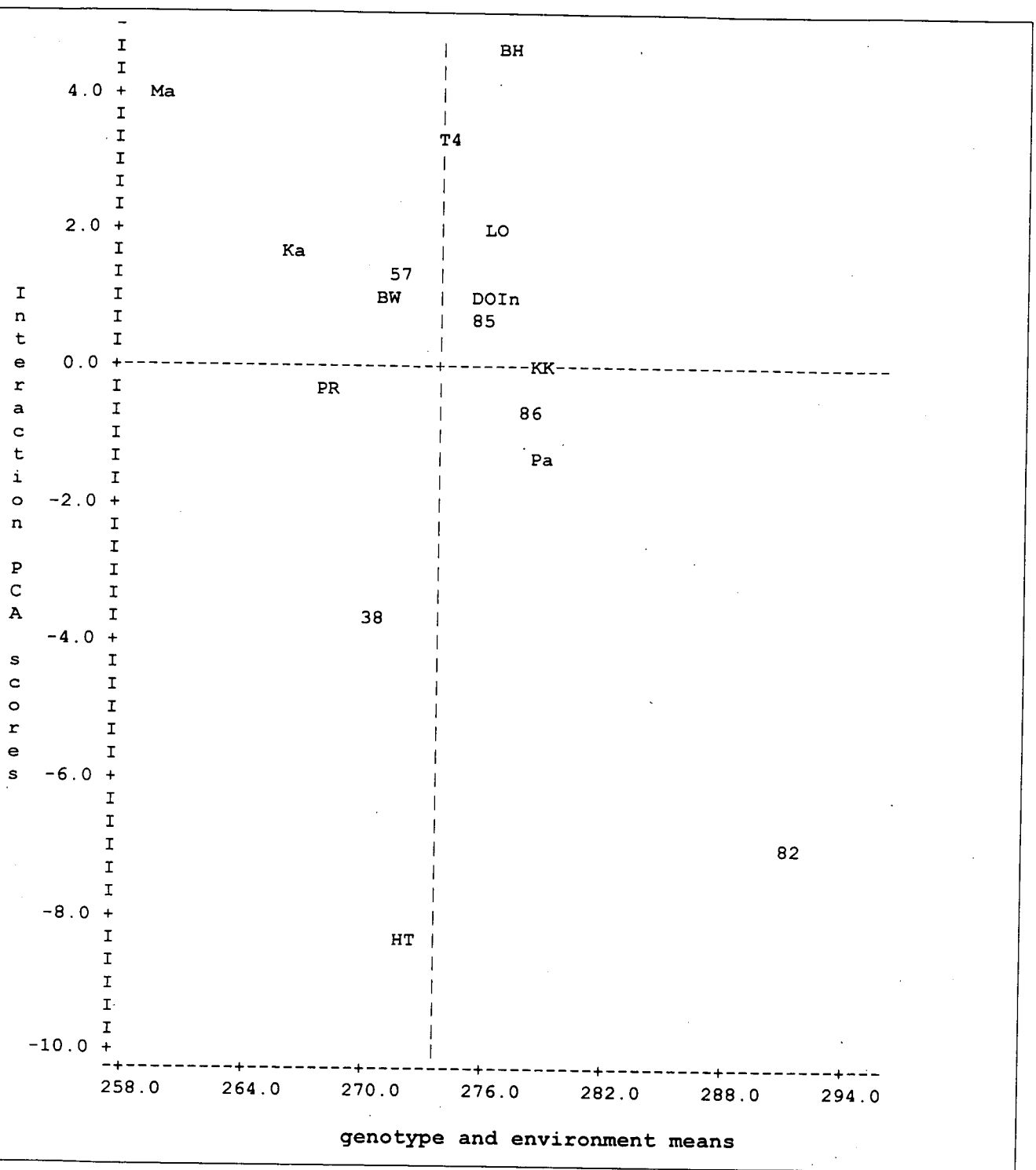


Figure 5.1.19 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for falling number in 1998.

Mixograph development time

The analysis of variance (Table 5.1.39) shows highly significant variations for treatment, environments, genotypes, interaction, IPCA as well as residual. The block effect was not significant, implying absence of environmental variation for particular genotypes within locations. The significant residual implies noise effects and thus not all interaction effects were revealed by the IPCA1. In 1997 both main effects and interaction had almost similar effects. However, in the 1998 results genotype contributed more to the variation than environment and interaction, which had lower and almost similar effects. This shows the parameter to be more genetically controlled and this is revealed more with less adverse environments. However, under adverse environments as it was for 1997, there is a slight decrease in genotype contribution and thus increasing environment and interaction effects. The respective contributions to the variation for environment, genotype and interaction were, 17.8%, 56.0% and 15.8%. From the interaction effect the IPCA captured 49.6%.

Table 5.1.39 Analysis of variance results for mixograph development time in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	90.04	0.431			
Treatment	69	80.62	1.168	16.83	0.000	
Environment (E)	6	15.99	2.665	38.38	0.000	17.8
Block	14	0.67	0.048	0.69	0.779	
Genotype (G)	9	50.39	5.598	80.64	0.000	56.0
G x E	54	14.24	0.264	3.80	0.000	15.8
IPCA	14	7.06	0.504	7.26	0.000	49.6
Residual	40	7.19	0.180	2.59	0.000	
Error	126	8.75	0.069			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 5.1.40) ranged between 2.07 to 2.87 at Prieska and Koedoeskop respectively, with a grand mean of 2.32. Compared to 1997, the 1998 results showed a decrease in mixing time for most of the genotypes and thus location means. The low protein and gluten content were the major causes of reduced mixing time for most of the genotypes at the cooler irrigation areas (BullHill, Prieska, Barkly West, Hopetown and Douglas). Except BullHill other sites had more than half of the genotypes with a mixing time lower than the recommended minimum value of ± 2.5 min. Since gluten (glutenin and gliadin) represents $\approx 80\%$ of the total protein (Pritchard and Brock, 1994; Tatham and Shewry, 1995) its effects at low

protein content may be affected. For the warmer irrigation areas (Loskop and Koedoeskop) only two genotypes had mixing times less than 2.4 min. At Loskop the protein and gluten contents were high and that is why most of the genotypes were not far from the recommended range of 2.5 to 3.0 min. This agrees with the results by Nel *et al.* (1998b) who also found an increase in mixing time at some of the sites, concomitant to the higher protein content. However, for Koedoeskop, despite having protein content closer to that of cooler irrigation areas, the gluten content was much lower. This may have interfered with glutenin-to-gliadin ratios and thus increased the mixing time, as at this site, half of the genotypes had mixing times above 3.11 min. It seems that the probability of higher mixing time in warmer areas is high as this was observed at Loskop also in 1997 despite having low protein for most of the genotypes. Again this is from the fact that gliadin is more susceptible to environmental effects, probably temperature.

The genotype means ranged between 1.38 to 2.99 for T4 and Marico respectively (Appendix 2), and two main groups were realised. Marico, SST57, Inia, Kariega, SST825 and SST822 were above the grand mean with Marico being much Higher. All were within the acceptable range of 2.5 to 3.0 min. SST38, SST876, Palmiet and T4 were lower than the mean and the minimum recommended value. Compared to the former group, these genotypes seem to have a lower genetic potential as they ranked lower at most of the sites. At Loskop and Koedoeskop, due to environment interactions some had higher mixing time but most of them still ranked relatively low. Therefore this signifies that genotype effect is largely responsible for the realised mixing time. Van Lill (1992) in a study of the effects of cropping systems, also observed that dough development time was principally genetically determined when compared to the effects of cropping systems or planting date, especially under climatically favourable weather conditions.

The AMMI biplot for genotype and environment means (Figure 5.1.20) showed slight environment interaction for Kariega and SST57 at Loskop. Kariega ranked first at this site but it was intermediate at other sites and thus showed negative interaction effect. On the other hand the positive environment interaction shown by SST57 was due to very low rank at Loskop but higher at other sites. Other genotypes proved to be stable as they showed less variation in ranks at most of the sites. The locations showed high negative environment interaction at Loskop and this caused this site to contrast with others. This was mainly due to SST57, which ranked very low at this site as mentioned above and also SST825 and SST876 ranked a bit lower than at other sites. Other sites showed less/no interaction, and therefore may give reliable ranking for most of the genotypes.

Table 5.1.40 Ranking of genotypes at each location for mixograph development time (min.) and environmental means in 1998.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	SST57 (2.82)	Marico (2.77)	Marico (2.76)	Marico (2.83)	Marico (2.77)	Kariega (3.67)	SST57 (3.47)
2	Marico (2.80)	SST57 (2.52)	SST57 (2.48)	SST57 (2.81)	SST57 (2.71)	Marico (3.57)	Marico (3.46)
3	Inia (2.66)	Inia (2.48)	Inia (2.46)	Inia (2.67)	Inia (2.58)	Inia (2.78)	Inia (3.31)
4	SST825 (2.63)	SST825 (2.39)	SST825 (2.35)	SST825 (2.63)	SST825 (2.53)	SST822 (2.51)	SST825 (3.28)
5	SST822 (2.46)	Kariega (2.35)	Kariega (2.35)	SST822 (2.47)	SST822 (2.38)	SST38 (2.49)	SST822 (3.11)
6	Kariega (2.23)	SST822 (2.27)	SST822 (2.24)	Kariega (2.28)	Kariega (2.25)	SST825 (2.44)	Kariega (2.90)
7	SST876 (1.87)	SST38 (1.76)	SST38 (1.75)	SST876 (1.88)	SST38 (1.78)	Palmiet (2.40)	SST876 (2.52)
8	SST38 (1.81)	SST876 (1.63)	Palmiet (1.60)	SST38 (1.84)	SST876 (1.78)	SST57 (2.39)	SST38 (2.47)
9	Palmiet (1.65)	Palmiet (1.61)	SST876 (1.60)	Palmiet (1.68)	Palmiet (1.62)	T4 (1.93)	Palmiet (2.34)
10	T4 (1.20)	T4 (1.16)	T4 (1.44)	T4 (1.22)	T4 (1.16)	SST876 (1.69)	T4 (1.86)
Mean	2.21	2.09	2.07	2.23	2.15	2.59	2.87

Grand mean = 2.317 LSD (0.05): treatment = 0.087 , environment = 0.275

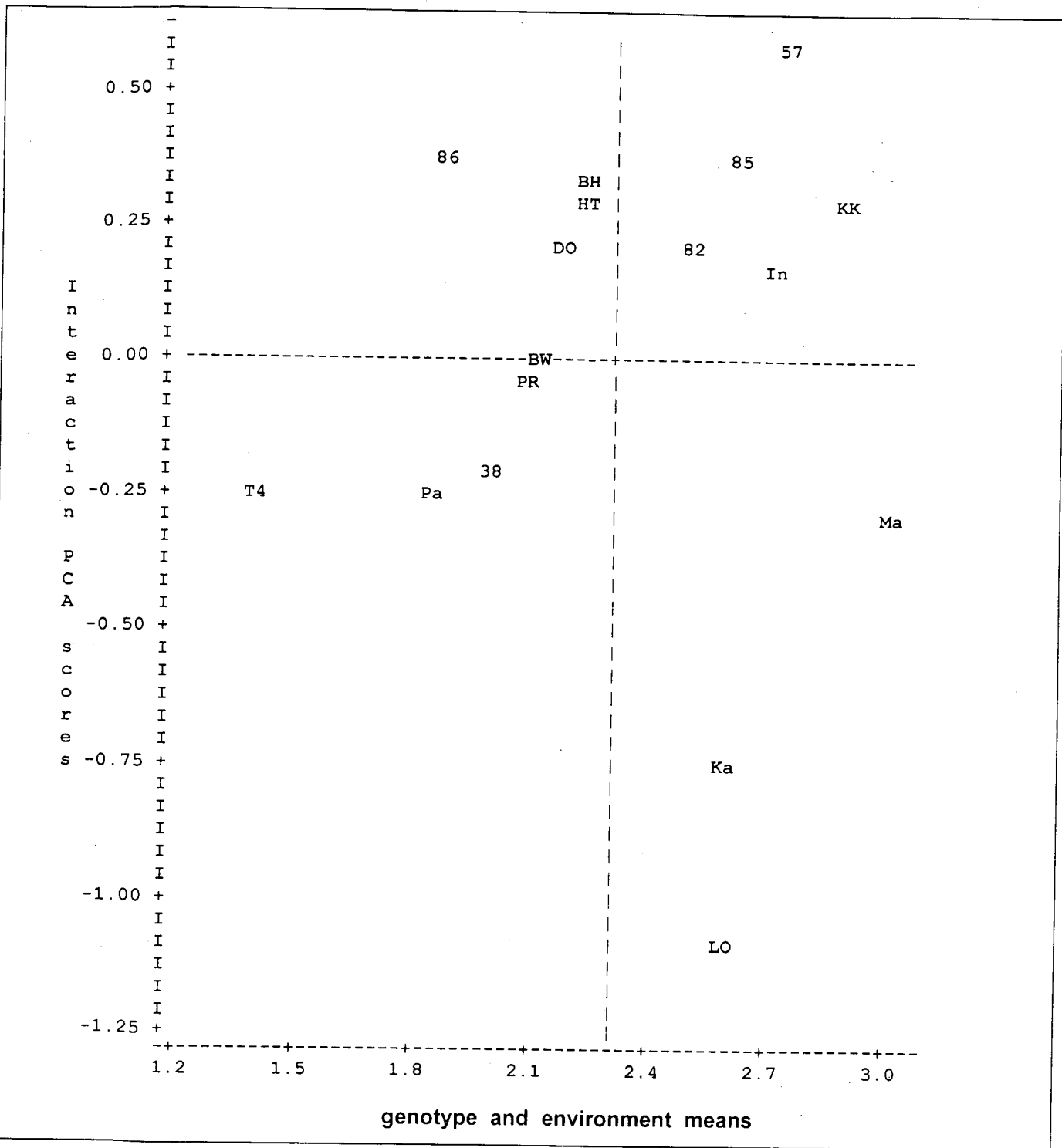


Figure 5.1.20 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for mixograph development time in 1998.

In summary, we can say, SST38, SST876, Palmiet and T4 showed low genetic potential for this parameter and may not give good results particularly at the cooler irrigation areas where they showed much lower mixing times. Other genotypes showed intermediate to higher mixing time at most of the sites and thus are expected to perform well. Also since genotype effects proved to be more important than environment and interaction effects, the genotype ranking at each site will be a reliable criteria. For the locations, only Loskop showed environment interactions and, care must be taken at this site for genotypes like Kariega and Marico, which showed very high mixing time. However, on the basis of temperature effects, the warmer and cooler irrigation areas showed higher and lower mixing times respectively for most of the genotypes. For better results therefore, warmer areas need genotypes with low to intermediate mixing times, and cooler areas intermediate to higher mixing times.

Mixograph point score

As it was for mixograph development time, the analysis of variance (Table 5.1.41) showed highly significant variation ($p < 0.001$) for treatment, main effects (environment and genotype), interaction, IPCA as well as residual. Block effect was not significant and this implies absence of variations for particular genotypes within locations. Comparable to the 1997 results, genotype effect was still leading in contribution to the variation and that of 1998 was a bit higher than that of 1997. This was followed by interaction and then environment which all showed decreased value. The respective contribution to the variation for the environment, genotype and interaction therefore were 13.0%, 60.0% and 16.0%. From the interaction effect the IPCA captured 49.9%.

Table 5.1.41 Analysis of variance results for mixograph point score in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	429.8	2.056			
Treatment	69	384.9	5.578	17.21	0.000	
Environment (E)	6	55.9	9.309	28.72	0.000	13.0
Block	14	4.0	0.289	0.89	0.570	
Genotype (G)	9	260.4	28.937	89.27	0.000	60.0
G x E	54	68.6	1.271	3.92	0.000	16.0
IPCA	14	34.2	2.443	7.54	0.000	49.9
Residual	40	34.4	0.861	2.65	0.000	
Error	126	40.8	0.324			

IPCA = Interaction Principal Component Analysis
SS Percentage contribution:

Genotype (G), Environment (E)
 and Interaction (G x E) } = (SS for Genotype, Environment or G x E /SS for total) x 100

IPCA = (SS for IPCA/SS for G x E) x 100

The environment means (Table 5.1.42) ranged between 2.30 to 3.83 at Hopetown and Koedoeskop respectively, with a grand mean of 2.96. The environment main effect showed two groups, with Koedoeskop and Loskop being higher than the grand mean. Other sites were lower than but very close to the mean except Hopetown which was much lower. General observations show that as it was for development time, higher and lower scores were obtained at warmer and cooler areas respectively. The higher and lower values were also realised from sites with much lower gluten content depending on genotype potential. Therefore it shows that the parameter is more influenced by protein quality particularly gluten. This is in terms of protein content and the extent to which the environmental conditions such as temperature interferes with its biochemical composition.

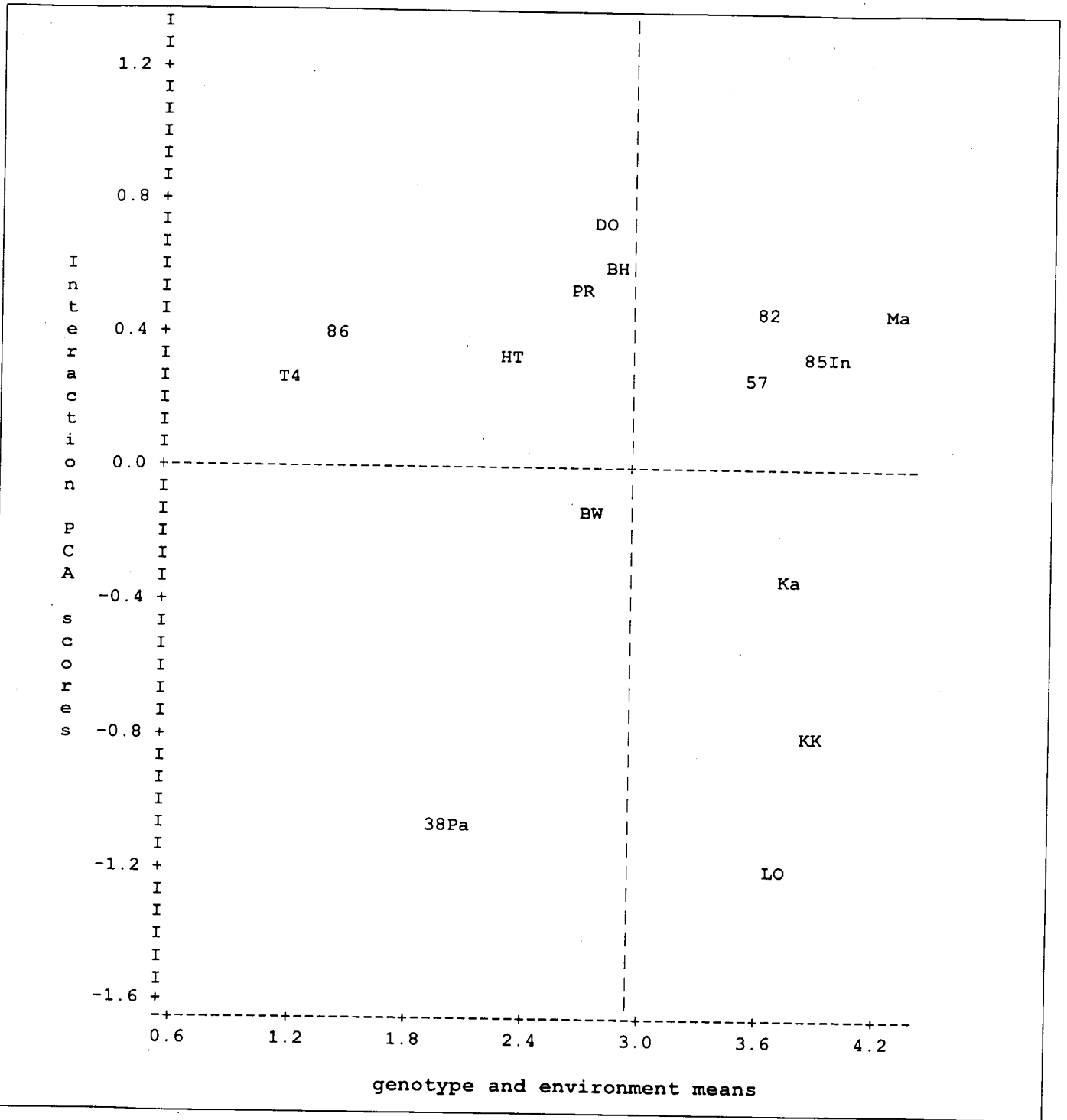
The genotype means ranged between 1.14 to 4.29 for T4 and Marico respectively (Appendix 2). The genotype main effect also showed two major groups. Marico, Inia, SST825, Kariega, SST822 and SST57 were significantly higher than the mean, confirming higher genetic potential for this parameter. Most of these genotypes had scores above 3.20 at most of the sites in the cooler areas and for the warmer areas, they were above the ideal score (4.0). Nevertheless Palmiet, SST38, SST876 and T4 were significantly lower than the mean, particularly SST876 and T4, which didn't show any interaction effect. Palmiet and SST38 showed environment interaction at Loskop and Koedoeskop and had scores close to ideal (Table 5.1.42). Therefore genotype potential is important to ensure required results for this parameter.

The AMMI biplot for genotype and environment means (Figure 5.1.21) shows environment interaction for Palmiet, SST38 and to a lesser extent Kariega. Palmiet and SST38 showed negative interactions at most of the sites (cooler areas), which made them different from other genotypes. Their scores at these sites were very low compared to Loskop and Koedoeskop (warmer areas), where they ranked intermediate with scores equal or close to ideal (4.0). This shows good performance for the two genotypes at warmer areas. However, Kariega was intermediate at cooler areas but ranked first with very high scores at warmer areas showing good performance in these areas. Other genotypes proved to be stable and gave reliable rank at most of the sites. The locations showed environment interactions at Loskop and Koedoeskop, which made these sites different from others. The genotypes responsible were Palmiet, SST38 and Kariega as mentioned above.

Table 5.1.42 Ranking of genotypes in each location for mixograph point score and environmental means in 1998.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	Marico (4.41)	Marico (3.98)	Marico (4.22)	Marico (3.77)	Marico (4.40)	Kariega (4.86)	Kariega (4.92)
2	Inia (3.96)	SST825 (3.61)	Inia (3.78)	Inia (3.36)	Inia (3.94)	Marico (4.43)	Marico (4.81)
3	SST825 (3.96)	Inia (3.61)	SST825 (3.78)	SST825 (3.35)	SST825 (3.94)	SST825 (4.19)	SST825 (4.52)
4	SST822 (3.75)	Kariega (3.54)	SST822 (3.56)	SST822 (3.11)	SST822 (3.74)	Inia (4.18)	Inia (4.51)
5	SST57 (3.56)	SST822 (3.31)	SST57 (3.38)	Kariega (2.98)	SST57 (3.54)	Palmiet (4.05)	SST57 (4.16)
6	Kariega (3.43)	SST57 (3.23)	Kariega (3.29)	SST57 (2.96)	Kariega (3.32)	SST38 (3.99)	SST822 (4.13)
7	SST876 (1.51)	Palmiet (1.92)	SST876 (1.32)	Palmiet (1.04)	SST876 (1.50)	SST57 (3.84)	Palmiet (3.80)
8	Palmiet (1.30)	SST38 (1.86)	Palmiet (1.22)	SST38 (0.98)	T4 (1.13)	SST822 (3.74)	SST38 (3.75)
9	SST38 (1.24)	SST876 (1.09)	SST38 (1.15)	SST876 (0.88)	Palmiet (1.10)	SST876 (1.57)	SST876 (1.94)
10	T4 (1.16)	T4 (1.16)	T4 (0.98)	T4 (0.57)	SST38 (1.04)	T4 (1.50)	T4 (1.81)
Mean	2.83	2.70	2.67	2.30	2.76	3.63	3.83

Grand mean = 2.96 LSD (0.05) : treatment = 0.189 , environment = 0.596



NB: Palmiet and SST38 show more contrast compared to other genotypes and for the sites. Loskop and Koedkop contrast with other sites

Figure 5.1.21 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for mixograph point score in 1998.

In conclusion we can say, except for Palmiet, SST38, SST876 and T4 most of the other genotypes are expected to give intermediate to higher scores at most of the sites. However, Palmiet and SST38 also may give intermediate to ideal scores at Loskop and Koedoeskop where they showed environment interactions. On the other hand care must be taken for Marico at BullHill, Prieska, Douglas and together with Kariega at Loskop and Koedoeskop where they showed scores above the ideal. For the locations, however, as it was for development time, the major difference is on the basis of temperature in addition to higher gluten content, which is necessary at all sites. The cooler areas (BullHill, Barkly West, Prieska, Hopetown and Douglas) need genotypes with intermediate to higher scores and management practices to increase protein content. Gluten content is also important. For the warmer areas (Loskop and Koedoeskop) genotypes with intermediate to low scores are needed and good timing of planting to ensure that grain filling does not coincide with very high temperatures.

The alveograph P/L ratio

The analysis of variance (Table 5.1.43) shows significant variations for treatment, main effects, interactions as well as the IPCA. The residual was significant at $p < 0.01$, implying slight noise effect as the IPCA1 also captured a large percentage (70.3) of the interaction effect. The block effect was not significant and this implies absence of variations for particular genotypes within locations. Contrary to 1997 results whereby genotype and environment contributions to the variation were much closer and higher than interaction, the 1998 results showed that genotype contribution was much higher than both environment and interaction. The respective contributions to variation were 24.9%, 43.6% and 21.0% for environment, genotype and interaction. This shows that with optimal environments, genotype effect increases while environment and interaction decrease.

Table 5.1.43 Analysis of variance results for the alveograph P/L ratio in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	5.960	0.029			
Treatment	69	5.332	0.077	16.86	0.000	
Environment (E)	6	1.486	0.248	54.03	0.000	24.9
Block	14	0.050	0.004	0.79	0.683	
Genotype (G)	9	2.596	0.288	62.93	0.000	43.6
G x E	54	1.251	0.023	5.05	0.000	21.0
IPCA	14	0.880	0.629	13.72	0.000	70.3
Residual	40	0.370	0.009	0.002		
Error	126	0.577	0.005			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 5.1.44) ranged between 0.33 to 0.60 at Barkly West and Prieska respectively, with 0.42 as the grand mean. This shows a decrease for both minimum and maximum values compared to 1997 results where the minimum value was more than the 1998 mean value. The environment main effect showed two groups of locations. Prieska and Douglas were above the mean with Prieska being much higher than the mean. More than half of the genotypes were above the mean at these sites. Other sites had less than half of the genotypes above the mean. The mean for Koedoeskop was equal to the grand mean, Loskop and Hopetown much closer to the mean and BullHill and Barkly West further from the mean. A general observation shows that for this parameter, protein contents closer to 12.0% and endosperm starch content are very important. Most of the sites had low protein content, with the exception of Loskop where protein content was high. This might have influenced the extensibility and elastic properties of the dough due to poor glutenin-to-gliadin ratios. On the other side, breakflour yield that increases when milling hard wheat, results in fine starch granules that are embedded on gluten matrix during bubble expansion. This reduces the extension and increases the bubble ability to withstand the pressure inside. This was revealed from the hardness index results from sites like Prieska and Douglas, which had higher hardness index values, which resulted in higher alveograph P/L ratios. Nevertheless BullHill and Barkly West, which had lower hardness index values, also resulted in lower alveograph P/L ratios.

The genotype means (Appendix 2) ranged between 0.23 to 0.64 for SST38 and SST825 respectively. The genotype main effect showed three groups. SST825, T4, Inia and Palmiet were above the mean and

SST825 was much higher than the mean. SST822, Marico, SST876 and Kariega were below the mean but much closer to it, whereas SST57 and SST38 were far below the mean. Except for the last two, which seems to have poor genetic potential for this parameter, other genotypes had either high protein content and/or high hardness index value.

The AMMI biplot for genotype and environment means (Figure 5.1.22) shows slight environment interactions for T4, SST825, Palmiet, Inia, Marico and SST57. The former three ranked higher at most of the sites but at Loskop SST825 ranked third and Palmiet and T4 much lower. They also had much lower mean values at this site and therefore showed negative environment interaction. Marico, Inia and SST57 ranked first, second and intermediate respectively at Loskop with higher means than at other sites and this caused them to show positive environment interaction. The former two ranked lower at Prieska but the means were not much lower. Other genotypes showed to be stable and gave reliable rank at most of the sites.

The locations showed environment interaction with genotypes, though not high, at Prieska, Loskop and Hopetown. SST825, Palmiet and T4 had very high mean values at Prieska but Inia and Marico ranked lower with intermediate values. However, it was the other way round at Loskop (Table 5.1.44). At Hopetown Marico had a lower mean value than at other sites.

Table 5.1.44 Ranking of genotypes in each location for the alveograph P/L ratio and environmental means in 1998.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	SST825 (0.51)	SST825 (0.51)	SST825 (0.97)	SST825 (0.69)	SST825 (0.71)	Inia (0.57)	SST825 (0.63)
2	Inia (0.45)	Inia (0.42)	T4 (0.88)	T4 (0.59)	T4 (0.60)	Marico (0.47)	T4 (0.47)
3	T4 (0.39)	T4 (0.40)	Palmiet (0.79)	Palmiet (0.52)	Palmiet (0.56)	SST825 (0.44)	Palmiet (0.48)
4	Palmiet (0.38)	Palmiet (0.37)	SST876 (0.59)	Inia (0.38)	Inia (0.50)	SST822 (0.38)	Inia (0.48)
5	Marico (0.35)	Marico (0.33)	SST822 (0.52)	SST876 (0.37)	SST876 (0.44)	SST57 (0.35)	Marico (0.39)
6	SST822 (0.32)	SST822 (0.30)	Kariega (0.52)	SST822 (0.34)	SST822 (0.42)	Kariega (0.33)	SST822 (0.38)
7	SST876 (0.30)	SST876 (0.29)	Inia (0.52)	Kariega (0.32)	Marico (0.41)	Palmiet (0.33)	SST876 (0.38)
8	Kariega (0.29)	Kariega (0.27)	Marico (0.44)	Marico (0.30)	Kariega (0.40)	SST876 (0.31)	Kariega (0.35)
9	SST57 (0.26)	SST57 (0.24)	SST57 (0.40)	SST57 (0.24)	SST57 (0.34)	T4 (0.31)	SST57 (0.31)
10	SST38 (0.18)	SST38 (0.16)	SST38 (0.33)	SST38 (0.16)	SST38 (0.26)	SST38 (0.27)	SST38 (0.23)
Mean	0.345	0.329	0.596	0.391	0.465	0.378	0.414

Grand mean = 0.417 LSD (0.05): treatment = 0.022 , environment = 0.071

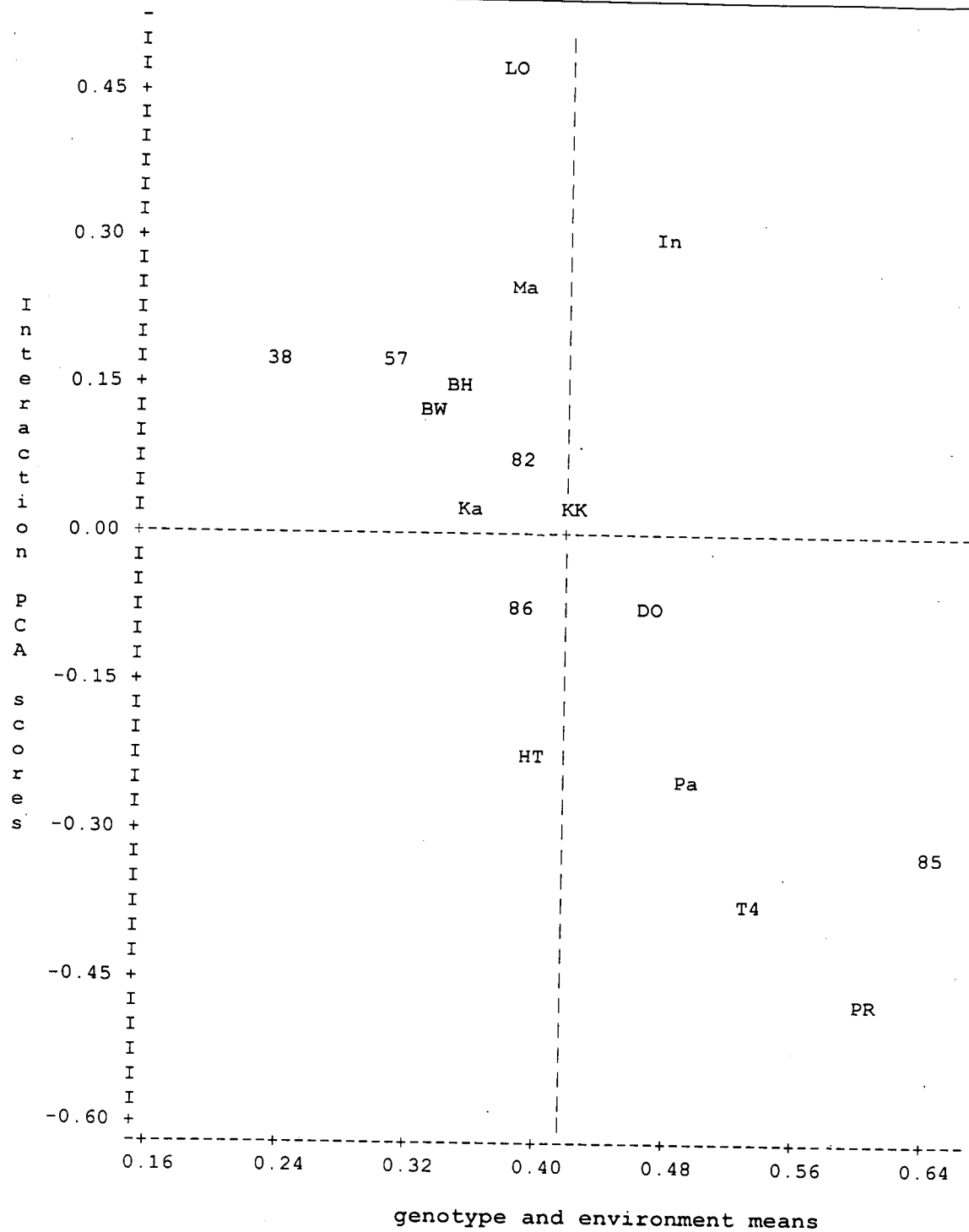


Figure 5.1.44 AMMI biplot of genotype and environment IPCA1 scores versus

Means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for the alveograph (P/L) ratio in 1998.

In conclusion, SST825, T4, Inia and Palmiet seem to have good genetic potential for this parameter and may give intermediate to higher mean values at most of the sites. Marico, SST822, SST876 and Kariega showed intermediate and SST57 and SST38 very low genetic potential as they ranked intermediate to very low at most of the sites. However, Marico and SST822 may perform well at Loskop where they showed positive environment interactions, but care must be taken for T4 which had negative interaction at the same site. Reliable mean values and rank for most of the genotypes may be achieved at Prieska, Douglas, Hopetown and Koedoeskop. The higher protein contents at Loskop and Barkly West and lower at BullHill together with less grain filling at both sites (as shown by low hardness index due to protein/starch dilution) caused lower means for most of the genotypes. Therefore the three sites need genotypes with wide adaptability for this parameter (such as SST825) and those showing positive environment interactions. Also management practices which will modify protein content to $\pm 12\%$, together with selection for genotypes showing higher hardness index may be necessary.

Alveograph strength (W/6.54)

The analysis of variance results (Table 5.1.45) shows highly significant F-values for treatment, environments, genotypes, interaction, IPCA as well as residual, which implies noise effect. The block effect was not significant and this implies absence of variations within locations for particular genotypes. Contrary to the 1997 results, the results of this year showed drastic decreased contributions to the variation by genotype and an increase in contribution by environment. This is from the fact that the parameter is more influenced by both proteins content as revealed by high correlation with protein content (Table 5.2.1) and quality aspects. It therefore seems genotype and environment effects tend to decrease and increase respectively with optimal environments and vice versa under adverse environments. The 1998 season resulted in lower protein content at most of the sites, except Loskop, which was exceptional and thus had very high protein content. The interaction contribution was not so high and it seems to be following the genotype trend. The respective contributions to the variations therefore were, 46.5%, 34.4% and 12.8% for environment, genotype and interaction. From the interaction effect the IPCA captured 55.3%.

Table 5.1.45 Analysis of variance results for alveograph strength (W/6.54) in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	36077	172.6			
Treatment	69	33799	489.8	30.64	0.000	
Environment (E)	6	16758	2793.0	174.69	0.000	46.5
Block	14	263	18.8	1.18	0.301	
Genotype (G)	9	12412	1379.2	86.26	0.000	34.4
G x E	54	4629	85.7	5.36	0.000	12.8
IPCA	14	2558	182.7	11.43	0.000	55.3
Residual	40	2070	51.8	3.24	0.000	
Error	126	2015	16.0			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100

IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 5.1.46) ranged between 23.92 to 52.43 at Hopetown and Loskop respectively, with a grand mean of 31.58. This shows a big range and it was due to lower protein content at other sites, compared to Loskop. Environment main effect showed two major groups. Loskop was alone with a mean significantly higher than the grand mean. Most of the genotypes at this site had very high strength (above the recommendation ± 35) and this confirmed protein content to be a prime factor. Other sites were very similar and did not differ significantly from the mean. Despite Barkly West having a protein content closer to optimum (12.0%) compared to Koedoeskop, strength was lower at cooler than at warmer areas. As it was for some of the parameters, the strength seems to be higher at warmer than at cooler areas, probably due to interference on protein quality. The genotype means ranged between 15.27 to 41.35 for T4 and SST825 respectively (Appendix 2). However, though the range was also large, the higher value was less than that of environment, showing that the main cause of higher values was environment. The genotype main effect showed at least three groups. SST825, Inia, Marico and Kariega had means higher than both the grand mean and the recommended value and ranked higher at most of the sites. SST822, SST38, SST57 and SST876 had means much closer to the grand mean particularly the former three, but they were below the recommended value and ranked intermediate to low at most of the sites. Palmiet and T4 had very low mean values and ranked last at most of the sites. This was mainly due to low protein content at most of the locations. They also seem to be genetically poor in quality especially T4 which had low mean even at Loskop. Therefore it shows that, genotype effect in terms of protein quality is also important for this parameter. This is from the fact that despite some of the genotypes having high protein content, but of poor

quality, they showed lower strengths. Therefore there was little interaction effects, but the main effects had a large influence on alveograph strength.

The AMMI biplot for genotype and environment means (Figure 5.1.45) shows small environment interactions for Kariega, SST38, Marico, SST876, Inia and T4. The major cause was the high protein content at Loskop, which resulted in higher strengths for most of the genotypes at this site. This caused changes in their rank compared to other sites and thus showing positive or negative interactions. Nevertheless all genotypes proved to be stable and may give reliable rank at most of the sites depending on their quality potential. Figure 5.1.45 shows very high environment interactions at Loskop and this made the site to contrast with others. Again this was a consequence of high protein content at this site.

In summary, we can say most of the genotypes proved to be stable and gave reliable rank at most of the sites. Considering the aspect of protein quality, Palmiet and T4 seem to have less potential for alveograph strength but other genotypes may give intermediate to higher strengths at most of the sites. However, Palmiet showed higher mean values at Loskop and Koedoeskop and thus it may give good results at these sites. Taking into account that temperature has an influence on protein quality as revealed by different results from warmer and cooler areas, it seems warmer areas (Loskop and Koedoeskop) need genotypes with intermediate to lower strengths and cooler areas, cultivars with intermediate to higher strengths. For the locations, management practices to ensure protein content closer to ideal (12%) are also important. However, all sites showed reliable rank for most of the genotypes. Another observation is that alveograph strength seems to be less stable over years and the results may vary from one year to another. This can be seen from the means (Tables 4.1.40 and 5.1.46) whereby the 1997 values were lower compared to those of 1998, particularly at Loskop.

Table 5.1.46 Ranking of genotypes in each location for alveograph strength (W/6.54) and environmental means in 1998.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	Inia (38.77)	Inia (39.43)	SST825 (35.75)	SST825 (33.39)	SST825 (37.41)	Kariega (68.93)	Inia (42.96)
2	SST825 (37.18)	SST825 (39.00)	Inia (34.18)	Inia (33.18)	Inia (35.93)	Marico (66.71)	SST825 (42.66)
3	Marico (30.29)	Marico (32.94)	Marico (31.11)	Marico (27.79)	Marico (32.71)	SST825 (64.04)	Marico (36.68)
4	SST57 (29.98)	Kariega (31.74)	Kariega (30.47)	Kariega (26.77)	Kariega (32.05)	SST38 (63.29)	Kariega (35.51)
5	SST822 (29.25)	SST822 (31.16)	SST822 (28.07)	SST822 (25.60)	SST822 (29.72)	SST822 (57.15)	SST822 (34.82)
6	Kariega (28.77)	SST57 (30.82)	SST38 (26.05)	SST57 (24.67)	SST38 (27.64)	Inia (52.19)	SST57 (34.37)
7	SST876 (28.74)	SST876 (28.85)	SST57 (25.90)	SST38 (22.51)	SST57 (27.63)	SST57 (45.58)	SST876 (32.33)
8	SST38 (27.56)	SST38 (27.56)	SST876 (22.67)	SST876 (22.30)	SST876 (24.45)	Palmiet (42.89)	SST38 (31.32)
9	Palmiet (18.04)	Palmiet (19.69)	Palmiet (16.14)	Palmiet (13.98)	Palmiet (17.81)	SST876 (35.85)	Palmiet (23.32)
10	T4 (14.61)	T4 (15.23)	T4 (9.94)	T4 (9.94)	T4 (11.69)	T4 (27.69)	T4 (18.76)
Mean	28.04	29.64	26.03	23.92	27.70	52.43	33.27

Grand mean = 31.58, LSD (0.05) : treatment = 1.325, environment = 4.19

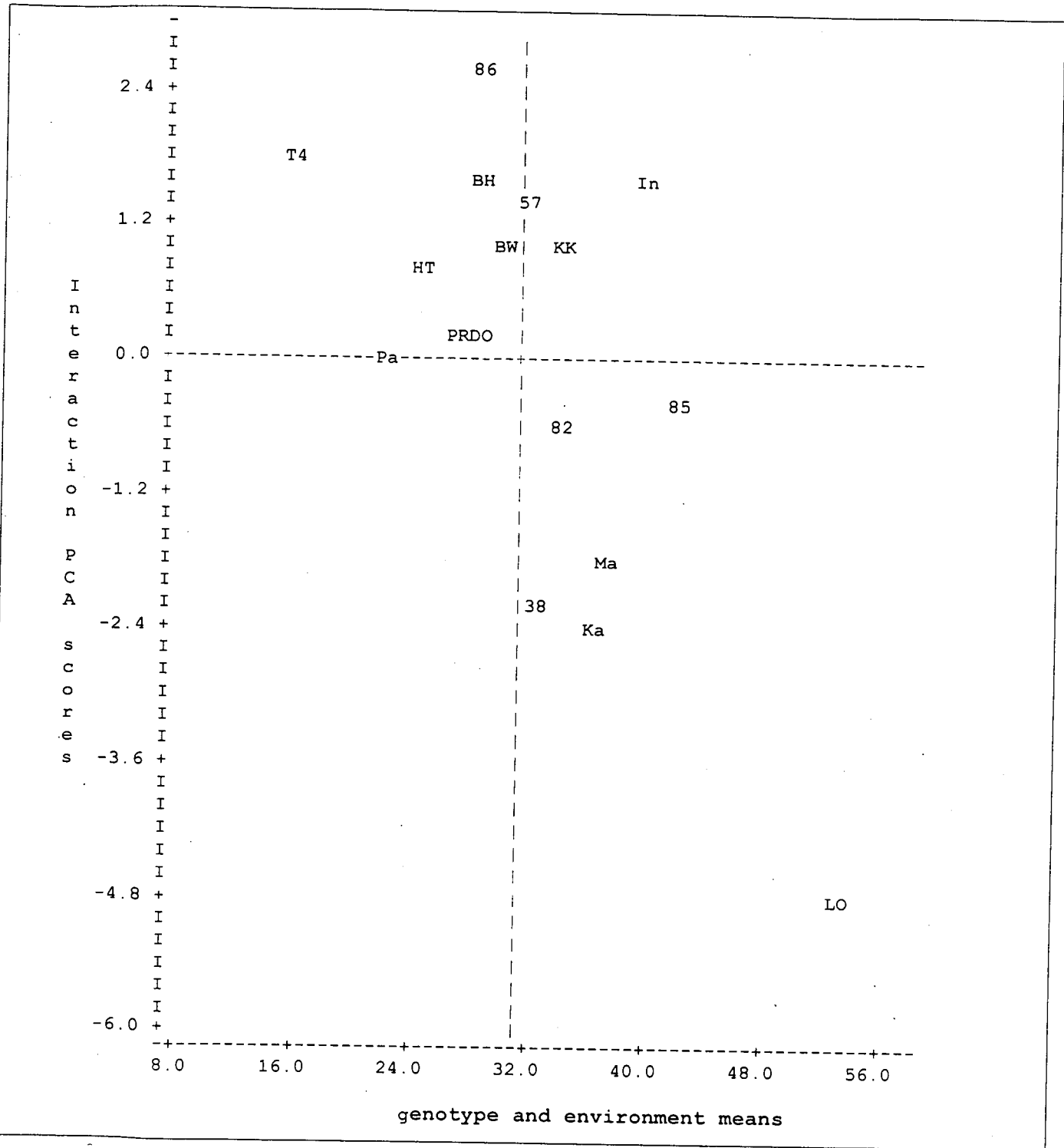


Figure 5.1.46 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities BH = Bullhill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for alveograph strength (W/6.54) in 1998.

Flour colour

The result for analysis of variance (Table 5.1.47) shows highly significant variation ($p < 0.001$) for treatments, environments, genotypes, interaction, IPCA as well as residual. The block effect was not significant, implying absence of variations within locations for particular genotypes. In comparison to the 1997 results, genotype effect was very similar and contributed less than environment and interaction to the variation. The 1998 results showed more contribution by interaction to the variation than environment, which was higher in 1997. This shows that for the two sources of variation, environment and interaction effects tend to increase in both adverse and ideal environments. Therefore the contributions were 19.8%, 14.9% and 41.0% for environment, genotype and interaction respectively. From the interaction effect, the IPCA explained 59.1%.

Table 5.1.47 Analysis of variance results for flour colour in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	329.6	1.577			
Treatment	69	249.5	3.616	6.246	0.000	
Environment (E)	6	65.1	10.855	18.749	0.000	19.8
Block	14	7.1	0.508	0.878	0.584	
Genotype (G)	9	49.1	5.452	9.416	0.000	14.9
G x E	54	135.3	2.506	4.328	0.000	41.0
IPCA	14	80.0	5.716	9.873	0.000	59.1
Residual	40	55.3	1.382	2.388	0.000	
Error	126	73.0	0.579			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E / SS for total) x 100
IPCA = (SS for IPCA / SS for G x E) x 100

The environment means (Table 5.1.48) ranged between 0.29 to 2.23 at Prieska and Loskop respectively, with a grand mean of 1.04. This shows that most of the genotypes had very low mean values at most of the sites. Environment main effect therefore showed two major groups of locations. Loskop was alone with a mean significantly higher than the grand mean. In this site (except Kariega), genotypes had means between 1.80 to 2.90 and therefore may be graded as suitable for white bread. Other sites had means lower than 1.5 (minimum range for white bread) and most of them were much closer to the mean except Prieska. However, it was only at Douglas and Koedoeskop where at least four genotypes had means close/above 1.5 and were thus being graded as suitable for white bread. Therefore most of the genotypes at these sites had very low means (<1.5) and at Barkly West not one attained 1.5. Consequently, except for Loskop, at other sites more than half or all genotypes showed flour colour not suitable for white bread. Compared to 1997 results, Douglas was the only site that showed lower means for most of the genotypes in both years. For other sites,

mean values increased with increase in protein content and thus most of the genotypes fell within the white bread category particularly in 1997. Genotype means ranged between 0.11 to 1.69 for Kariega and SST822 respectively (Appendix 2). The genotype main effect also showed two major groups. SST822, SST57, SST825, Palmiet and Marico were above the grand mean and showed good potential for white bread flour particularly SST822, SST57 and SST825.

Unless adversely affected by environment interactions, these genotypes ranked intermediate to higher at most of the sites. Inia, SST876, T4, SST38 and Kariega were below the mean and Kariega deviated significantly from the mean. They all ranked intermediate to very low at most of the sites indicating that they are not suitable for bread-making. However, at Loskop they managed to fall within white bread grades but still ranked low. Contrary to environment effect whereby mean values increased with increase in protein content, this was not true for genotypes. For the genotypes, higher/low mean values were independent of genotype protein content probably due to protein quality. That is why the correlation between this parameter and protein content was intermediate, showing quality to be involved. You cannot really deduct the genetic potential from this, if the environmental effect is low, then you can deduct that the heritability is high.

The AMMI biplot for genotype and environment means (Figure 5.1.47) shows high environment interaction for Palmiet, T4 and to a lesser extent SST825 and SST822. Palmiet was intermediate at Loskop, very low and last at Douglas, last at Prieska but ranked first at other sites. T4 ranked second at Hopetown, intermediate at BullHill and Koedoeskop but very low at other sites. The lower mean values shown by T4 and Palmiet at Prieska together with Kariega that ranked very low/last at most of the sites caused them to show contrast from other genotypes. SST825 and SST822 ranked intermediate to very high at most of the sites but they had lower means at Hopetown and SST825 at BullHill. Other genotypes showed stability, with reliable rank at most of the sites. The sites showed high environment interactions at Prieska and Hopetown. As mentioned above, Palmiet and T4 were responsible for high interaction at Prieska and T4 at Hopetown where they showed very low and high mean values.

In conclusion we can say that, although interaction showed contribution to the variation, it doesn't apply to most of the genotypes compared to main effects. SST822, SST825, SST57, Marico and Palmiet showed higher genetic potential and probability of being graded as suitable for white bread at most of the sites. With higher environment protein content most of the genotypes fell within the white bread category. Due to environment interactions, Palmiet and T4 may not give good results for white colour at Prieska and Douglas. Most of environments gave reliable rank for most of the genotypes. However, higher protein content was important for most of the sites, except Douglas that showed less variation with increase in environmental protein content and most of the genotypes had very low means. Therefore this site needs genotypes with high probability to fall within the white bread range.

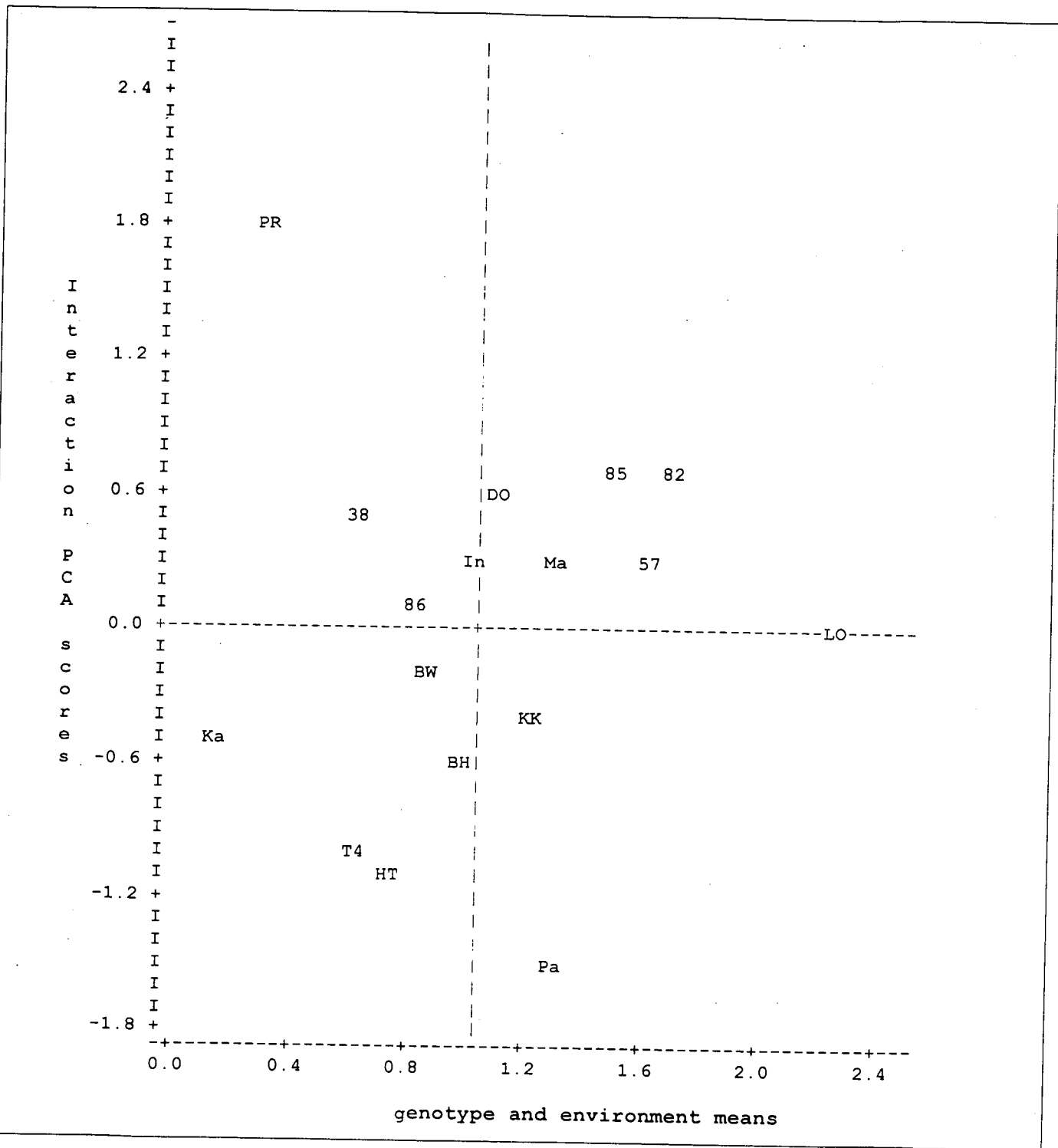


Figure 5.1.48 AMMI biplot of genotype and environment IPCA1 scores versus means for ten genotypes (Pa = Palmiet, 38 = SST38, T4 = T4, Ma = Marico, Ka = Kariega, 82 = SST822, 85 = SST825, In = Inia, 86 = SST876 and 57 = SST57) at seven localities (BH = BullHill, BW = Barkly West, PR = Prieska, HT = Hopetown, DO = Douglas, LO = Loskop and KK = Koedoeskop) for flour colour in 1998.

Table 5.1.48 Ranking of genotypes in each location for flour colour and environmental means in 1998.

Rank	BullHill	BarkWes	Prieska	Hopetown	Douglas	Loskop	Koedkop
1	Palmiet (2.17)	Palmiet (1.36)	SST822 (2.20)	Palmiet (2.65)	SST822 (2.13)	SST822 (2.87)	Palmiet (2.00)
2	SST57 (1.31)	SST822 (1.33)	SST825 (1.97)	T4 (1.31)	SST825 (1.90)	SST57 (2.78)	SST57 (1.62)
3	SST822 (1.15)	SST57 (1.31)	SST57 (1.42)	SST57 (0.91)	SST57 (1.82)	SST825 (2.65)	SST822 (1.57)
4	T4 (1.11)	SST825 (1.11)	Marico (1.12)	SST822 (0.57)	Marico (1.50)	Palmiet (2.51)	SST825 (1.35)
5	Marico (0.97)	Marico (0.98)	Inia (0.81)	Marico (0.56)	Inia (1.21)	Marico (2.46)	Marico (1.29)
6	SST825 (0.93)	Inia (0.70)	SST38 (0.75)	SST876 (0.36)	SST38 (0.94)	Inia (2.17)	T4 (1.09)
7	Inia (0.69)	T4 (0.55)	SST876 (0.19)	SST825 (0.35)	SST876 (0.87)	SST876 (1.97)	Inia (1.01)
8	SST876 (0.64)	SST876 (0.55)	Kariega (-1.52)	Kariega (0.34)	Palmiet (0.48)	T4 (1.80)	SST876 (0.89)
9	Kariega (0.35)	SST38 (0.30)	T4 (-1.84)	Inia (0.29)	T4 (0.10)	SST38 (1.80)	SST38 (0.57)
10	SST38 (0.21)	Kariega (-0.01)	Palmiet (-2.17)	SST38 (-0.27)	Kariega (-0.12)	Kariega (1.32)	Kariega (0.45)
Mean	0.95	0.82	0.29	0.71	1.08	2.23	1.18

Grand mean = 1.04 LSD (0.05): treatments = 0.252 , environments = 0.797

5.2 Correlation matrix

Compared to the 1997 results, the 1998 results showed slightly higher correlation values for some of the parameters. Correlation values were lower for yield related parameters such as hectoliter mass and kernel mass. Due to very low significance levels (0.142 and 0.185 for $p < 0.05$ and $p < 0.01$ respectively) it shows that most of the parameters were significantly correlated. Therefore our discussion will start at higher magnitude (± 0.50) so as to involve the parameters, which had stronger correlations. The hectoliter mass had positive correlation ($r \geq 0.52$) with thousand kernels mass and single kernel characterisation system-weight. However, the correlation with flour yields was low ($r = 0.22$) and this contradicts with the results of Nel *et al.* (1998b), which was ($r = 0.63$, $p < 0.05$). It seems Prieska and Douglas caused such a low correlation in our results. Despite this, the two sites had higher hectoliter and kernel masses. Their flour yields were comparable to most of the other sites. This was probably a consequence of very low moisture contents realised at these sites and this may have caused problems in endosperm separation from the bran. The grain protein content as determined by the three parameters (GPC-LECO, GPC-FL and GPC-WH), showed positive and very high correlation ($r \geq 0.95$) among themselves, indicating to have identical effects. They also showed very high positive correlation with flour protein parameters (LECO & NIR) ($r \geq 0.93$). This agrees with the results by Van Lill *et al.* (1995a), who also found a very high ($r = 0.90$) significant ($p < 0.01$) correlation between grain and flour protein content. The grain protein content also showed high correlations with, wet gluten content at 12% protein ($r \geq 0.88$), and alveograph strength ($r \geq 0.73$). Correlations of protein content were observed with vitreous kernels ($r \geq 0.55$) and farinograph absorption ($r \geq 0.63$). This implies that an increase in protein content will have a positive influence on these parameters.

Breakflour yield showed negative correlations with most of the parameters. The correlation with SKCS-HI was moderately high ($r = -0.49$). SKCS-HI together with most of the other parameters, which showed negative correlations with BFLY, are influenced by protein content (not necessarily high but with good quality) as well as high endosperm starch content. The protein quality depends on its composition and molecular weight distribution, which tends to change at very high/low protein content. Also climatic conditions like high temperatures may interfere with quality. That is why a site like Loskop, despite having higher breakflour yields for most of the genotypes, due to very high protein content, SKCS-HI and most of the parameters were lower. This again confirms not to use breakflour yield as a prime parameter in wheat evaluation. This is due to its low or negative correlation with most of the parameters.

Flour yield showed negative correlation ($r = -0.52$) with flour colour. The main cause was Loskop, whereby despite having higher values for flour colour, the flour yields were comparable to most of the sites. The positive correlations (though not high) between flour yield and kernel mass, hectoliter mass and breakflour yield, shows these parameters to be reliable indicators of higher flour yield. The positive correlation shown by vitreous kernels with grain protein was also revealed with flour protein contents (both LECO and NIR) which

were ($r = 0.48$) and ($r = 0.51$) respectively. The slightly higher correlation with NIR, suggests this method as being more efficient than LECO. Correlations ($r = 0.49$) and ($r = 0.48$) were also observed with wet gluten at 12% protein content and alveograph strength respectively. Consequently higher vitreous kernels may be a good indicator of increased gluten content, alveograph strength and even farinograph absorption and this implies proper balance between protein and starch. Barlow *et al.* (1973) reported that it is the strength of starch-protein interactions that causes endosperm hardness. Also Bechtel *et al.* (1996) noted that wheat grains harvested 15 to 18 days after flowering were softer than the ones harvested at 25 days. They suggested that probably storage proteins have not been significantly synthesised at 15–18 days after flowering to allow for much protein to be present to bind to the numerous starch granules already present. In addition to the high correlation with hectoliter mass, thousand kernel mass also showed positive and high correlation ($r = 0.90$) and ($r = 0.85$) with SKCS-W and SKCS-diameter respectively. The correlation with SKCS-W is due to the fact that the weight is probably taken from the same amount, 1000 kernels. However, the important correlation is that with SKCS-diameter, and the correlation was almost the same for both years. This confirms SKCS-diameter to be important in ensuring higher kernel mass. Compared to the 1997 results, it shows that with optimal environments (as that of 1998) thousand kernel mass tends to have less negative correlation with most of the parameters. Also positive correlations were observed with farinograph absorption ($r = 0.22$), alveograph P/L ratio ($r = 0.20$), loaf volume at 12% protein ($r = 0.26$) and sedimentation volume ($r = 0.28$). This suggests thousand kernel mass to be important in wheat evaluation.

Falling number as it was in 1997, showed low correlation with all parameters and this was because sprouting did not occur. This also agrees with the results by Van Lill *et al.* (1995a). As discussed, wet gluten content at 12% protein, showed positive correlation ($r \geq 0.82$) with both grain and flour protein contents as well as vitreous kernels. The parameter also showed correlation, ($r = 0.72$) and ($r = 0.53$) with farinograph absorption and alveograph strength respectively. This shows that, protein quality in terms of polymeric protein content (HMW-GS) is important for increased flour absorption and strength. This is confirmed by very similar correlation values for gluten at normal protein and that at 12% protein content implying that only a small part of gluten is involved and not the whole amount. Negative correlation ($r = -0.51$) was observed between gluten content and loaf volume at 12% protein content. However, this was mainly due to Loskop where loaf volume was lower than any other site, despite protein and gluten contents being higher.

In addition to the correlations already discussed, the two flour protein content parameters (NIR and LECO) showed very high positive correlation among themselves. This shows that the methods had almost identical effects. The methods also showed positive, high correlation ($r = >0.60$) and ($r = >0.71$) with farinograph absorption and alveograph strength respectively. This indicates that increase in protein content with good quality is also important for the two parameters. The correlation with loaf volume at normal protein content was positive ($r = >0.56$) for both parameters. However, when determined at 12% protein content, the correlations became negative ($r = -0.36$) and ($r = -0.53$) for (NIR) and (LECO) respectively. The main cause

was Loskop, where despite having higher protein and gluten contents, the loaf volume was much lower for all genotypes. Lorenzo *et al.* (1986) also reported that a high protein content is not necessarily a prerequisite for high loaf volume. The lower correlation shown by (NIR) as mentioned earlier proves this method to be more efficient than (LECO).

Compared to other protein related parameters, SDS-sedimentation showed lower (though significant) correlations with protein contents (grain and flour) indicating an association with quality aspects. However, Van Lill *et al.* (1995a) found moderately high correlations ($r = >0.51$) between SDS-sedimentation and both grain and flour protein contents. In our case the main cause was probably the lower protein contents realised at other sites as compared to Loskop. Nevertheless the correlation values were positive and very similar for both two years and this shows the parameter to be highly stable and thus reliable for cultivar evaluation.

The positive correlation (though not high), of protein content with mixograph development time and point score, suggests high protein content to be necessary for the two parameters. However, Van Lill *et al.* (1995a) found a negative correlation (though not highly significant) between mixograph development time and protein content (grain and flour). In addition to the correlation already discussed, farinograph absorption showed intermediate negative correlation ($r = -0.47$) with loaf volume at 12% protein content. This is from the fact that absorption tends to increase with increase in protein content provided the grain filling (starch content) was also optimum. However, this does not apply for loaf volume at 12% protein as higher protein contents are not desirable. Therefore higher farinograph absorption at intermediate protein content (close to 12% protein) will be better than at very high protein content.

Mixograph development time and mixograph point score in addition to the correlations already discussed, showed very high correlation ($r = 0.91$) among themselves. This indicates that they measure the same character. They also showed high positive correlation ($r \geq 0.66$) and ($r \geq 0.62$) with alveograph strength and SDS-sedimentation respectively. It seems protein quality is also important as the correlation with protein content for the two parameters (though significant) were not so high. This is shown by the negative correlation (although not significant) with WGC12%. Khan *et al.* (1989), also found negative and significant correlation between wet gluten and mixing time. Therefore increase in strength and sedimentation will also lead to an increase in mixograph development time and point score, as it was also realised in 1997. The positive correlation for the two parameters with loaf volume at normal protein content was intermediate ($r = >0.48$). However, the correlation with loaf volume at 12% protein was low and not significant. As mentioned earlier, the two parameters increase with protein content as it was at Loskop, and that is why there are recommended ideal values.

Alveograph P/L ratio showed significant negative correlations with protein content and related parameters. The correlation with loaf volume at normal protein was intermediate ($r = -0.50$) but that with loaf volume at

12% protein was significant but much lower. This shows that, in addition to protein quality there are other aspects, which influence this parameter. The endosperm starch content is also important for alveograph P/L ratio and that is why it showed positive correlation with hectoliter and kernel mass. As mentioned earlier, starch-protein interaction increases kernel hardness, which in turn increases breakflour yield during milling. The breakflour yield is important in increasing the strength of gluten matrix during bubble expansion. This was the cause of intermediate positive correlation ($r = 0.43$) between SKCS-HI and alveograph P/L ratio. Therefore hardness index is important as it was the only parameter, which showed higher correlation with alveograph P/L ratio.

In addition to the correlations discussed, alveograph strength also showed high positive correlation ($r \geq 0.65$) with loaf volume at normal protein and sedimentation. However, the parameter showed negative correlation with loaf volume at 12% protein though not so high. This implies strength is influenced more by protein content than quality and that is why it showed a higher value at Loskop and high positive correlation with protein content.

For SDS-sedimentation, as already discussed, most of the correlations were positive and significant. Those with protein content (grain and flour) were slightly lower showing that sedimentation is not influenced more by higher protein contents. Other significant correlations with mixograph development time, mixograph point score, alveograph strength, loaf volume at normal protein were high but that with loaf volume at 12% protein was slightly lower. This indicates SDS -sedimentation to be a more stable parameter, not much influenced by environmental conditions and thus reliable for cultivar evaluation. From the study by Van Lill *et al.* (1995a), sedimentation was the only parameter, which showed high correlation ($r = 0.66^{**}$) with baking strength index (BSI).

In conclusion, due to optimal environment and increased grain filling, most of the correlations were slightly higher than those of 1997. However, the higher protein content at Loskop and lower protein at other sites was not desirable. This caused protein related parameters, particularly loaf volume at 12% protein content to show negative correlation with most of the parameters. This suggests management practices and cultivar selection to ensure protein content close to 12% to be very important. For flour yield, higher hectoliter mass, kernel mass and diameter and breakflour yield are important. However, as it was in 1997, breakflour yield showed negative correlation with most of the parameters, farinograph absorption inclusive. This again suggests that verification is necessary to see if absorption is higher in addition to higher breakflour yield. This is probably due to the fact that soft/loose endosperm (such as due to inadequate grain filling) may result in bran contamination at the milling process. As a result breakflour yield is high but from bran and not starch granules, which have an ability of absorbing water. This was the case in 1997. This is also supported by the moderately high negative correlation ($r \geq -0.49$) for both years between breakflour yield and SKCS-HI, implying that the realised breakflour yield was not from harder kernels. Therefore indirect selection for higher

vitreous kernels and hardness index, which showed significant positive correlations with farinograph absorption, will be desirable. For the protein related parameters, alveograph P/L ratio was significantly negative correlated although not so high, with protein content and related parameters. The significant positive correlations with hectoliter mass, kernel mass and diameter suggests grain filling to be important. Therefore hardness index, which reflects a proper balance between starch and protein, may be important to reveal high alveograph P/L ratio. This is from the fact that only this parameter showed intermediate ($r = 0.43$) and high ($r = 0.62$) positive correlation in 1997 and 1998 respectively with alveograph P/L ratio. Other parameters were not much influenced with increase in protein content. Nevertheless protein content around 12% is necessary for good results of most of the parameters, especially loaf volume.

5.3 Canonical variate to find groupings between genotypes

In this season the variates were 27 quality characteristics measured on each of ten genotypes at seven localities. Those variates, which were not important, were then deleted one-by-one from the analysis until only those with reasonable correlation coefficients were retained. Ten variates were retained, which includes breakflour yield, thousand-kernel mass, mixograph development time, mixograph point score and alveograph P/L ratio. Others were alveograph strength, loaf volume at 12% protein, sedimentation, single kernel characterisation system-weight and SKCS-kernel diameter. Therefore this shows that genotypes had a large influence on these variates.

The first two canonical variates (CV1 and CV2) together accounted for 70.4% of the total variation among groups. Table's 5.3.1 and 5.3.2, show the canonical variate mean scores and percentages for the two CVs as well as correlation coefficients between the variates and the first two CVs respectively.

Table 5.3.1 Canonical variate percentage variation and mean scores of the first two canonical variates of the 10 genotypes.

Variates	CVA1	CVA2
	36.29%	34.10%
Marico	0.4061	-2.3463
Kariega	1.5928	-1.3582
T4	-3.6364	0.8487
Palmiet	-1.9229	0.8453
SST825	2.3714	4.1347
SST822	0.7794	-0.6962
SST876	-0.8408	-0.0761
SST38	0.3215	-1.2617
SST57	-0.7702	0.3805
Inia	1.6992	-0.4707

It is evident from Table 5.3.1 that SST825 and to a lesser extent Inia and Kariega contrasts the most with the other genotypes particularly T4 and Palmiet. This is due to higher positive CV1 scores versus small positive, negative and higher negative scores. The horizontal separation (CV1) accounted for nearly 36.3% of the total variation. Grouping of the 10 genotypes is more clearly shown by a plot of the two canonical variates mean scores (Figure 5.3.1). Points closer or further apart in such a plot are similar or dissimilar respectively, with respect to their general response to the variates that discriminate between them. Considering all the variates included in the final CVA, the genotypes SST825 and T4 were dissimilar to most other genotypes. For SST825 it was mainly alveograph P/L ratio which was responsible but for T4, most of the variates were responsible. However, for the other genotypes, two major groups were also realised. Inia, Kariega, SST822, SST38 and Marico were similar, with Marico deviating slightly from the group. SST57, SST876 and Palmiet

were also similar with the last one deviating from the group. This is due to the fact that different cultivars may respond differently to environment (Huebner and Bietz, 1994).

The main variates which discriminated between genotypes for CV1 (x-axis) (Figure 5.3.1) were SDS-sedimentation ($r = 0.794$), mixograph point score ($r = 0.696$), alveograph strength ($r = 0.654$) and mixograph development time, ($r = 0.651$). To a lesser extent single kernel characterisation system weight ($r = 0.526$) and loaf volume at 12% protein ($r = 0.494$) were also involved. All these variates correlated positively with the CV1 scores. Thus, generally T4 had low rating for most and Palmiet to some of the above variates. The other genotypes, were either average, when close to the zero line or higher (Figure 5.3.1) and (Table 5.3.3). However, for mixograph development time and point score, SST57 was above and SST38 below the mean (Table 5.3.3).

The discrimination between SST825 and most of the genotypes on the CV2 (y-axis), which accounted for 34.1% of the variation, was mainly due to alveograph P/L ratio ($r = 0.58$). This shows that although it was only one variate involved in this axis, its contribution to the variation was high. The mean value for SST825 was 0.638, much higher than others. Other genotypes, which were above the grand mean, were T4, Palmiet and Inia (Table 5.3.3). Therefore the four genotypes may be grouped together for this variate. Taking into account the mean values for most of the variates, the genotypes, T4, Palmiet, SST876 and SST38 were below the grand means. This shows that mixing either of these genotypes will suppress the quality variates. It is better to mix with genotypes like SST825, Inia, Kariega, SST822 and Marico, which had, mean values above grand means for most of the variates. Consequently this will improve the quality by bringing the values closer to the means.

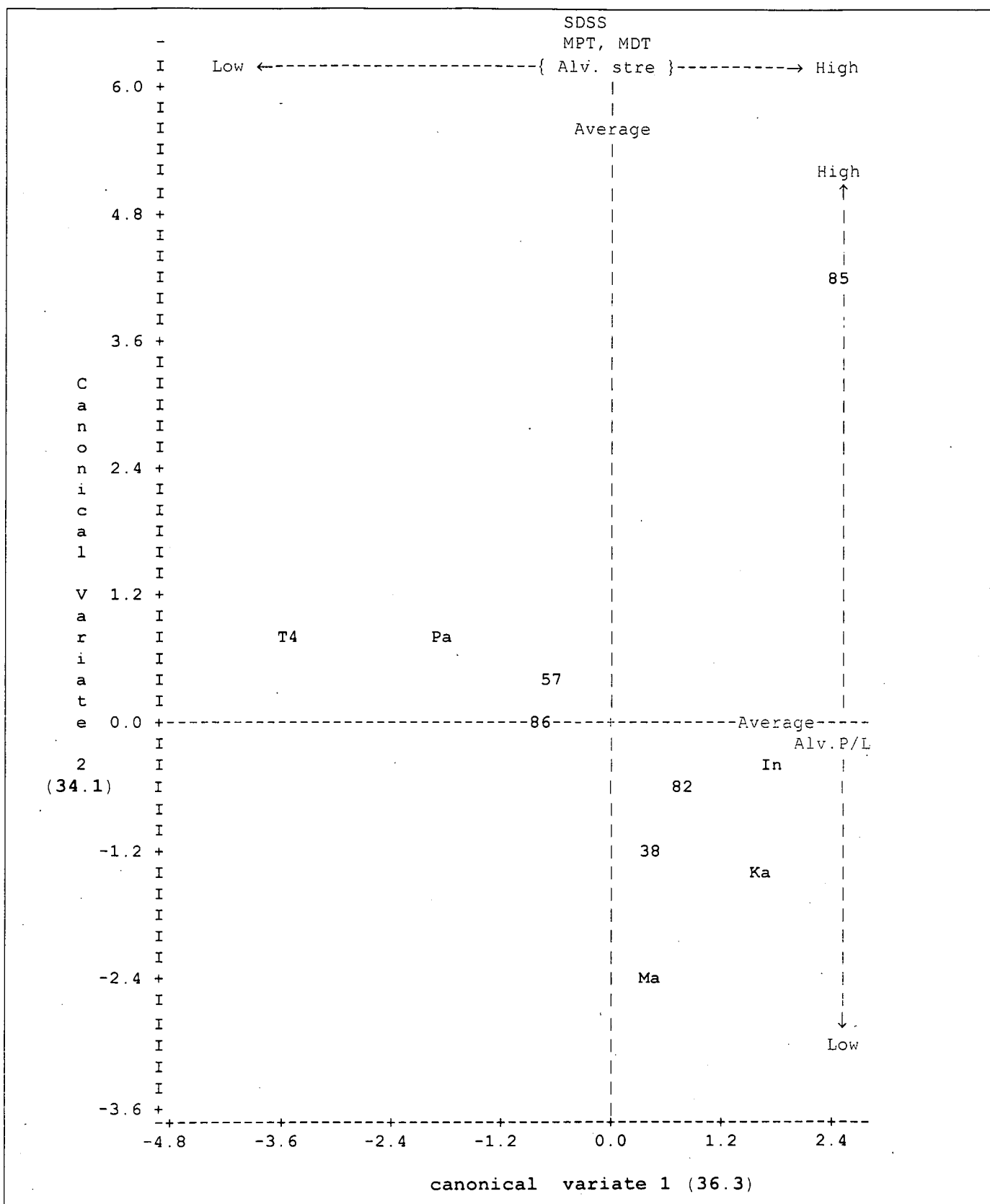
With exception of alveograph P/L ratio, it is possible for most of these parameters to be improved simultaneously. The genotypes with good potential include, SST825, Inia, Kariega, SST822, Marico and SST57. As it was for 1997, alveograph P/L ratio showed much contrast with other variates and therefore this parameter needs separate strategies. The genotypes with good potential for this variate include, T4 and particularly SST825, Inia and Palmiet, which also showed intermediate to high performance in other parameters. They may be used as donor parents. However, as it was seen from the correlations, breakflour yield showed scores, which were similar for both axes. As a result, genotypes, which were on the lower part for most of the variates, were the ones showing high breakflour yields. This implies much contrast between this parameter and others. Therefore emphasis should not be directly on higher breakflour yield, but rather indirect parameters like vitreous kernels and hardness index.

Table 5.3.2 Correlation coefficients of those variates retained in the final CVA with each other and the first two canonical variates.

BFLY	1.000										
TKM	-0.256	1.000									
MDT	-0.013	0.053	1.000								
MPT	-0.010	0.118	0.910	1.000							
Alv. P/L	-0.341	0.182	-0.123	-0.023	1.000						
Alv. stre.	-0.060	0.154	0.669	0.681	-0.075	1.000					
LFV12%	-0.361	0.256	0.247	0.191	-0.210	-0.159	1.000				
SDSS	0.019	0.281	0.651	0.627	-0.337	0.633	0.298	1.000			
SKCS-W	-0.209	0.899	0.063	0.138	0.149	0.227	0.174	0.287	1.000		
SKCS-diam	-0.268	0.846	0.005	0.092	0.231	0.198	0.144	0.178	0.964	1.000	
CVA [1]	-0.300	0.524	0.651	0.696	-0.001	0.654	0.494	0.794	0.526	0.520	
CVA [2]	-0.436	-0.015	-0.169	-0.094	0.580	-0.032	-0.181	-0.484	0.024	0.267	
	BFLY	TKM	MDT	MPT	Alv- P/L	Alv- stre	LFV12%	SDSS	SKCS-W	SKCS- diam	

Table 5.3.3 Mean values of the 10 genotypes for all variates considered in the canonical variate analysis.

GENO.	BFLY	TKM	MDT	MPT	Alv.P/L
Marico	24.01	37.21	2.990	4.286	0.3843
Kariega	24.89	39.75	2.576	3.762	0.3552
T4	25.06	34.19	1.381	1.143	0.5257
Palmiet	23.13	37.42	1.838	2.062	0.4905
SST825	20.48	40.07	2.610	3.905	0.6376
SST822	23.62	39.66	2.490	3.619	0.3814
SST876	21.70	38.61	1.853	1.400	0.3829
SST38	22.47	38.55	1.986	2.000	0.2295
SST57	23.46	33.28	2.743	3.524	0.3076
Inia	22.97	41.16	2.705	3.905	0.4743
Mean	23.18	37.99	2.317	2.960	0.4169
GENO.	Alv.stre	LFV12%	SDSS	SKCS-W	SKCS-Diam
Marico	36.89	930.6	87.05	35.26	2.461
Kariega	36.32	950.9	88.76	37.70	2.642
T4	15.27	823.4	63.95	32.88	2.442
Palmiet	21.70	889.8	68.66	35.01	2.538
SST825	41.35	936.0	78.95	38.66	2.821
SST822	33.68	954.6	81.95	38.03	2.660
SST876	27.88	924.1	76.60	36.97	2.621
SST38	31.87	972.3	83.48	36.46	2.580
SST57	31.28	947.3	75.14	31.68	2.374
Inia	39.52	958.6	84.62	39.74	2.743
Mean	31.58	928.7	78.92	36.24	2.588



NB: T4 contrast with other genotypes for most of the parameters while SST825 is due to high P/L ratio
Figure 5.3.1 Plot of mean scores of genotypes, canonical variate one plotted against canonical variate two.

Ma = Marico, In = Inia, Ka = Kariega, Pa = Palmiet, 85 = SST825, 82 = SST822, 86 = SST876, 38 = SST38, T4 = T4 and 57 = SST57.

5.4 Canonical variate analysis to find groupings between environments

As it was for the genotypes, those variates, which were not important, were deleted one-by-one from the analysis until only those with reasonable correlation coefficients were retained. About 12 variates were retained but this was due to the five protein parameters (three for grain and two for flour). The variates include; hectoliter mass, grain protein content methods (WH, FL and LECO), vitreous kernels, wet gluten content at 12% protein, flour protein content methods (NIR and LECO), farinograph absorption, alveograph strength, loaf volume at 12% protein and moisture content. Therefore this shows that environmental effects had more influence on these variates compared to others.

The first two canonical variates (CV1 and CV2) together accounted for 88.3% of the total variation among groups. Tables 5.4.1 and 5.4.2, shows the canonical variate mean scores and percentages for the two CVs as well as correlation coefficients between the variates and the first two CVs respectively.

Table 5.4.1 Canonical variate percentage variation and mean scores of the first two canonical variates of the seven locations.

Variates	CV1	CV2
	70.0%	18.3%
BullHill	2.939	0.738
BarkWes	-0.715	1.091
Prieska	3.958	-2.675
Hopetown	1.581	0.765
Douglas	2.944	-1.532
Loskop	-8.889	-2.182
KoedKop	-1.818	3.795

Table 5.4.1 shows that Loskop contrasts the most with other locations. This is due to very high negative CV1 score versus small positive and negative scores for the other sites. The horizontal separation (CV1) accounted for nearly 70.0% of the total variation and made a large contribution. Grouping of the seven locations is more clearly shown by a plot of the two canonical variates mean scores (Figure 5.4.1). Points closer in such a plot are similar, with respect to their general response to the variates that discriminate between them. Taking into account all the variates included in the final CVA, Loskop was dissimilar to most of the other sites particularly for protein content (both grain and flour) and related variates. Other sites were similar in protein content and most of the variates associated with protein content, particularly Prieska and Douglas. However, for the variates influenced by optimum grain filling and starch-protein interactions, Prieska, Douglas and Loskop were similar. Other sites were also not so much different from the above three, except BullHill, which was much lower for vitreous kernels. For Loskop difference was due to the fact that the environments were not so adverse in this season. However, with adverse environments as it was in 1997, it

will show lower values and therefore only Prieska and Douglas seemed to have good potential for most of the variates.

The main variates which discriminated between locations for CV1 (x-axis) (Figure 5.4.1) were grain protein content – WH ($r = -0.858$), grain protein content – FL ($r = -0.901$), grain protein content – LECO ($r = -0.896$), wet gluten content at 12% protein ($r = -0.775$), flour protein content – NIR ($r = -0.796$), flour protein content – LECO ($r = -0.886$), alveograph strength ($r = -0.662$) and to a lesser extent loaf volume at 12% protein ($r = 0.575$). Except loaf volume, the first seven variates correlated the strongest negative and loaf volume positive, with the CV1 scores. Therefore, generally Loskop had higher rating for protein contents (grain and flour), wet gluten content at 12 % protein and alveograph strength than other sites. Nevertheless for loaf volume at 12% protein content it was the other way round and Loskop was far from the grand mean (Figure 5.4.1) and (Table 5.4.3). Laubscher (1980) also described the complex interaction of South African spring wheat cultivars with environment for loaf volume, mixing requirement, grain protein content and gluten content.

The CV2 (y-axis), accounted for only 18.3% of the total variation and thus it had much lower contribution. Therefore the variates, which discriminated between locations, were hectoliter mass ($r = -0.569$), farinograph absorption ($r = -0.587$) and vitreous kernels ($r = -0.514$). This shows low negative correlation, and though the difference between sites was not so high Prieska, Douglas and Loskop were a bit higher than the means. Other sites were either close or lower than the means, and BullHill in particular was much lower for vitreous kernels. The higher values shown by Prieska, Douglas and particularly Loskop for farinograph absorption and vitreous kernels were mainly influenced by high grain filling and protein content. The scores for moisture content were high for both axes and it was only Loskop, Koedoeskop and Barkly West that showed higher moisture contents than other sites. Therefore at least two major environmental groups were realised, which were Loskop alone and the other sites together. For the other sites, Koedoeskop, Bullhill, Barkly West and Hopetown were intermediate for some variates as compared to Prieska and Douglas. Canonical variate analysis done by Van Lill *et al.* (1995b) showed that, climatic conditions during grain filling influenced yield, protein content and dough development time. Also modifications of storage or cytoplasmic protein ratios by favourable climatic factors appeared to affect mixing requirements. This agrees with most of our results such as the high protein content at Loskop and also higher mixing times at this site and Koedoeskop despite the latter site having lower protein contents. This was because the two sites are in the warmer areas. For better results it is therefore necessary to mix the products from the two sites with others, particularly Prieska and Douglas, which showed good results for most of the variates. Other sites like BullHill, Barkly West and Hopetown may also need this exercise to improve some of the variates when it is necessary.

Table 5.4.2 Correlation coefficients of those variates retained in the final CVA with each other and the first two canonical variates.

HLM	1.000												
GPC WH	0.043	1.000											
GPC FL	-0.009	0.974	1.000										
GPC LECO	-0.062	0.982	0.985	1.000									
VK	0.278	0.640	0.591	0.556	1.000								
WGC12%	0.003	0.897	0.895	0.903	0.505	1.000							
FPC NIR	-0.033	0.890	0.888	0.893	0.519	0.835	1.000						
FPC LECO	-0.118	0.932	0.943	0.950	0.499	0.875	0.868	1.000					
FABS	0.171	0.674	0.661	0.659	0.409	0.740	0.640	0.624	1.000				
Alv. Stre	-0.001	0.730	0.737	0.728	0.489	0.554	0.716	0.752	0.415	1.000			
LFV12%	0.030	-0.476	-0.505	-0.507	-0.297	-0.534	-0.383	-0.540	-0.495	-0.159	1.000		
Moist	-0.206	0.314	0.364	0.334	0.115	0.193	0.311	0.369	-0.048	0.390	-0.117	1.000	
CV1	0.169	-0.858	-0.901	-0.896	-0.461	-0.775	-0.796	-0.886	-0.490	-0.662	0.575	-0.684	
CV2	-0.569	-0.416	-0.356	-0.358	-0.514	-0.414	-0.316	-0.255	-0.587	-0.165	0.300	0.619	
	HLM	GPC- WH	GPC- FL	GPC- LECO	VK	WGC12%	FPC- NIR	FPC- LECO	FABS	ALV. STRE	LFV12%	MOIST	

Table 5.4.3 Mean values of the 10 locations for all variates considered in the canonical variate analysis.

ENVIR.	HLM	GPC- WH	GPC- FL	GPC- LECO	VK	WGC12%	FPC- NIR	FPC- LECO	FABS	Alv. Stre	LFV12%	Moist
BullHill	76.15	10.54	11.53	12.37	44.19	33.46	11.05	11.56	61.78	28.04	956.8	9.530
BarkWes	76.25	11.94	12.57	13.37	65.27	37.60	12.23	12.86	61.71	29.64	927.6	10.020
Prieska	81.38	11.11	11.64	12.17	72.13	33.56	11.08	10.67	62.42	26.03	955.7	9.368
Hopetown	76.73	11.08	11.67	12.43	62.53	32.98	11.31	11.45	62.24	23.92	959.0	9.894
Douglas	79.26	11.31	11.81	12.32	67.86	33.17	11.13	11.24	62.08	27.70	936.6	9.509
Loskop	78.10	15.66	16.19	17.40	82.67	48.34	15.91	17.16	66.80	52.43	810.8	10.349
KoedKop	77.33	11.12	12.01	12.47	60.87	31.92	11.32	11.67	59.67	33.27	954.7	10.818
Mean	77.89	11.82	12.49	13.22	65.07	35.85	12.00	12.37	62.38	31.58	928.7	9.930

Compared to the 1997 results for the parameters influenced by environments, hectoliter mass, vitreous kernels, farinograph absorption and moisture content were more influenced by the environment variations between locations than between years. Therefore for these parameters focus is needed on individual locations in terms of management and genotype selection for higher values. Other parameters like kernel mass, flour colour, mixograph development time, loaf volume at 12% protein, kernel diameter, SKCS-hardness index, wet gluten content at 12% protein, alveograph strength and protein content, are influenced by environmental variations between locations and years. Therefore in addition to management practices there is a need to select genotypes with wide adaptability for these parameters particularly in risky environments. For the locations, except Loskop, management practices to increase protein content at other sites particularly Prieska are important. However, Loskop needs separate strategies in terms of management and cultivar selection to ensure that protein content does not vary too much between years.

5.5 Canonical variate analysis to find groupings between environment x genotype

The interpretation of the performance of a number of genotypes evaluated in a broad range of environments is always affected by genotype x environment interaction. Differential genotype responses to variable environmental conditions, especially associated with changes in ranks of genotypes, limit accurate estimates of yield and other parameters and thus identification of superior, stable genotypes. With the biplot facility from AMMI analysis, both genotypes and locations occur on the same scattergram, and inferences about specific genotype x location combinations can be made (Crossa *et al.*, 1991).

Similarly for genotypes and environments, those variates, which were not important, were deleted one-by-one from the analysis until only those with reasonable correlation coefficients were retained. About 13 variates were retained but as it was for environment, the main contribution was due to the five protein parameters (three for grain and two for flour). The variates include; grain protein content (methods; WH, FL and LECO), breakflour yield, wet gluten content at 12% protein, flour protein content (methods; NIR & LECO), mixograph development time and point score (MDT and MPT), alveograph strength, loaf volume at 12% protein, sedimentation and moisture content. Therefore this shows that in addition to main effects, the interaction had more influence on these variates compared to others. General observation shows mainly protein content and quality caused interaction effects in this season. This differed from 1997 where grain filling and hardness were also involved.

The first two canonical variates (CV1 and CV2) together accounted for 63.4% of the total variation among groups. Tables 5.5.1 and 5.5.2, show the canonical variate mean scores and percentages for the two CVs as well as correlation coefficients between the variates and the first two CVs respectively.

It is evident from Table 5.5.1 that the interaction combinations LoMa(51), LoKa(52), LoT4(53), LoPa(54), Lo85(55), Lo82(56), Lo86(57), Lo38(58), Lo57(59) and LoIn(60) contrasts the most with other interaction combinations. This is due to higher positive CV1 scores versus intermediate to small positive/negative scores for the other interactions. The horizontal separation (CV1) accounted for nearly 40.9% (more than half) of the total variation. Grouping of the 70 GxE interactions is more clearly shown by a plot of the two canonical variates mean scores (Figure 5.5.1). Points closer or further apart in such a plot are similar or dissimilar respectively, with respect to their general response to the variates that discriminate between them. Taking into account all the variates included in the final CVA, most of the interactions realised at Loskop were dissimilar to those of the other sites. This was particularly due to the fact that all the interactions were associated with increase in protein content (both grain and flour) and related variates such as wet gluten content at 12% protein and mixograph point score. Taking into account other variates which are influenced by both protein content and quality such as mixograph development time, mixograph point score, alveograph strength and SDS-sedimentation, two more interaction groups were realised. The interaction effects shown by Palmiet, T4 and SST876 at Douglas, Hopetown, Barkly West, BullHill, Koedoeskop and

Loskop (codes; 43, 44, 33, 34, 13, 14, 3, 63, 53 and 57) were negative and thus had low values for these variates. However, due to positive environment interactions shown by SST825, Inia, Palmiet and Marico at Prieska, Douglas, BullHill, Koedoeskop and Loskop (codes; 25, 45, 10, 61, 64, 65 and 51), higher mean values were realised for the variates mentioned above. Other interaction effects showed less deviation and were close to the mean for most of the parameters. breakflour yield and moisture content didn't show a clear trend, but breakflour yield was higher at Loskop for some of the genotypes due to higher protein. This is supported by Van Lill and Smith (1997) who reported that, grains containing a higher protein content were inclined to be harder, which in turn increased flour yield. Moisture content was slightly higher at Loskop and Koedoeskop, but the two parameters had less influence on other parameters.

Table 5.5.1 Canonical variate percentage variation and mean scores of the first two canonical variates of the 70 G x E interaction combinations.

Envi x Gen	CV1	CV2	Envi x Gen	CV1	CV2
	40.9%	22.6%			
BH Ma 1	-2.814	0.847	HT 82 36	-1.008	0.141
BH Ka 2	-2.019	2.266	HT 86 37	-3.537	0.448
BH T4 3	-2.787	10.059	HT 38 38	-1.095	1.833
BH Pa 4	-3.230	1.014	HT 57 39	-2.654	0.426
BH 85 5	-4.263	-2.194	HT In 40	-1.041	-0.590
BH 82 6	-1.744	1.513	DO Ma 41	-3.674	-1.626
BH 86 7	-3.878	-0.305	DO Ka 42	-1.951	-1.520
BH 38 8	-3.186	-0.500	DO T4 43	-4.174	5.156
BH 57 9	-4.066	-0.319	DO Pa 44	-4.452	6.432
BH In 10	-1.894	-5.099	DO 85 45	-5.706	-7.393
BW Ma 11	1.936	0.370	DO 82 46	-2.902	-2.174
BW Ka 12	3.533	1.223	DO 86 47	-5.390	0.206
BW T4 13	3.101	8.103	DO 38 48	-3.923	-0.208
BW Pa 14	0.483	8.118	DO 57 49	-2.894	0.147
BW 85 15	-0.379	-3.423	DO In 50	-2.386	-2.955
BW 82 16	0.288	1.563	LO Ma 51	9.234	-5.100
BW 86 17	0.676	1.292	LO Ka 52	14.045	-0.590
BW 38 18	1.997	0.741	LO T4 53	11.787	9.063
BW 57 19	-0.036	0.677	LO Pa 54	8.742	-2.032
BW In 20	0.869	-0.488	LO 85 55	11.316	-2.469
PR Ma 21	-5.407	-1.789	LO 82 56	11.028	-0.066
PR Ka 22	-3.592	-2.260	LO 86 57	9.232	3.391
PR T4 23	-5.954	4.579	LO 38 58	13.061	-1.096
PR Pa 24	-5.955	4.605	LO 57 59	9.852	1.435
PR 85 25	-6.631	-5.400	LO In 60	10.076	-2.275
PR 82 26	-4.092	-1.442	KK Ma 61	2.096	-5.381
PR 86 27	-4.458	1.325	KK Ka 62	1.983	-3.283
PR 38 28	-4.629	0.676	KK T4 63	-0.091	4.414
PR 57 29	-4.090	0.211	KK Pa 64	-0.423	-5.601
PR In 30	-4.025	-2.805	KK 85 65	0.024	-8.711
HT Ma 31	-0.389	1.385	KK 82 66	1.947	-2.934
HT Ka 32	0.887	2.019	KK 86 67	0.837	-3.153
HT T4 33	-1.964	6.760	KK 38 68	0.686	-2.904
HT Pa 34	-1.713	6.288	KK 57 69	1.873	-4.086
HT 85 35	-3.205	-4.062	KK In 70	2.062	-2.544

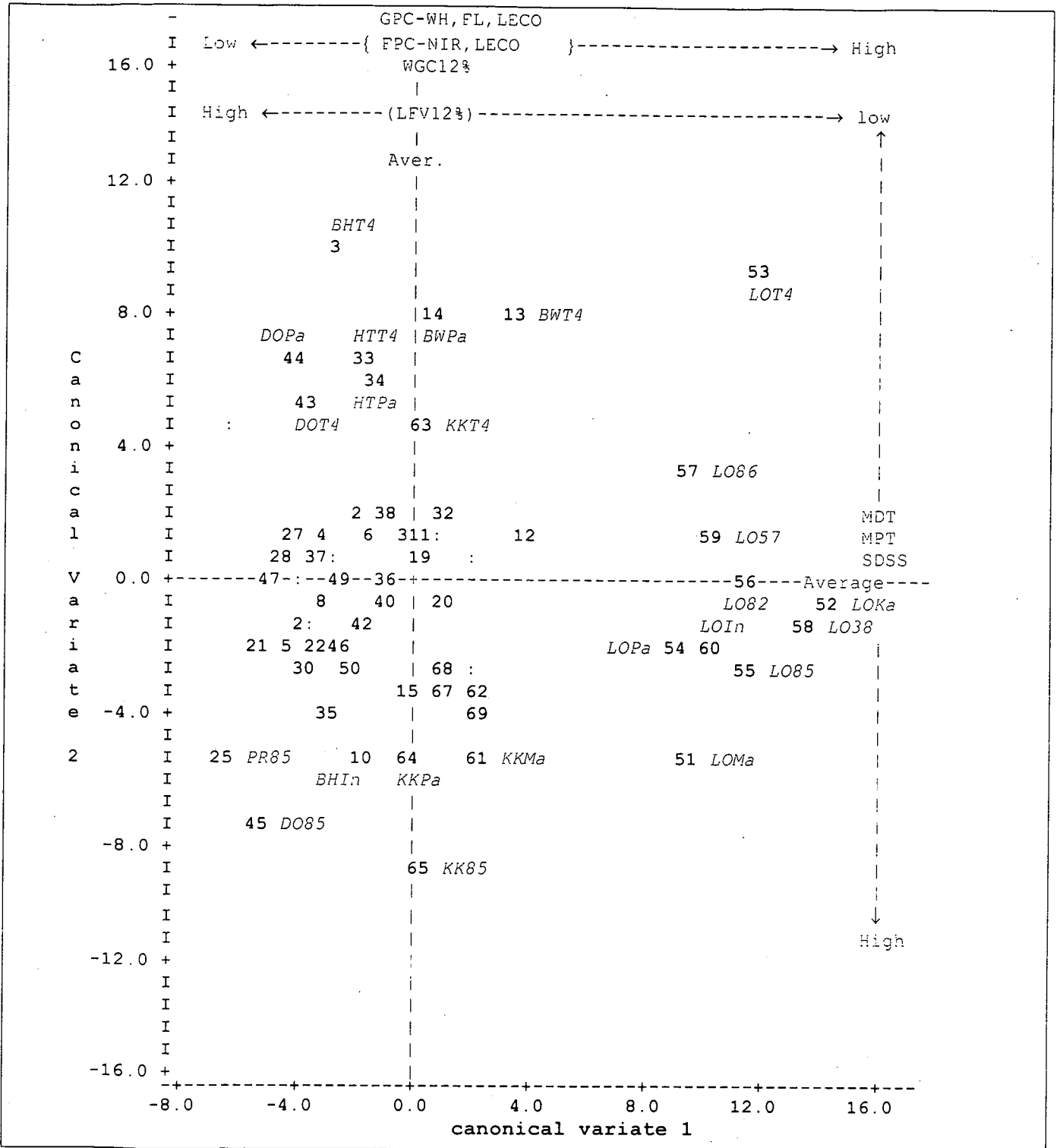
The main variates which discriminated the interaction effects for CV1 (x-axis) (Figure 5.5.1) were grain protein content-WH ($r = 0.864$), grain protein content-FL ($r = 0.902$), wet gluten content at 12% protein ($r = 0.785$), flour protein content-NIR ($r = 0.79$), flour protein content-LECO ($r = 0.906$) and loaf volume at 12% protein ($r = -0.562$). The first six variates correlated strongest positive and the last one negative with the CV1 scores. As already mentioned, protein content (grain and flour) including wet gluten contents were higher for most of the interactions realised at Loskop than in other sites. However, it was the other way round for loaf volume at 12% protein. The variates, which discriminated the interaction effects for CV2 (y-axis), accounted for 22.6% of the total variation implying a lower contribution. These were mainly mixograph development time

($r = -0.752$), mixograph point score ($r = -0.708$) and to a lesser extent SDS-sedimentation ($r = -0.564$). The first two variates correlated strongest and the last one less but all negative with the CV2 scores. This was due to the fact that most of the interactions for the three variates had negative effects. It is quiet clear from Figure 5.5.1 and Table 5.5.3 that, most of the negative environment interactions at most of the locations were caused by T4 and Palmiet and to a lesser extent SST876. T4 as such (code 53), gave very high protein content (grain and flour) as well as wet gluten content at 12% protein.

Table 5.5.2 Correlation coefficients of those variates retained in the final CVA with each other and the first two canonical variates.

GPC-WH	1.000													
GPC-FL	0.974	1.000												
GPC-LECO	0.962	0.985	1.000											
BFLY	0.081	0.107	0.140	1.000										
WGC12%	0.897	0.895	0.903	0.106	1.000									
FPC-NIR	0.890	0.838	0.893	0.006	0.835	1.000								
FPC-LECO	0.932	0.943	0.950	0.179	0.875	0.868	1.000							
MDT	0.217	0.247	0.231	-0.013	-0.063	0.208	0.242	1.000						
MPT	0.249	0.273	0.252	-0.010	-0.019	0.226	0.270	0.910	1.000					
Alv.stre	0.730	0.737	0.728	-0.060	0.554	0.716	0.752	0.669	0.681	1.000				
LFV12%	-0.476	-0.505	-0.507	-0.361	-0.534	-0.383	-0.540	0.247	0.191	-0.159	1.000			
SDSS	0.350	0.342	0.321	0.019	0.135	0.324	0.366	0.651	0.627	0.633	0.298	1.000		
Moist	0.314	0.364	0.334	0.197	0.183	0.311	0.369	0.420	0.344	0.390	-0.117	0.240	1.000	
CV1	0.864	0.902	0.903	0.392	0.785	0.790	0.906	0.280	0.283	0.666	-0.562	0.324	0.638	
CV2	-0.102	-0.106	-0.073	0.580	0.125	-0.128	-0.078	-0.752	-0.708	-0.631	-0.464	-0.564	-0.289	
	GPC-WH	GPC-FL	GPC-LECO	BFLY	WGC12%	FPC-NIR	FPC-LECO	MDT	MPT	Alv.stre	LFV12%	SDSS	Moist	

Nevertheless it had a much lower mixograph development time and point scores, alveograph strength and loaf volume at 12% protein although sedimentation was above the recommendation. The same genotype showed slightly higher gluten content at Barkly West (13) but it was lower for other parameters, probably due to glutenin-to-gliadin ratios. According to Uthayakumaran *et al.* (1999), protein content and glutenin-to-gliadin ratio independently affected dough and baking properties. Differences in the quality observed from flour to flour are thus determined, in part, by a superimposition of the effects of protein content and glutenin-to-gliadin ratio. Other interactions for T4 at Koedoeskop (63), Hopetown (33), BullHill (3), Douglas (43) together with Palmiet at Barkly West (14), Hopetown (34) and Douglas (44), had negative effects. Consequently all showed low values for protein content, wet gluten, mixograph development time and point score, alveograph strength, sedimentation and loaf volume. Therefore as mentioned earlier, the two genotypes particularly T4 seem to have low genetic potential for most of the parameters. This is in agreement with finding by Ivanov *et al.* (1998) who noted high influence of cultivar on the total protein content, and composition (globulins, gliadins and glutenins).



NB: Most of the interactions at Loskop show more contrast with others due to high protein

Figure 5.5.1 Plot of mean scores of genotypes x environments interactions, canonical variate one plotted against canonical variate two.

PR = Prieska, BH = BullHill, BW = Barkly West, DO = Douglas, HT = Hopetown, KK = Koedoeskop and LO = Loskop. Ma = Marico, In = Inia, Ka = Kariega, Pa = Palmiet, 85 = SST825, 82 = SST822, 86 = SST875, 38 = SST38, T4 = T4 and 57 = SST57.

Palmiet showed some positive interactions, like with Koedoeskop (64), BullHill (4) and Loskop (54) where it managed to have higher loaf volumes closer to the mean. SST876 at Loskop (57) showed much lower mixograph development time and point score.

Genotypes; which showed positive environment interactions in addition to Palmiet, were, SST825, Inia, Marico, SST38, SST57, SST822 and Kariega. SST825 had low protein content at Prieska (25) but at Douglas (45) and Koedoeskop (65) it was close to optimum (12%). For the first two sites, mixograph development time and point score were close to optimum (2.5 – 3) and (4.0) respectively. However, at Koedoeskop these parameters were higher than optimum values. This agrees with the results by other researchers (Van Lill *et al.*, 1995b; Finney *et al.*, 1987), who also found an increase in mixograph development time at lower flour protein levels (<12%). Taking into account that Koedoeskop is in a warmer area, the higher mixograph development time, might have been due to modification of cytoplasmic and storage proteins ratios. The protein content for Inia at BullHill (10) was close to optimum and both mixograph development time and point score were close to optimum. This was also true for Marico at Koedoeskop (61). However, due to much higher protein content at Loskop, Marico (51) showed much higher mixograph point score and particularly development time consequently loaf volume was decreased. However, due to environment main effect at Loskop, all genotypes also showed higher protein and gluten content at this site. However, although mixograph development times and point scores were close to optimum for most of the genotypes, the loaf volumes were lower than the mean. The low loaf volume for most of the genotypes at this site was also a consequence of much higher sedimentation and alveograph strengths.

In conclusion, T4 and Palmiet are risky to use as they showed negative environment interactions with most of the sites. Nevertheless Palmiet showed positive interactions at Loskop, Koedoeskop and BullHill for only loaf volume, which was slightly higher than most of the genotypes. Therefore these genotypes may be included among the selections for these sites. On the other hand, SST825 and Marico interacted with Koedoeskop and Loskop respectively where they showed positive environment interaction for mixograph development time and point score. For the locations, most of them need genotypes, which do not show negative environment interactions. Since most of the interaction effects at Prieska showed less deviation from the mean, this site may give reliable results for most of the genotypes. However, due to much change in protein yield at Loskop between years, this site needs genotypes which does not show much change in other parameters particularly mixograph development time and point score. This was the case for Palmiet, SST57, SST822, Inia, Kariega, SST38 and SST825. Also loaf volume and alveograph strength were influenced by both genotype, environment and interaction. This signifies how complex it is to get optimum values for the two parameters. The implication here is that there is a need for identification of genotypes, environments and interaction effects which will result in optimum values particularly for these two parameters.

Table 5.5.3 Mean values of the 70 G x E interaction combinations for all variates considered in the canonical variate analysis.

ENV x GEN	GPC-WH	GPC-FL	GPC-LECO	BFLY	WGC12%	FPC-NIR	FPC-LECO	MDT	MPT	Alv.stre	LFV12%	SDSS	Moist
BH Ma 1	10.47	11.40	12.07	25.73	30.97	10.67	10.97	2.933	4.333	30.73	946.3	86.33	9.453
BH Ka 2	10.57	11.67	12.33	24.80	33.93	11.07	11.17	2.000	2.333	26.13	955.0	83.33	9.627
BH T4 3	10.30	11.07	11.83	25.97	35.17	10.50	11.33	1.033	1.000	9.10	783.3	55.00	9.297
BH Pa 4	10.60	11.70	12.53	22.80	32.75	11.28	11.52	2.087	2.133	22.47	996.4	75.87	9.577
BH 85 5	10.10	11.00	11.73	22.80	30.60	10.67	10.80	2.400	4.000	32.17	998.0	83.00	9.673
BH 82 6	10.37	11.57	12.37	25.60	34.10	10.90	11.70	2.500	4.000	29.70	978.7	84.33	9.607
BH 86 7	10.64	11.48	12.17	22.05	34.50	11.08	11.57	1.937	2.133	27.47	974.4	81.88	9.544
BH 38 8	11.33	12.00	12.87	20.80	37.47	11.80	12.27	1.633	1.000	27.40	989.3	77.67	9.593
BH 57 9	9.63	11.10	12.70	23.27	30.93	10.67	11.20	2.667	3.333	27.10	970.3	72.33	9.367
BH In 10	11.40	12.30	13.13	22.47	34.20	11.83	13.10	2.933	4.000	48.10	976.0	89.00	9.567
BW Ma 11	11.47	12.30	13.00	24.93	32.37	12.23	12.63	2.733	4.000	32.60	914.7	88.33	10.243
BW Ka 12	12.40	12.77	13.43	25.77	36.67	13.00	13.10	2.400	3.667	34.53	979.3	87.67	10.423
BW T4 13	11.90	12.70	13.60	25.87	39.77	11.67	13.13	1.233	1.000	15.77	833.0	65.00	10.060
BW Pa 14	11.03	11.80	12.53	26.13	37.30	10.93	11.40	1.200	1.000	13.30	849.0	63.33	9.950
BW 85 15	12.17	12.87	13.50	21.10	38.63	12.57	12.77	2.333	3.333	40.57	946.0	78.33	9.967
BW 82 16	10.73	11.70	12.30	25.63	33.43	10.80	11.47	2.333	3.000	26.77	973.0	81.67	10.243
BW 86 17	12.77	13.10	14.30	21.80	43.63	13.60	14.27	1.667	1.000	33.83	911.0	74.00	9.643
BW 38 18	12.23	12.73	13.47	23.50	36.70	12.53	13.73	2.133	2.667	30.80	947.3	86.67	10.157
BW 57 19	12.07	12.70	13.60	23.67	37.57	12.43	12.53	2.600	3.667	30.37	967.0	73.33	9.803
BW In 20	12.63	13.07	13.93	23.27	39.93	12.50	13.53	2.300	3.667	37.90	955.3	85.00	9.710
PR Ma 21	11.03	11.83	12.27	22.65	30.33	10.57	10.80	2.933	4.333	28.83	1013.0	84.00	9.153
PR Ka 22	11.37	11.73	12.47	22.30	33.50	10.87	11.90	2.433	4.000	33.67	1002.3	89.33	9.433
PR T4 23	10.57	11.00	11.33	22.73	33.00	10.20	9.93	1.267	1.000	15.30	837.7	65.67	9.210
PR Pa 24	10.53	11.13	11.60	22.40	33.40	9.87	10.13	1.267	1.000	14.07	833.0	63.33	9.110
PR 85 25	10.70	11.37	11.80	18.67	32.00	10.53	10.83	2.400	3.667	34.63	925.0	75.67	9.430
PR 82 26	12.17	12.20	12.70	21.43	37.33	12.33	11.40	2.200	3.333	32.47	1012.3	78.33	9.403
PR 86 27	10.53	11.50	12.30	21.13	33.30	11.67	10.43	1.533	1.000	20.67	917.7	68.00	9.543
PR 38 28	12.03	12.30	12.70	21.23	36.33	12.27	10.73	1.633	1.000	23.20	1030.7	78.33	9.337
PR 57 29	11.07	11.53	12.27	23.00	33.50	12.17	10.20	2.533	3.333	27.10	980.3	72.67	9.567
PR In 30	11.13	11.77	12.27	21.90	32.87	10.33	10.37	2.533	4.000	30.33	1005.3	78.33	9.697
HT Ma 31	11.70	12.13	13.07	24.90	32.20	11.63	12.33	2.733	4.000	27.42	966.7	87.67	9.680
HT Ka 32	11.33	11.90	12.80	25.33	32.97	11.23	12.03	2.200	3.000	25.33	980.3	88.33	10.117
HT T4 33	10.07	11.00	11.87	25.97	31.40	10.17	10.43	1.533	1.000	11.21	894.3	63.33	9.823
HT Pa 34	10.57	11.27	12.17	24.73	32.73	11.07	11.07	1.500	1.000	12.13	879.0	65.33	9.800
HT 85 35	10.83	11.40	12.00	21.17	31.07	11.37	11.03	2.567	3.000	35.12	948.7	78.33	10.053

Table 5.5.3 continued

ENV x GEN	GPC-WH	GPC-FL	GPC-LECO	BFLY	WGC12%	FPC-NIR	FPC-LECO	MDT	MPT	Alv.stre	LFV12%	SDSS	Moist
HT 82 36	11.17	12.03	12.57	23.80	33.57	11.47	11.67	2.433	3.000	28.19	976.7	84.00	9.957
HT 86 37	10.93	11.37	12.00	21.40	34.27	10.80	11.23	1.733	1.000	20.64	960.7	71.00	9.907
HT 38 38	11.70	11.97	12.67	23.57	35.53	11.97	11.93	1.967	1.000	22.43	1017.7	87.33	9.920
HT 57 39	10.93	11.50	12.27	23.67	31.60	11.43	11.13	2.900	3.000	24.57	959.7	76.67	9.803
HT In 40	11.53	12.10	12.87	24.20	33.50	12.00	11.67	2.733	3.000	32.11	1006.7	84.33	9.877
DO Ma 41	11.23	11.77	12.23	22.73	29.47	11.03	12.13	2.800	4.333	33.73	906.3	83.67	9.347
DO Ka 42	11.70	12.07	12.63	22.80	33.40	11.27	11.97	2.333	3.667	34.10	958.0	90.00	9.650
DO T4 43	10.97	11.57	11.93	23.50	33.33	10.47	10.57	1.300	1.000	16.10	842.3	63.33	9.300
DO Pa 44	10.25	10.87	11.22	24.67	31.52	9.55	9.74	1.243	0.967	11.68	831.4	58.41	9.491
DO 85 45	11.33	11.90	12.27	18.20	32.00	11.83	11.20	2.700	4.333	40.60	975.3	80.33	9.573
DO 82 46	11.57	12.20	12.63	21.70	33.77	10.87	11.50	2.533	4.000	30.03	976.7	82.67	9.663
DO 86 47	10.80	11.30	11.87	20.73	34.03	11.33	11.13	1.800	1.000	23.83	914.7	80.33	9.360
DO 38 48	12.07	12.30	12.90	20.87	36.57	12.27	11.37	1.733	1.000	25.43	1022.0	84.00	9.407
DO 57 49	11.43	11.90	12.63	22.53	33.90	11.40	11.43	2.500	3.333	26.47	934.3	73.33	9.603
DO In 50	11.73	12.27	12.83	22.30	33.70	11.30	11.37	2.600	4.000	35.07	1005.3	87.00	9.697
LO Ma 51	14.97	15.50	16.67	24.96	41.10	15.07	16.30	3.533	5.000	66.97	858.0	94.00	10.347
LO Ka 52	16.13	16.27	17.63	29.13	49.20	14.57	17.83	3.633	5.000	67.94	796.7	94.33	10.497
LO T4 53	15.07	15.83	16.83	26.70	48.33	14.13	16.87	1.867	2.000	25.54	707.0	75.67	10.327
LO Pa 54	15.80	16.30	17.37	20.87	44.00	15.33	16.80	2.600	4.000	44.60	838.0	80.33	10.277
LO 85 55	16.23	17.03	18.20	21.57	53.60	17.77	18.40	2.433	4.000	63.15	774.0	80.33	10.283
LO 82 56	15.57	16.40	17.80	23.77	50.93	17.03	17.53	2.500	4.000	56.32	808.7	84.00	10.220
LO 86 57	15.50	16.40	17.23	21.93	53.30	16.50	17.03	1.700	1.000	36.24	828.7	82.00	10.177
LO 38 58	16.30	16.47	17.67	25.17	47.93	16.13	18.43	2.433	4.000	64.37	772.7	89.00	10.507
LO 57 59	15.10	15.53	16.90	24.90	48.40	15.20	15.90	2.367	3.000	45.26	874.0	79.33	10.460
LO In 60	15.97	16.20	17.73	22.13	46.57	17.37	16.50	2.800	4.333	53.92	850.0	84.00	10.397
KK Ma 61	11.50	12.50	12.87	22.13	31.60	11.03	11.77	3.267	4.000	37.93	909.3	85.33	10.900
KK Ka 62	10.73	11.83	11.93	24.10	29.53	11.17	10.93	3.033	4.667	32.53	984.3	88.33	11.127
KK T4 63	10.00	10.93	11.43	24.67	30.93	10.43	10.10	1.433	1.000	13.87	866.0	59.67	10.713
KK Pa 64	11.57	12.17	12.87	20.30	32.77	11.60	12.00	2.967	4.333	33.63	1001.7	74.00	10.627
KK 85 65	11.33	12.40	12.97	19.83	32.87	11.63	11.97	3.433	5.000	43.20	984.7	76.67	10.783
KK 82 66	11.07	12.23	12.53	23.40	31.67	11.07	11.80	2.933	4.000	32.30	956.3	78.67	10.923
KK 86 67	10.83	11.87	12.27	22.83	32.00	11.03	11.30	2.600	2.667	32.50	961.3	79.00	10.863
KK 38 68	11.57	11.97	12.50	22.13	33.30	11.37	11.80	2.367	3.333	29.47	1026.3	81.33	10.787
KK 57 69	11.50	12.40	13.03	23.17	33.20	12.27	12.23	3.633	5.000	38.10	945.7	78.33	10.737
KK In 70	11.07	11.80	12.30	24.53	31.30	11.63	12.80	3.033	4.333	39.20	911.3	84.67	10.720
Mean	11.82	12.49	13.22	23.18	35.85	12.00	12.37	2.317	2.960	31.58	928.7	78.92	9.930

Conclusion for the 1998 results

As it was mentioned, this year had more optimal environment conditions compared to 1997. Consequently grain filling was higher at most of the locations and this was revealed by higher hectoliter and kernel mass. As a result, in addition to protein related parameters, kernel parameters were also responsible for genotype variation. Therefore genotype potential may be used to improve or obtain optimum values for most of the parameters. These include, mixograph development time and point score, alveograph P/L ratio and strength (W/6.54), loaf volume at 12% protein, SDS-sedimentation, kernel mass, kernel diameter and breakflour yield. The contrasting environment at Loskop compared to other sites, resulted in very high protein content for most of the genotypes. Because of that, protein content (grain and flour) was one of the sources of variations between locations. Parameters like hectoliter mass, vitreous kernels, farinograph absorption, loaf volume and moisture content were also responsible for the variations between genotypes and particularly environments. However, these parameters seem to be more sensitive to the environmental variation between locations than years. This suggests that classifying the sites according to their potential should give optimum values for these parameters. Other parameters that were responsible for the variations between genotypes and environments were alveograph strength and wet gluten content at 12% protein. However, these two, together with flour colour and SKCS-hardness index values, which were obtained in 1997, are more sensitive to variations between years than locations. This suggests identification of genotypes for each site that will be stable for these parameters from one year to another. For the interactions, the parameters responsible were protein content (grain and flour) and protein related characteristics. However, it shows that both environment and genotypes influenced interaction, but except for protein content most of the parameters were influenced by genotypes. Compared to 1997 results, it shows that mixograph development time, sedimentation, moisture content and breakflour yields were not more influenced by the variation between years. Therefore the results for these parameters at particular sites are not expected to change much from one year to another. However, this was not true for protein content, mixograph point score, alveograph strength, loaf volume at 12% protein, hectoliter mass, vitreous kernels, farinograph absorption, alveograph P/L ratio and hardness index. For these parameters the variations between years may also interfere with the interaction effects. Therefore genotypes need to be selected which are stable from one year to the next. Nevertheless above all, management practices to ensure optimum protein content and grain filling together with genotype selection will result in values close to optimum for most of the parameters.

CHAPTER 6

COMBINED ANALYSIS

The environmental conditions do not vary only between sites but also between years and may have an impact on quality parameters. The combined analysis was done using canonical variate analysis to find groupings between genotype x environment interactions for the two years. As it was for the former analysis, those variates, which were not important, were deleted one-by-one from the analysis until only those with reasonable correlation coefficients were retained. It therefore seems that most of the interactions shown by SST38 were not retained and that is why only nine interaction combinations, involving other genotypes were retained per year. Of all the variates, only seven were retained which includes; vitreous kernels, mixograph development time, alveograph P/L ratio, SDS-sedimentation, kernel diameter, SKCS-hardness index and moisture content. General observation shows that the variations were associated with endosperm starch (as a result of grain filling) and protein content. Above all the balance between starch and protein was important and this caused major differences between the two years.

The first two canonical variates (CV1 and CV2) together accounted for 90.5% of the total variation among groups. Tables 6.1 and 6.2 show the canonical variate mean scores and percentages for the two CVs as well as correlation coefficients between the variates and the first two CVs respectively. It is evident from Table 6.1 that there was a big contrast between the two seasons (1997 and 1998) as the pattern of genotypes within seasons was similar. This is due to intermediate negative CV1 scores versus intermediate to low positive scores. The horizontal separation (CV1) accounted for nearly 76.9% (much higher) of the total variation and thus made a large contribution. Also the interaction effects shown by T4, Palmiet and to a lesser extent SST57 deviated more from the others. Grouping of the 18 GxE interactions is more clearly shown by a plot of the two canonical variates mean scores (Figure 6.1). Points closer in such a plot are similar, with respect to their general response to the variates that discriminate between them.

Table 6.1 Canonical variate percentage variation and mean scores of the first two canonical variates of the 18 G x E interaction combinations for two years.

Seas x Gen	CV1	CV2	Seas x Gen	CV1	CV2
	76.9%	13.6%			
97 Pa 1	-4.418	-0.840	98 Ma 10	4.518	-0.501
97 T4 2	-4.547	2.724	98 Ka 11	4.327	-1.299
97 Ma 3	-3.760	-0.257	98 T4 12	1.952	3.239
97 Ka 4	-2.194	-1.110	98 Pa 13	2.292	1.970
97 82 5	-3.345	-1.751	98 85 14	2.600	-1.510
97 85 6	-4.002	-1.687	98 82 15	3.349	-0.938
97 In 7	-2.779	-0.767	98 86 16	3.279	0.596
97 86 8	-4.730	0.264	98 57 17	2.968	1.401
97 57 9	-4.257	1.284	98 In 18	3.884	-1.122

The correlations between variates (Table 6.2) show vitreous kernels had a positive correlation ($r = 0.54$) with SKCS-hardness index. The correlations with alveograph P/L ratio and moisture content were also positive ($r \geq 0.31$) but slightly lower. All four parameters showed higher values in 1997 than in 1998. With exception of moisture content, optimum endosperm starch and protein contents are very important for alveograph P/L ratio and particularly vitreous kernels and SKCS-hardness index. Increase or decrease in either starch or protein may cause dilution (lack of sufficient bonds for interaction) in the other and this results in lower values for these parameters. This was the case for 1998 where grain filling was higher at all sites. Nevertheless the higher protein at Loskop and lower protein at other sites caused starch and protein dilution respectively. Mixograph development times showed low and negative correlation with most of the parameters. However, correlation with SDS-sedimentation and moisture content were positive with the moisture content being close to intermediate. Contrary to most of the parameters, both mixograph development time and sedimentation tends to increase with increase in protein content. Also higher development times were realised in 1997 where most of the sites had higher moisture contents.

The alveograph P/L ratio showed negative correlation with mixograph development time and SDS - sedimentation with the latter being high ($r = -0.52$). This was due to the fact that lower alveograph P/L ratios were realised where the two parameters were higher, particularly at Loskop in 1998. Other correlations were positive and that with SKCS-hardness index was relatively high ($r = 0.62$). As mentioned earlier, the two parameters are influenced by optimum balance between starch and protein and thus they were both higher in 1997 than 1998. With exception of mixograph development time, SDS-sedimentation showed negative correlation with most of the parameters and correlation with SKCS-hardness index and moisture content were relatively high ($r = -0.63$) and ($r = -0.58$) respectively. This was due to the fact that sedimentation values were higher in 1998 at most of the sites, with other parameters being low particularly SKCS-hardness index and moisture content. SKCS- kernel diameter showed relatively low correlation with most of the parameters

and correlation with development time and sedimentation were negative. This was due to the fact that though genotypes had more influence in SKCS–kernel diameter, the values were slightly higher in 1997 than 1998. However, this was contrary to development time and particularly SDS–sedimentation which had relatively higher values in 1998 than 1997. SKCS–hardness index, as already discussed, also showed intermediate positive correlation ($r = 0.42$) with moisture content and this was due to 1997 when the two parameters were higher at most of the locations. Therefore very high sedimentation and mixograph development times as influenced by higher protein are not desirable. On the other hand since SKCS–hardness index was the only parameter that showed high positive correlation with alveograph P/L ratio, there is a need to insist on higher values for this parameter.

Table 6.2 Correlation coefficients of those variates retained in the final CVA with each other and the first two canonical variates.

VK	1.000						
MDT	-0.029	1.000					
P L	0.343	-0.115	1.000				
SDSS	-0.247	0.263	-0.521	1.000			
Diam	0.201	-0.102	0.280	-0.161	1.000		
HI	0.539	-0.171	0.623	-0.624	0.094	1.000	
Moist	0.304	0.317	0.267	-0.577	0.092	0.416	1.000
Cv1	-0.368	-0.073	-0.495	0.875	-0.230	-0.647	-0.883
CV2	-0.319	-0.449	-0.025	-0.396	-0.550	-0.090	-0.205
	VK	MDT	Alv. P/L	SDSS	Diam	SKCS-HI	Moist

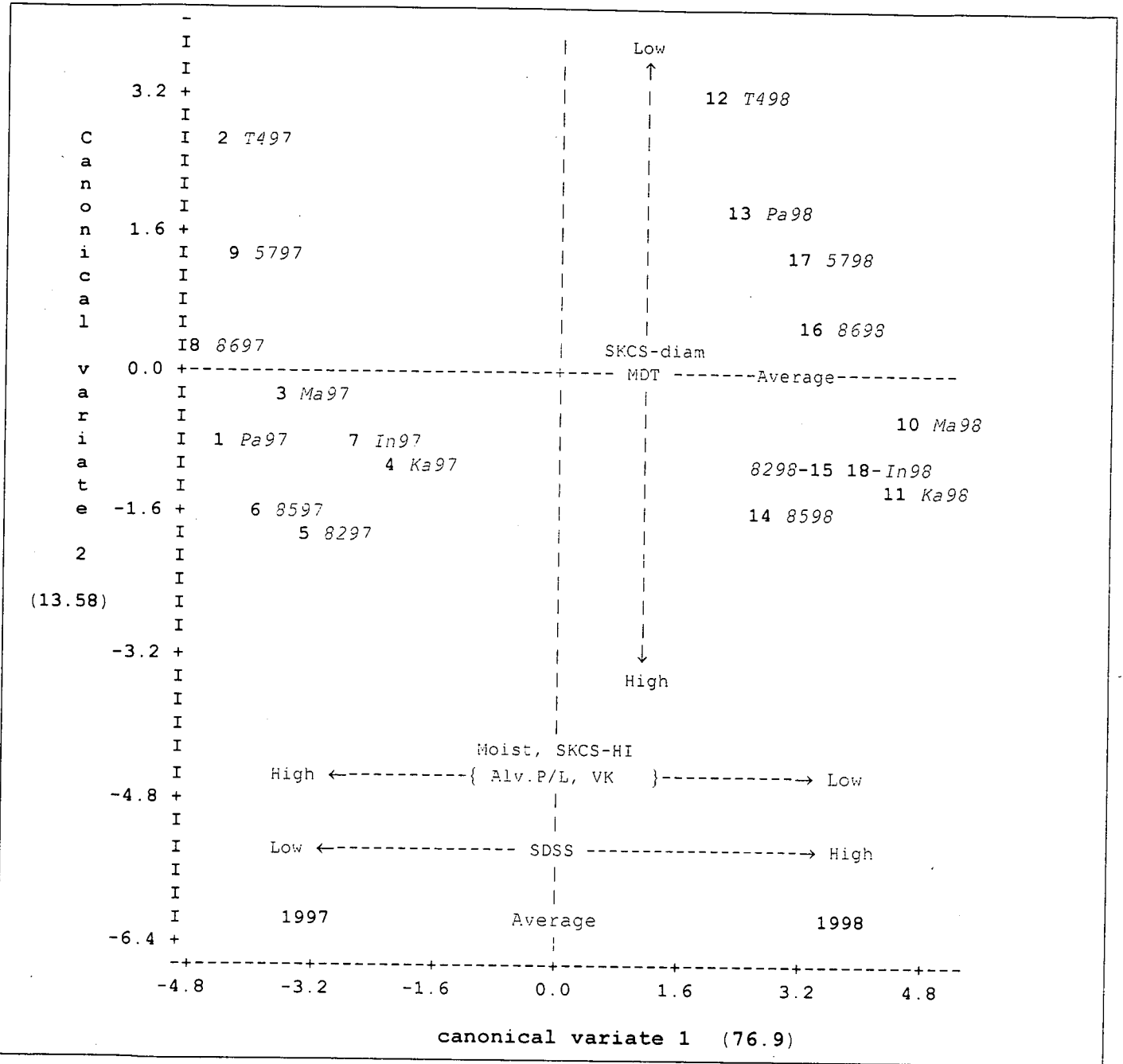
The main variates which discriminated between interaction effects CV1 (x-axis) (Figure 6.1) were SDS–sedimentation ($r = 0.875$), and moisture content ($r = -0.883$), SKCS–HI ($r = -0.647$) and alveograph P/L ratio ($r = -0.495$), which had the most significant correlation with CV1 scores. Thus, generally SDS–sedimentation values were higher and those of moisture content, SKCS–hardness index and alveograph P/L ratio lower in 1998 and vice versa in 1997. For the 1998 season it seems the environmental conditions were more optimal as revealed by higher grain filling. Therefore it also seems that gel-proteins (responsible for sedimentation) were not much influenced. That is why the SDS–sedimentation values were higher in this season despite most of the sites having low protein content for most of the genotypes. However, the low values for other parameters were due to protein and starch dilution (lack of sufficient bonds for interaction) at other sites and Loskop respectively. This is due to the fact that parameters like SKCS–hardness index and vitreous kernels are influenced by the extent of starch-protein interaction. Therefore any increase or decrease in one of the two may interfere with these parameters. Also since SKCS–hardness index and vitreous kernels lead to increase in breakflour yield, this again has a positive influence on other parameters including alveograph P/L ratio. The lower grain filling in 1997 implies less optimal environments, which may have influenced the gel-proteins and thus the realised low sedimentation values. Nevertheless for this season starch-protein interaction was not interfered as neither starch (due to higher grain filling) nor protein was

much higher at most of the sites. That is why vitreous kernels, SKCS-hardness index and alveograph P/L ratio were higher in this season. Moisture content was also higher as most of the sites had higher moisture content compared to 1998 in which only Loskop had high moisture content. This shows that in 1998 there was a delayed harvesting in other sites as compared to Loskop.

The main variates which discriminated between interaction effects for CV2 (y-axis) (Figure 6.1) were SKCS-kernel diameter ($r = -0.55$) and mixograph development time ($r = -0.449$) showing negative correlations with the CV2 scores. The CV2 accounted for only 13.6% of the total variation and this implies less contribution to the variations. This is shown by less variations among interactions for the two variates particularly development time, as shown by the scores. Therefore except for SST876 (codes 8 and 16), genotypes like T4 (2 and 12), SST57 (9 and 17), Palmiet (13) and Marico (3 and 10) showed slightly lower kernel diameter than the others. For mixograph development time, it was T4 and SST876 in 1997 and T4, Palmiet and SST876 in 1998, which showed lower development times compared to other genotypes. Also the 1998 season showed slightly higher development times for most of the genotypes. However, in both seasons, except for Marico, other genotypes that had low diameter and/or development time also showed low sedimentation values.

Table 6.3 Mean values of the 18 G x E interactions (two years) for all variates considered in the canonical variate analysis.

SEAS x GEN	VK	MDT	P/L	SDSS	Diam	HI	Moist
1 Pa97	78.44	2.500	0.6439	55.28	2.814	73.45	11.69
2 T497	69.56	1.261	0.7750	45.17	2.574	70.51	11.52
3 Ma97	81.44	3.862	0.6450	59.50	2.584	68.98	11.71
4 Ka97	74.11	2.578	0.4672	69.11	2.676	62.07	11.89
5 8297	83.78	2.750	0.5433	62.44	2.751	75.70	11.60
6 8597	81.89	2.664	0.8134	57.28	2.911	76.78	11.43
7 In97	80.64	2.920	0.6267	62.43	2.716	68.52	11.47
8 8697	73.78	1.983	0.6650	50.89	2.758	73.39	11.67
9 5797	69.44	3.234	0.5039	52.94	2.487	69.57	11.69
10 Ma98	69.33	2.990	0.3843	87.05	2.461	59.58	9.87
11 Ka98	68.95	2.576	0.3552	88.76	2.642	54.71	10.12
12 T498	60.95	1.381	0.5257	63.95	2.442	60.78	9.82
13 Pa98	58.82	1.838	0.4905	68.66	2.538	60.43	9.83
14 8598	69.33	2.610	0.6376	78.95	2.821	63.41	9.97
15 8298	62.10	2.490	0.3814	81.95	2.660	61.23	10.00
16 8698	63.83	1.853	0.3829	76.60	2.621	58.16	9.86
17 5798	67.81	2.743	0.3076	75.14	2.374	61.05	9.91
18 In98	65.24	2.705	0.4743	84.62	2.743	54.98	9.95
Mean	70.62	2.486	0.5272	68.63	2.639	64.74	10.71



NB: The most distinct contrast is between the two seasons (CV1) - the pattern for cultivars within season is very similar - compare points 2 Vs 12(T4) and 7 Vs 18 (Inia)

Figure 6.1 AMMI biplot of mean scores of genotypes - CVA 1997/98 for 9 genotypes, T4 = T4, 57 = SST57, 86 = SST876, Ma = Marico, Pa = Palmiet, In = Inia, Ka = Kariega, 82 = SST822 and 85 = SST825. For the years, 97 = 1997 and 98 = 1998.

In conclusion, it was shown that the pattern for genotypes within seasons was very similar. This is shown by codes, 2 and 12 (T4), 7 and 18 (India), 6 and 14 (SST825) and 3 and 10 (Marco). This shows, despite the environmental conditions having influence on quality parameters, genotype potential should be the prime objective together with positive environment interactions. In ascending order, genotypes like T4, Palmiet and SST876 had less potential for most of the parameters, particularly T4 and Palmiet. Nevertheless Palmiet showed positive environment interactions in some locations and it may perform well. Also the performance was intermediate at most of the sites when the environments were not as ideal as it was for 1997. SST57 showed intermediate potential, whereas Marico, Kariaga, SST822, SST825 and Inia showed intermediate to higher potentials. Therefore these genotypes may give desirable results at most of the sites for various parameters despite seasonal environment variations.

CHAPTER 7

CONCLUSIONS

The AMMI model proved to be the most effective in describing the influence of genotypes, environments as well as genotype x environment interaction for all the quality parameters. The three sources of variation were significant at $p < 0.01$ for most of the parameters. This implied presence of variations among genotypes, environmental conditions and various interaction effects in their response to quality parameters. However, by far, environment was the most dominant factor that contributed to the variations in most of the parameters. This was particularly true for protein content (including quality) and endosperm starch content. For the genotypes, T4 ranked lower for most of the parameters and it may be risky for large commercial production. However, the same genotype ranked intermediate to higher for single kernel characterisation system—hardness index, farinograph absorption and alveograph P/L ratio. This is due to its property of low grain filling and protein content that does not interfere much with starch-protein interaction, which is important for these parameters. Therefore the genotype may be used as a donor parent in improvement of these parameters. Other genotypes, which also showed less potential, include, SST65, SST55, SST876 and Palmiet. These genotypes should be grown under conditions where they are expected to perform well. An example is Palmiet at Loskop, Koedoeskop and BullHill where it showed positive environment interactions (1998) for loaf volume at 12% protein. Also if the protein yield is expected to be close to optimum (not very low) as it was in 1997, Palmiet may perform intermediate for most of the parameters. SST55 and SST65 showed higher loaf volumes at 12% protein and may be used to improve this parameter. Nevertheless they were lower in other parameters, particularly mixograph development time and point score, and sedimentation. Kariega ranked lower for alveograph P/L ratio in both years and may need improvement for this parameter. However, this genotype together with SST38, SST57, SST822, SST825, Inia and Marico showed intermediate to higher rank for most of the parameters. Therefore they may be reliable at most of the sites unless environment becomes less optimal or negative environment interactions occur.

The environment effect includes that between years and locations and may have different influences on quality parameters. Starting with years, it seems the main difference was associated with grain filling and protein content. The 1997 season showed less grain filling but the protein contents were close to optimum at most of the sites. This agrees with findings by Ivanov *et al.* (1998) who found that, year conditions highly influenced the total protein content and all its fractions (composition). Despite this season showing low SDS-sedimentation values, it seems the starch-protein interactions and glutenin-to-gliadin ratios were not much influenced. As a result, this season showed higher values for most of the parameters related to protein and starch-protein interaction. Nevertheless for 1998 the situation was reversed, as the grain filling was higher at all sites. Genotypes at Loskop had very high protein content and most of the sites had lower protein

content for most of the genotypes. This caused negative influence on most of the parameters. Therefore management practices and cultivar selection to ensure optimum grain filling and protein content are important to minimise variations between years. For the locations, Loskop was the site that showed the most contrast with other sites. This is due to the fact that for other sites, management practices should be aimed to increase fertility and thus nitrogen yield. The higher hectoliter and kernel masses at most of the sites implies higher grain yields and this was the main cause of realised low protein content. This is from the fact that a negative relationship is most often observed between grain yield and protein content (Johnson *et al.*, 1985; Koekemoer, 1997). However, at Loskop fertility should be controlled to reduce nitrogen yield especially when the conditions are ideal. Also at Loskop, Koedoeskop (warmer areas) and Barkly West, cultivar selection and timing of seeding are necessary to ensure that grain filling is not influenced or does not coincide with higher temperature. Again this is due to the fact that, temperatures $\geq 30^{\circ}\text{C}$ is associated with an increase in flour protein content (Van Lill, 1992).

Genotype x environment interactions were observed for protein content and related parameters. Grain filling was also responsible for this interaction particularly for the parameters influenced by starch-protein interaction. For each parameter, the genotype and environment interactions are well explained by the AMMI biplots. However, Prieska, and to a lesser extent Douglas showed less environment interactions compared to other sites. The correlation matrix showed low correlation between breakflour yield and farinograph absorption. This suggests that breakflour yield is not a reliable indicator of higher absorption and it is better to rely on other parameters like SKCS-hardness index and vitreous kernels. Both grain and flour protein methods showed similar effects, but the grain method (GPC-single kernel) and flour method (FPC-NIR) seem to be more efficient. Under high yielding environments, soil fertility is important to ensure nitrogen supply for plant growth and storage protein. That is why protein content showed negative correlation with indicators of higher grain filling like hectoliter mass, kernel mass and kernel diameter. The negative correlation between protein content and alveograph P/L ratio and loaf volume at 12% protein, indicates very high protein (above ideal 12%) which is not desirable for the two parameters especially loaf volume. Therefore direct selection for higher values of the two parameters is important. For alveograph P/L ratio, higher SKCS-hardness index is also important and for loaf volume it is mixograph development time and alveograph-strength which is important.

The canonical variate analyses for genotypes, showed that 10 parameters were mainly responsible for the variations among genotypes. Mixograph development time, mixograph point score, alveograph P/L ratio, alveograph strength (W/6.54), loaf volume at 12% protein and SDS-sedimentation occurred in both two seasons (1997 and 1998). However, with ideal environments as it was in 1998; breakflour yield, kernel mass (TKM and SKCS-W) and SKCS-diameter were also responsible for genotype variation. Therefore for all these parameters, genetic potential is imperative for desirable values though environment may have a large influence particularly for breakflour yield, kernel mass (TKM and SKCS-W) and SKCS-diameter. The

canonical variate analysis for environments showed more parameters, about 13 being influenced by the environment variations. Hectoliter mass, vitreous kernels, farinograph absorption and moisture content also occurred in both seasons (1997 and 1998). This shows that these parameters are more influenced by the environment variations between locations than seasons. On the other hand, protein content (grain and flour), kernel mass and diameter, flour colour, mixograph development time and loaf volume (at normal and 12% protein), wet gluten content at 12% protein, alveograph–strength (W/6.54) and SKCS–hardness index, all occurred in one season only (either 1997 or 1998). This implies that the variations between seasons had more influence on these parameters. Therefore management practices to ensure protein content closer to optimum (12%) and increased grain filling are important as this will also result in optimal starch-protein interaction. Three characteristics (protein content closer to 12%, increased grain filling and optimum starch-protein interaction) are responsible for the variations in most of the parameters. These include; alveograph–strength and P/L ratio, SKCS–hardness index, loaf volume at 12% protein, kernel mass and diameter, flour colour, mixograph development time, breakflour yield, hectoliter mass, vitreous kernels and farinograph absorption. This mainly shows a reduced environment influence on most of these parameters and thus optimum values will be achieved.

The canonical variate for genotype x environment interaction showed more parameters being involved and for both seasons (1997 and 1998) it is a total of 14 parameters. However, only mixograph development time, breakflour yield, SDS-sedimentation and moisture content occurred in both 1997 and 1998. This shows more interaction effects for these parameters with environmental variations between sites than seasons. Other parameters like hectoliter mass, vitreous kernels, farinograph absorption, alveograph P/L ratio, SKCS–hardness index, protein content (grain and flour), wet gluten content at 12% protein, mixograph point score, alveograph–strength and loaf volume at 12% protein, all occurred either in 1997 or 1998. This shows that seasonal variation may reduce interaction effects for these parameters. This is because, probably protein content and its interaction with starch is responsible for optimum values for most of these parameters. However, the interaction involved most of the parameters, which were also influenced by genotypes and environments. Therefore in addition to management practices, identification of positive genotype x environment interactions for quality parameters at various locations is important. Ultimately, as we have seen, wheat quality involves a number of parameters, which are influenced by genotype, environment and their interactions. The three sources of variation show different influences on the quality parameters, particularly environment which varies among locations and seasons. The quality parameters themselves do not show a similar trend as an increase in one parameter may have a negative/positive influence on others. This becomes pronounced with large deviations in environmental conditions from what is expected. Table 7.1 shows the schematic presentation of classes and grades of bread wheat for South Africa.

Table 7.1 Classes and grades of bread wheat for South Africa (Guidelines for wheat Production in the winter rainfall region)

Subclass	BP	BS	BL	
Protein (12% mb)	≥ 12	≥ 10	≥ 9	
Falling number (min)	250s	250s	250s	
Grade				
Kg/hl min	79	BPS	BSS	BLS
	76	BP1	BS1	BL1
	74	BP2	BS2	BL2
	70	UT	(Utility grade – Falling number (min) 150 s)	

Table 7.2 Grades of the genotypes at each location for 1997 and 1998

1997	BH	BW	PR	HT	DO	LO	KK
SST876	BPS	BSS	BSS	BPS	BSS	BS2	
Palmiet	BPS	BP1	BSS	BPS	BSS	BS2	
SST822	BPS	BP1	BSS	BPS	BSS	BP2	
T4	BSS	BS1	BSS	BP1	BSS	BS2	
Marico	BSS	BS1	BSS	BP1	BSS	BS2	
Inia	BPS	BP1	BSS	BP1	BPS	BP2	
SST55	BPS	BS1	BSS	BPS	BSS	BS2	
SST825	BP1	BP1	BSS	BSS	BSS	BS2	
SST65	BP1	BS1	BSS	BP1	BSS	BS2	
SST57	BP1	BS1	BSS	BP1	BSS	BS2	
Kariega	BS1	BS1	BS1	BP2	BS1	BS2	
1998							
SSS876	BS1	BP1	BSS	BSS	BSS	BPS	BS1
Palmiet	BS1	BS1	BSS	BS2	BSS	BP1	BS1
SST822	BS1	BS1	BSS	BS1	BSS	BPS	BS1
T4	BS1	BS1	BSS	BS2	BS1	BP1	BS1
Marico	BS2	BP1	BSS	BP2	BS1	BP1	BS1
Inia	BS1	BP1	BSS	BS1	BPS	BPS	BSS
SST825	BS1	BP2	BSS	BSS	BSS	BP1	BS1
SST57	BS2	BP2	BSS	BS1	BS1	BP1	BS2
SST38	BS1	BP1	BSS	BSS	BSS	BPS	BSS
Kariega	BS1	BP1	BSS	BS2	BS1	BP1	BS1

According to grading requirements (Table 7.2), Douglas and particularly Prieska gave the most stable grades. This is due to the fact that most of the genotypes were a BSS grade especially in 1997. However, in 1998, some of the genotypes at Douglas were a BS1. BullHill, Hopetown and Barkly West showed intermediate stability. At Barkly West in both seasons, most of the genotypes were BP1/BS1 with few deviating to BP2 particularly in 1998. At BullHill and Hopetown, most of the genotypes in 1997 were BPS, BP1 and a few BSS, which was due to high protein content. However, in 1998 most were BS1 and BS2 due to low protein content. This indicates the two sites to be less stable between seasons. Since Koedoeskop was only included in 1998, it seems to be similar to BullHill and Hopetown. However, Loskop showed to be highly unstable and contrasted a lot with other sites. In 1997 it had a low BS2 grade for all genotypes. In 1998 the grades were better for most of the genotypes as they were BPS and BP1. Therefore at this site the environment effect seems to be higher such that genotypes do not show much difference. Despite Loskop showing good grade, as was the case for 1998, some of the quality parameters like mixing time and loaf volume were not optimum. SST825, SST822, Inia, SST38, SST57, SST876 and to a lesser extent Palmiet were stable. These genotypes were BPS, BSS, BF1 or BS1 grades. Genotypes like Kariega, Marico, SST55, SST65 and T4 were less stable and depending on location or season they may be BS2 grade. However, above all management practices to ensure higher grain filling and optimum protein content is important.

The complexity of wheat quality starts at the breeder's level, in developing cultivars, which will meet all the quality requirements and show less deviations at various environments. This is supported by the study on the effect of environment on the yield, bread-making quality and quantitative protein composition of five South African winter wheat cultivars (Van Lill, 1992). He reported that, genotype accounted for very little of the total variation noted for these characteristics, signifying the difficulty of simultaneous improvement through conventional breeding. For the farmers it is also risky if the environments deviate more than is expected and cultivars show negative environment interactions. Finally for the processing industries, unless they get good quality wheat from farmers, they can't deliver good quality products. Therefore there is a need for the three groups, particularly researchers and farmers to work closer together. This will help to identify which cultivars and management practices need to be implemented at certain locations in order to have good quality crops. Also, since farmers are risk takers, despite following all the recommendations, environmental deviation may cause their products to have reduced/poor quality. This is supported by a national survey of South African wheat cultivars conducted by Fowler (1978) who concluded that, protein content and typical quality characteristics of cultivars were subjected to variability. In such a case, the government and processing industries should have a programme of supporting such farmers.

CHAPTER 8

SUMMARY

The primary aim of this study was to examine the effect of environment, genotype and their interaction on bread-making quality characteristics of irrigated spring wheat cultivars. The wheat samples were obtained from trials conducted in irrigation areas by the Small Grain Institute (Breeding Department), during 1997 and 1998. The trials were conducted at six localities in 1997 and seven in 1998. Among the localities five were in cooler and two in warmer irrigation areas. For the cultivars nine were common in both years but two were added in 1997, and one in 1998 making a total of 11 and 10 respectively. The source of cultivars was Small Grain Institute (5) and Sensako (7). Trials were conducted at experimental stations or farms of collaborators where the soil and climate are representative of a specific area. A randomised block design with four replications was used. Interrow spacing was maintained at 0.17 m and planting rate varied according to 1000 kernel mass of a specific cultivar. This was to ensure that a uniform stand of plants per m^{-2} is achieved. Fertilizers were applied according to recommendations on the basis of individual soil analyses. Other management practices were performed as required and a net plot of six rows ($5.1 m^{-2}$) was harvested. The samples were analysed for a total of 21 quality characteristics, important for bread-making.

The statistical analysis of the results showed that both genotype, environment and their interaction had significant influence on quality characteristics. This implied presence of variations among genotypes, environmental conditions as well as interaction effects in their response to quality parameters. However, above all, environment was the most dominant factor, which contributed to the variation for most of the characteristics. Protein content (particularly flour) closer to 12% (optimum) and with good quality was very important. This character together with higher grain filling to ensure optimum starch-protein interaction were necessary for cultivars, sites and interaction effects to show good quality characteristics. Generally climatic conditions particularly temperature showed interference with quality parameters especially in warmer areas. This is due to the fact that high temperature has an influence on protein composition and definitely the ratios of glutenin-to-gliadin part of the protein. However, for cooler areas, the protein quality was probably not affected, but the higher grain filling realised at some of the sites caused protein content to be low. This is again due to the fact that in high potential environments, nitrogen (N) is first utilised for maximum plant growth and yield. Thereafter the excess N is then translocated to the grain for storage as protein. Considering the quality parameters themselves, some showed negative correlations with others. This indicates that improvement of one characteristic will have a negative influence on the other, and this is the cause of breeders delay in releasing new cultivars. By using the canonical variate analysis (component of AMMI), it was possible to see which characteristics group together in discriminating among genotypes, locations and

interaction effects. Therefore with this analysis it was possible to determine which characters need appropriate genotype, environment or interaction effects to get optimum values.

From the study results we can recommend that, T4, which ranked lower for most of the quality parameters may be risky for very large commercial production. However, this genotype may be used as a donor parent for improvement of alveograph P/L ratio for which it showed good results. Other genotypes, which also showed less potential, include, SST65, SST55, SST876 and Palmiet. These genotypes should be grown under conditions where they are expected to perform well. An example is Palmiet at Loskop, Koedoeskop and BullHill where it showed positive environment interactions for loaf volume at 12% protein. Also with environment protein yield closer to optimum (not very low), Palmiet may perform intermediately for most of the parameters. SST55 and SST65 showed higher loaf volumes at 12% protein and may be used to improve this parameter. Nevertheless they were lower in other parameters particularly mixograph development time, mixograph point score and SDS-sedimentation. Kariega ranked lower for alveograph P/L ratio in both years and may need improvement for this parameter. However, this genotype together with SST38, SST57, SST822, SST825, Inia and Marico showed intermediate to higher rank for most of the characteristics. Therefore they may be reliable at most of the sites unless environment becomes less optimal or negative environment interactions occur.

For the locations, Loskop was the site that showed the most contrast with other sites. This is due to the fact that this site had values for mixograph development time, and to a lesser extent mixograph point score above recommended values for both years. Also the high protein realised at this site implies management practices should be aimed at reducing fertility and thus nitrogen yield. Therefore at Loskop, Koedoeskop (warmer areas) and Barkly West, cultivar selection and timing of seeding are necessary to ensure that grain filling is not influenced or does not coincide with higher temperatures. The higher hectoliter and kernel masses at most of the sites except Loskop implies higher grain yields and this was the main cause of realised low protein content. Therefore for other sites in addition to cultivar selection, management practices to increase fertility and thus protein content are necessary particularly at Prieska. Also since leaching may lose fertility, there is a need to control the irrigation water. Genotype x environment interactions were observed for protein content and related parameters. Grain filling was also responsible for this interaction particularly for the parameters influenced by starch-protein interaction. However, Prieska, and to a lesser extent Douglas showed less environment interactions compared to other sites. Therefore at Loskop, Koedoeskop, Hopetown, BullHill and Barkly West identification of genotypes with positive environment interactions will be necessary.

The canonical variate analyses for genotypes showed that 10 parameters were mainly responsible for the variations among genotypes. Mixograph development time, mixograph point score, alveograph P/L ratio, alveograph strength, loaf volume at 12% protein, SDS-sedimentation, breakflour yield, kernel mass (TKM

and SKCS-W) and SKCS-diameter were responsible for genotype variation. Therefore for all these parameters, identification of cultivars, which will give desirable values, is important. Breeders may give them priority when making selection in their programmes. The canonical variate analysis for environments showed more parameters, about 13 being influenced by the environment variations. However, most of them were associated with protein content and grain filling. Most of the characteristics, which discriminated the interaction effects, were those under genotype and environment. Therefore identification of cultivars, which will give good results, and management to ensure higher protein with good quality and higher grain filling, are necessary. Taking into account the grading of wheat Prieska and Douglas showed to be stable and may give a BSS grade for most of the cultivars. BullHill, Hopetown, Barkly West and Koedoeskop had intermediate stability and gave BS1 and BS2 grade for most of the cultivars particularly in 1998 due to low protein content. Loskop was alone showing to be highly unstable as it gave BS2 in 1997 for all cultivars, and in 1998 they were BPS and BP1. However, for this site despite the grade being higher, quality characteristics may show low values. Therefore cultivar selection and management are important to ensure that the grades are maintained and quality characteristics to be closer to optimum. Also mixing the products, particularly from Loskop and to a lesser extent BullHill, Barkly West, Hopetown and Koedoeskop when the environments are not optimal with those of Prieska and Douglas will improve the quality. The probable cultivars to be mixed are SST825, Inia, SST822, SST57, SST38 and to a lesser extent Marico and Kariega. Therefore there is a need for processing industries and particularly researchers and farmers to work closer together. This will help to identify which cultivars and management practices need to be implemented at certain locations in order to have good quality crops. Also, since farmers are risk takers, despite following all the recommendations, environmental deviation may cause their products to have reduced/poor quality. In such a case, the government and processing industries should have a programme of supporting such farmers.

OPSOMMING

Die primêre doel van hierdie studie was om die effek van die omgewing, genotipe en die interaksie daarvan te bepaal op broodbak kwaliteit eienskappe van lente besproeiings koring cultivars. Die koring cultivars is verkry vanaf proewe wat in die besproeiings areas gedoen is deur die Kleingraan Instituut (telings afdeling) gedurende 1997 en 1998. Die proewe is uitgevoer in ses lokaliteite in 1997 en sewe in 1998. Vyf van die lokaliteite was in die koeler en twee in die warmer besproeiings areas. Nege cultivars was gemeenskaplik vir albei jare, maar daar was twee ekstra in 1997, en een in 1998, wat 'n totaal van 11 cultivars vir 1997 en 10 vir 1998 gee. Die bron van cultivars was die Kleingraan Instituut (5) en Sensako (7). Proewe is gedoen op navorsings plase of plase van samewerkers waar die grond en klimaat verteenwoordigend is van die spesifieke area. 'n Gerandomiseerde blok ontwerp met vier herhalings is gebruik. Interry spasiering was 0.17 m en plant digtheid is bereken volgens die 1000 korrel massa van die cultivars sodat 'n univorme plant stand per area verkry is. Bemesting is gedoen volgens grond analises. Ander bewerkings praktyke is uitgevoer soos nodig, en uiteindelik is ses rye (5 m^{-1}) geoes. Die monsters is geanaliseer vir 'n totaal van 21 kwaliteits eienskappe wat belangrik is vir broodbak kwaliteit.

Die statistiese analise van die resultate het aangetoon dat beide genotipe, omgewing en hulle interaksie 'n betekenisvolle invloed het op kwaliteits eienskappe. Dit het die aanwesigheid van variasie aangetoon tussen genotypes, omgewing en die interaksie effekte in hulle reaksie op kwaliteits eienskappe. Omgewing was die dominante faktor wat bygedra het tot variasie vir meeste van die eienskappe. Proteïen inhoud (veral meel proteïen) na aan 12% (optimum) en met goeie kwaliteit, was baie belangrik. Hierdie eienskap, tesame met hoër graanvul wat optimum stysel-proteïen interaksie gee, was nodig vir cultivars, omgewings en interaksie effekte voordat goeie kwaliteits eienskappe getoon is. Oor die algemeen het omgewing, en veral temperatuur 'n groot invloed gehad op kwaliteits eienskappe, veral in die warmer areas. Dit is omdat hoër temperatuur 'n invloed het op proteïen samestelling en veral die glutenien tot gliadien verhouding. Maar vir die koeler areas is die proteïen kwaliteit waarskynlik nie beïnvloed nie, maar die hoër graanvul wat gerealiseer is by party areas het laer proteïen inhoud veroorsaak. Dis weereens a.g.v. die feit dat in hoër potensiaal omgewings stikstof (N) eerste gebruik word om maksimum plant groei en opbrengs te verseker. Daarna word die orige N gebruik om proteïen te stoor. Vir die kwaliteits eienskappe was daar 'n aantal negatiewe korrelasies. Dus sal seleksie vir een eienskap 'n ander negatief beïnvloed, wat veroorsaak dat teling vertraag word. Deur die gebruik van 'n kanoniese variaat analise ('n komponent van AMMI), was dit moontlik om te sien watter eienskappe saam groepeer tussen genotypes, omgewings en interaksie effekte. Met hierdie analise was dit moontlik om te sien watter eienskappe sekere genotypes, omgewings of interaksie benodig om optimum waardes te kry. N.a.v. hierdie studie word aanbeveel dat T4, wat laag op die rangorde was vir meeste kwaliteits eienskappe riskant is vir kommersiële produksie. Die cultivar kan wel gebruik word vir die verbetering van alveogram P/L verhouding, waar dit goeie waardes gehad het. Ander genotypes wat ook

swak vertoon het was, SST65, SST55, SST876 en Palmiet. Hierdie genotipes moet net in omgewings geplant word waar dit goed sal presteer. Bv. Palmiet by Loskop, Koedoeskop en BullHill waar dit positiewe omgewings interaksie getoon het vir brood volume by 12% proteïen. Ook waar proteïen inhoud optimaal is (nie te laag nie) sal Palmiet gemiddeld presteer vir meeste eienskappe. SST55 en SST65 het hoër brood volumes getoon by 12% proteïen en kan gebruik word om hierdie eienskap te verbeter. Maar hulle het weer swakker presteer vir ander eienskappe veral miksogram ontwikkelings tyd en punt waarde en SDS sedimentasie. Kariëga het laer waardes gehad vir P/L verhouding in beide jare en hierdie eienskap sal waarskynlik verbeter moet word. Tog het hierdie genotipe saam met SST38, SST57, SST822, SST825, Inia en Marico gemiddeld tot effens beter vertoon vir meeste eienskappe. Hulle mag daarom betroubaar wees in meeste omgewings behalwe as die omgewing verswak of negatiewe interaksies met die omgewing voorkom.

Vir die omgewings het Loskop die meeste kontras met die ander getoon. Dit was a.g.v. die feit dat hierdie omgewing waardes bo die aanbevole waardes gehad het vir miksogram ontwikkelingstyd en tot 'n mindere mate die punt waarde vir beide jare. Die hoë proteïen inhoud wat gerealiseer is vir hierdie omgewing dui aan dat bestuurspraktyke gerig moet wees daarop om die grond vrugbaarheid te verlaag sodat N opbrengs verlaag kan word. Daarom by Loskop, Koedoeskop (warmer areas) en Barkly Wes is dit nodig om planttyd te reel sodat graanvul periode nie beïnvloed word of ooreenstem met die warmste tye nie. Die hoër hektoliter massa en korrel massas by meeste lokateite behalwe Loskop dui hoër graan opbrengs aan, wat die hoof rede was vir verlaagde proteïen inhoud. Daarom, vir hierdie lokaliteite, behalwe vir cultivar seleksie, moet bestuurs praktyke aangepas word om grondvrugbaarheid te verhoog, en gevolglik proteïen inhoud. Stikstof mag verlore gaan a.g.v. logging, en besproeiing moet daarom effektief toegedien word. Genotipe x omgewing interaksies is gesien vir proteïen inhoud en verwante eienskappe. Graanvul was ook verantwoordelik vir hierdie interaksie veral vir eienskappe wat beïnvloed is deur stysel-proteïen interaksie. Maar, Prieska, en tot 'n mindere mate Douglas het minder interaksies aangetoon in vergelyking met ander lokaliteite. Daarom, by Loskop, Koedoeskop, Bullhill en Barkly Wes is identifikasie van cultivars met positiewe omgewings interaksies nodig. Die kanoniese variaat analise vir genotypes het aangetoon dat 10 eienskappe verantwoordelik is vir variasie tussen genotipes. Miksogram ontwikkelingstyd en punt waarde, alveogram P/L verhouding, alveogram sterkte, brood volume by 12% proteïen, SDS-sedimentasie, breekmeel opbrengs, korrel massa (TKM en SKCS-W) en SKCS deursnee was verantwoordelik vir die variasie. Daarom, vir al hierdie eienskappe is identifikasie van genotipes nodig wat gewenste waardes sal gee. Telers moet voorkeur hieraan gee as seleksies in programme gemaak word. Die kanoniese variaat analise vir omgewings toon dat ongeveer 13 eienskappe verantwoordelik is vir omgewings variasies. Meeste van hulle was geassosieer met proteïen inhoud en graanvul. Meeste van die eienskappe wat gediskrimineer het tussen interaksie effekte was dieselfde as die vir genotipe en omgewing. Daarom sal identifikasie van cultivars wat goeie resultate sal gee, sowel as bestuurspraktyke om hoër proteïen met goeie kwaliteit en hoër graanvul te gee, noodsaaklik. Met die gradering was cultivars by Prieska en Douglas stabiel en sal dit BSS graad gee vir meeste cultivars.

Bullhill, Hopetown, Barkly Wes en Koedoeskop gee gemiddelde stabiliteit met BS1 en BS2 gradering vir meeste cultivars, veral in 1998 a.g.v. lae proteïen. Loskop was hoogs onstabiel met BS2 gradering in 1997 vir alle cultivars, en in 1998 BPS en BP1. Ten spyte van hoër gradering kan sekere kwaliteits eienskappe swak wees. Daarom is cultivar seleksie en bestuur belangrik om te verseker dat grade behou word, en dat kwaliteits eienskappe naby optimum is. Produkte kan vermeng word vir Loskop, en tot 'n mindere mate ook Bullhill, Barkly Wes, Hopetown en Koedoeskop met Prieska en Douglas om kwaliteit te verbeter as die omgewings nie optimaal is nie. Die waarskynlike cultivars wat gemeng moet word is SST825, Inia, SST822, SST57, SST38 en tot 'n mindere mate Marico en Kariëga. Daar is gevolglik 'n behoefte aan samewerking tussen die proesserings bedryf, die navorsers en die boere. Dit sal help om goeie cultivars en bestuurspraktye te identifiseer vir sekere lokaliteite om goeie kwaliteit koring te produseer. Boere is risiko nemers, en al volg hulle aanbevelings, kan ongewings afwykings veroorsaak dat hulle produkte swak of verlaagde kwaliteit het. In hierdie geval moet die staat en die industrie 'n ondersteunings program hê vir sulke boere.

Bullhill, Hopetown, Barkly Wes en Koedoeskop gee gemiddelde stabiliteit met BS1 en BS2 gradering vir meeste cultivars, veral in 1998 a.g.v. lae proteïen. Loskop was hoogs onstabiel met BS2 gradering in 1997 vir alle cultivars, en in 1998 BPS en BP1. Ten spyte van hoër gradering kan sekere kwaliteits eienskappe swak wees. Daarom is cultivar seleksie en bestuur belangrik om te verseker dat grade behou word, en dat kwaliteits eienskappe naby optimum is. Produkte kan vermeng word vir Loskop, en tot 'n mindere mate ook Bullhill, Barkly Wes, Hopetown en Koedoesop met Prieska en Douglas om kwaliteit te verbeter as die omgewings nie optimaal is nie. Die waarskynlike cultivars wat gemeng moet word is SST825, Inia, SST822, SST57, SST38 en tot 'n mindere mate Marico en Kariëga. Daar is gevolglik 'n behoefte aan samewerking tussen die prosesserings bedryf, die navorsers en die boere. Dit sal help om goeie cultivars en bestuurspraktye te identifiseer vir sekere lokaliteite om goeie kwaliteit koring te produseer. Boere is risiko nemers, en al volg hulle aanbevelings, kan ongewings afwykings veroorsaak dat hulle produkte swak of verlaagde kwaliteit het. In hierdie geval moet die staat en die industrie 'n ondersteunings program hê vir sulke boere.

Appendix 1 Genotype means for 1997

NG	Genotype	FLY	HLM	TKM	Diam	BFLY	VK	HI	SKCS-W	FPC-LECO	FPC-NIR	FABS	GPC-WH
1	Palmiet	74.07	79.27	40.84	2.814	19.69	78.44	73.45	41.34	12.31	11.97	62.88	12.63
2	SST65	75.24	77.95	39.49	2.666	23.15	79.33	63.55	39.62	12.17	12.02	61.19	12.46
3	SST55	75.89	78.89	42.91	2.739	24.42	80.44	60.23	42.65	11.71	11.59	60.97	12.32
4	T4	75.70	78.54	35.39	2.574	23.32	69.56	70.51	35.34	10.95	10.69	63.27	11.23
5	Marico	77.33	78.16	38.09	2.584	24.24	81.44	68.98	38.83	12.01	11.86	59.40	12.44
6	Kariega	76.38	76.72	37.72	2.676	25.35	74.11	62.07	38.85	12.09	11.67	60.82	12.31
7	SST822	74.98	79.11	39.88	2.751	22.68	83.78	75.70	40.21	12.63	12.18	62.60	12.81
8	SST825	75.86	78.96	40.66	2.911	20.19	81.89	76.78	40.90	12.56	11.76	64.18	12.34
9	Inia	74.66	78.54	39.71	2.716	22.45	80.64	68.52	40.13	13.27	12.65	62.29	13.21
10	SST876	76.99	80.36	39.22	2.758	20.92	73.78	73.39	39.95	12.02	11.49	62.37	11.69
11	SST57	75.84	77.92	33.59	2.488	23.12	69.44	69.57	33.92	12.41	11.67	59.51	12.23
	LSD(0.05)	0.724	0.897	1.513	0.067	0.819	5.543	2.74	1.405	0.705	0.798	0.959	0.637
NG	Genotype	LFV12%	SDSS	WGC12%	FLN	MDT	MPT	P/L	W	Strength	FCL	Moisture	
1	Palmiet	952.8	55.28	33.61	288.1	2.50	3.33	0.644	205.4	31.41	3.38	11.69	
2	SST65	975.3	59.66	34.71	283.7	2.03	2.06	0.374	194.3	29.72	1.70	11.83	
3	SST55	968.7	63.31	34.05	278.7	2.12	2.17	0.386	175.4	26.83	1.52	11.71	
4	T4	838.7	45.17	32.20	280.4	1.26	1.00	0.775	107.3	16.41	1.87	11.52	
5	Marico	936.5	59.50	30.97	295.6	3.86	4.89	0.645	256.2	39.19	1.34	11.71	
6	Kariega	951.2	69.11	33.62	286.3	2.58	3.50	0.467	228.9	34.99	1.57	11.89	
7	SST822	944.1	62.44	34.37	288.7	2.75	3.61	0.543	216.3	33.07	2.80	11.60	
8	SST825	935.0	57.28	34.45	292.9	2.66	3.60	0.813	266.2	40.71	2.55	11.43	
9	Inia	974.1	62.43	34.99	284.7	2.92	4.04	0.627	268.3	41.03	2.73	11.47	
10	SST876	913.8	50.89	34.24	277.2	1.98	2.00	0.665	193.6	29.60	1.38	11.67	
11	SST57	899.6	52.94	33.38	302.1	3.23	3.56	0.504	198.8	30.39	1.72	11.69	
	LSD(0.05)	30.59	2.643	1.834	21.59	0.194	0.53	0.083	27.72	4.238	0.632		

Appendix 2 Genotype means for 1998

NG	Genotype	FLY	HLM	TKM	Diam	BFLY	VK	HI	SKCS-W	FPC-LECO	FPC-NIR	FABS	GPC-LECO	GPC-FL
1	Marico	75.93	76.73	37.21	2.46	24.01	69.33	59.58	35.26	12.42	11.75	60.37	13.17	12.49
2	Kariega	76.73	77.46	39.75	2.64	24.89	68.95	54.71	37.70	12.70	11.88	62.48	13.32	12.60
3	T4	75.53	77.52	34.19	2.44	25.06	60.95	60.78	32.88	11.77	11.08	63.12	12.69	12.01
4	Palmiet	74.38	77.56	37.42	2.54	23.13	58.82	60.43	35.01	11.81	11.38	62.57	12.90	12.18
5	SST825	74.93	77.85	40.07	2.82	20.48	69.33	63.41	38.66	12.43	12.34	64.40	13.21	12.57
6	SST822	75.35	78.31	39.66	2.66	23.62	62.10	61.23	38.03	12.44	12.07	63.74	13.27	12.62
7	SST876	76.32	78.68	38.61	2.62	21.70	63.83	58.16	36.97	12.42	12.29	62.53	13.16	12.43
8	SST38	76.39	79.05	38.55	2.58	22.47	64.38	57.39	36.46	12.90	12.62	62.22	13.54	12.82
9	SST57	74.86	76.68	33.28	2.37	23.46	67.81	61.05	31.68	12.09	12.22	59.89	13.34	12.38
10	Inia	75.20	79.02	41.16	2.74	22.97	65.24	54.98	39.74	12.76	12.42	62.53	13.58	12.79
	LSD (0.05)	0.830	0.976	1.677	0.10	0.626	5.64	2.985	1.896	0.607	0.845	0.872	0.411	
NG	Genotype	GPC-WH	LFV12%	LFVPT	SDSS	WGC12%	FLN	MDT	MPT	P/L	Strength	FCL	Moisture	
1	Marico	11.77	930.6	87.20	87.05	32.58	259.0	2.99	4.29	0.384	36.89	1.27	9.88	
2	Kariega	12.03	950.9	88.10	88.76	35.60	265.6	2.58	3.76	0.355	36.32	0.11	10.13	
3	T4	11.27	823.4	81.25	63.95	35.99	273.9	1.38	1.14	0.526	15.27	0.59	9.82	
4	Palmiet	11.48	889.8	82.32	68.66	34.93	278.1	1.84	2.06	0.491	21.70	1.29	9.83	
5	SST825	11.81	936.0	82.14	78.95	35.82	275.8	2.61	3.91	0.638	41.35	1.47	9.97	
6	SST822	11.80	954.6	87.80	81.95	36.40	290.9	2.49	3.62	0.381	33.68	1.69	10.00	
7	SST876	11.72	924.1	88.82	76.60	37.86	277.6	1.85	1.40	0.383	27.88	0.78	9.86	
8	SST38	12.46	972.3	91.07	83.48	37.69	269.9	1.99	2.00	0.230	31.87	0.61	9.96	
9	SST57	11.68	947.3	88.69	75.14	35.59	271.2	2.74	3.52	0.308	31.28	1.60	9.91	
10	Inia	12.21	958.6	89.29	84.62	36.01	276.5	2.71	3.91	0.474	39.52	0.98	9.95	
	LSD (0.05)	0.480	29.071	4.087	3.451	2.092	16.208	0.230	0.499	0.059	3.506	0.667		

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In conclusion we can say, except for Palmiet, SST38, SST876 and T4 most of the other genotypes are expected to give intermediate to higher scores at most of the sites. However, Palmiet and SST38 also may give intermediate to ideal scores at Loskop and Koedoeskop where they showed environment interactions. On the other hand care must be taken for Marico at BullHill, Prieska, Douglas and together with Kariëga at Loskop and Koedoeskop where they showed scores above the ideal. For the locations, however, as it was for development time, the major difference is on the basis of temperature in addition to higher gluten content, which is necessary at all sites. The cooler areas (BullHill, Barkly West, Prieska, Hopetown and Douglas) need genotypes with intermediate to higher scores and management practices to increase protein content. Gluten content is also important. For the warmer areas (Loskop and Koedoeskop) genotypes with intermediate to low scores are needed and good timing of planting to ensure that grain filling does not coincide with very high temperatures.

The alveograph P/L ratio

The analysis of variance (Table 5.1.43) shows significant variations for treatment, main effects, interactions as well as the IPCA. The residual was significant at $p < 0.01$, implying slight noise effect as the IPCA1 also captured a large percentage (70.3) of the interaction effect. The block effect was not significant and this implies absence of variations for particular genotypes within locations. Contrary to 1997 results whereby genotype and environment contributions to the variation were much closer and higher than interaction, the 1998 results showed that genotype contribution was much higher than both environment and interaction. The respective contributions to variation were 24.9%, 43.6% and 21.0% for environment, genotype and interaction. This shows that with optimal environments, genotype effect increases while environment and interaction decrease.

Table 5.1.43 Analysis of variance results for the alveograph P/L ratio in 1998.

Source	DF	SS	MS	F-value	Pr>F	SS%
Total	209	5.960	0.029			
Treatment	69	5.332	0.077	16.86	0.000	
Environment (E)	6	1.486	0.248	54.03	0.000	24.9
Block	14	0.050	0.004	0.79	0.683	
Genotype (G)	9	2.596	0.288	62.93	0.000	43.6
G x E	54	1.251	0.023	5.05	0.000	21.0
IPCA	14	0.880	0.629	13.72	0.000	70.3
Residual	40	0.370	0.009	0.002		
Error	126	0.577	0.005			

IPCA = Interaction Principal Component Analysis

SS Percentage contribution:

Genotype (G), Environment (E)
and Interaction (G x E) } = (SS for Genotype, Environment or G x E /SS for total) x 100

IPCA = (SS for IPCA/SS for G x E) x 100

The environment means (Table 5.1.44) ranged between 0.33 to 0.60 at Barkly West and Prieska respectively, with 0.42 as the grand mean. This shows a decrease for both minimum and maximum values compared to 1997 results where the minimum value was more than the 1998 mean value. The environment main effect showed two groups of locations. Prieska and Douglas were above the mean with Prieska being much higher than the mean. More than half of the genotypes were above the mean at these sites. Other sites had less than half of the genotypes above the mean. The mean for Koedoeskop was equal to the grand mean, Loskop and Hopetown much closer to the mean and BullHill and Barkly West further from the mean. A general observation shows that for this parameter, protein contents closer to 12.0% and endosperm starch content are very important. Most of the sites had low protein content, with the exception of Loskop where protein content was high. This might have influenced the extensibility and elastic properties of the dough due to poor glutenin-to-gliadin ratios. On the other side, breakflour yield that increases when milling hard wheat, results in fine starch granules that are embedded on gluten matrix during bubble expansion. This reduces the extension and increases the bubble ability to withstand the pressure inside. This was revealed from the hardness index results from sites like Prieska and Douglas, which had higher hardness index values, which resulted in higher alveograph P/L ratios. Nevertheless BullHill and Barkly West, which had lower hardness index values, also resulted in lower alveograph P/L ratios.

The genotype means (Appendix 2) ranged between 0.23 to 0.64 for SST38 and SST825 respectively. The genotype main effect showed three groups. SST825, T4, Inia and Palmiet were above the mean and

SST825 was much higher than the mean. SST822, Marico, SST876 and Kariega were below the mean but much closer to it, whereas SST57 and SST38 were far below the mean. Except for the last two, which seems to have poor genetic potential for this parameter, other genotypes had either high protein content and/or high hardness index value.

The AMMI biplot for genotype and environment means (Figure 5.1.22) shows slight environment interactions for T4, SST825, Palmiet, Inia, Marico and SST57. The former three ranked higher at most of the sites but at Loskop SST825 ranked third and Palmiet and T4 much lower. They also had much lower mean values at this site and therefore showed negative environment interaction. Marico, Inia and SST57 ranked first, second and intermediate respectively at Loskop with higher means than at other sites and this caused them to show positive environment interaction. The former two ranked lower at Prieska but the means were not much lower. Other genotypes showed to be stable and gave reliable rank at most of the sites.

The locations showed environment interaction with genotypes, though not high, at Prieska, Loskop and Hopetown. SST825, Palmiet and T4 had very high mean values at Prieska but Inia and Marico ranked lower with intermediate values. However, it was the other way round at Loskop (Table 5.1.44). At Hopetown Marico had a lower mean value than at other sites.