IDENTIFICATION OF GENETIC VARIATION IN BREAD WHEAT QUALITY CHARACTERISTICS IN THE WESTERN CAPE

by

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CHAPTER 1

INTRODUCTION

The objective of the wheat-breeder is to develop improved genotypes, which are superior for one or more important characteristics. The development of bread wheat cultivars provides a great challenge to a wheat breeder. Improvement in wheat quality and yield can be aided if the biochemical and genetic factors influencing these characteristics, are understood (Branlard & Dardevet, 1985). The aim of the breeder is to develop cultivars with a stable and high yield and good quality characteristics.

For the effective improvement of quality and yield, a plant breeder must have knowledge of the inheritance of quality traits and of the joint inheritance of quality and agronomic traits (Baker, Tipples and Campbell, 1971).

Grain quality is critically important to the producer today because it directly influences profit. Grain quality consists of a number of characteristics which are influenced by different factors, some genetic, some environmental and some both. Genotype x environment interactions are significant for milling and baking traits (McGuire and McNeal, 1974). Wheat breeders develop cultivars that express appropriate end use qualities for a relatively small, defined, and expected growth area for which the cultivar is intended. Poorly adapted wheat cultivars produce poor end use qualities when grown outside their intended production area. Wheat quality is influenced by both the genotype and environment, but because of the polygenic nature of the characteristics involved, the environment largely influences their expression (Gaines, Finney & Raubenthaler, 1996; Poehlman, 1987).

Protein content is influenced by genotype and temperature conditions under which the crop is grown (Gauer, Grant, Gehl & Bailey, 1992). Cold winters, followed by

hot, dry summers that induce rapid ripening, characterise hard wheats of high protein content (Leonard & Martin, 1963). Abundant rainfall during the period of kernel development usually results in low protein content and high yield, whereas dry conditions during that period favour high protein content with a decrease in yield (Halverson & Zeleny, 1988). High rainfall regions, like the Western Cape, are traditionally low protein environments (Gaines *et al.*, 1996).

The inheritance of quality characteristics is complex (Ausemus, McNeal & Schmidt, 1967). The negative correlations which often exist between quality and yield characteristics is a further restriction in breeding. Grain quality is therefore very complex with a lot of different aspects to be taken into account.

To successfully increase the important quality characteristics and yield simultaneously, the choice of breeding parents is extremely important. The parental line must be environmentally stable, and possess outstanding quality characteristics. Furthermore these characteristics have to possess a high narrow sense heritability as well as a good GCA. This will ensure that the desirable characteristics can be selected with minimum environmental influences.

The aims of this study were therefore to:

1) Identify suitable parental lines that possess stable quality characteristics over environments, which can be used to produce superior progeny in the Western Cape.
2) Determine the GCA and SCA of measured characteristics as well as the GCA:SCA ratio.
3) Determine the correlations between the different quality and yield characteristics.
4) Determine the broad and narrow sense heritability of the quality characteristics.
5) Determine the indirect response to selection based on the heritability and genetic correlations.

CHAPTER 2

LITERATURE REVIEW

2.1 Bread Wheat Quality

Identification of the basic components determining quality and explanation of their mode of function and interrelationships has perplexed cereal chemists for decades. This resulted in a proliferation of quality tests, each which professes to measure some important baking qualities (Fowler & De la Roche, 1975a). Quality attributes important for the end use of hard red winter wheat include flour extraction (milling yield), grain hardness, dough handling and bread making quality. Millers and bakers are interested in the development of rapid tests for the prediction of inherent end use quality potential (Graybosch, Peterson, Shelton & Beanziger, 1996).

Grain quality is based on protein quality and quantity. Thus, protein quality and quantity (content) are very important in grain quality. Protein quality and quantity are both considered primary factors in measuring the potential of flour in relation to its end use (Mailhot & Patton, 1988). Protein quality is influenced largely by genetic factors and protein quantity largely by the environment, that is, each wheat variety inherits the quality of its protein from its parents (Bushuk, 1985). The producer can adjust the content, but quality is inherent to the cultivar and has to be adjusted by breeding methods (Mailhot & Patton, 1988). Protein content is used as a quick estimate of wheat quality (Wikström & Bohlin, 1996) and exerts a marked influence upon a number of quality characteristics (Marais, 1982).

All the morphological parts of the wheat grain contain protein, with the embryo and scutellum containing the highest concentration per unit weight. However,

because of their small size, the components contribute very little to the total protein of the grain. The major proportion of the total protein (usually between seventy-five and eighty-five per cent), is contributed by the gliadin and glutenin components of the storage protein. These components therefore strongly influence the amino acid composition of the wheat flour (Simmonds, 1981). Numerous polypeptides contribute to the formation of gluten, the visco-elastic protein responsible for the unique properties of wheat flour (Graybosch, 1992). The breadmaking potential of flours from widely different wheat varieties can differ due to differences in the structure of their gluten proteins, which is generally referred to as the protein quality for breadmaking (Bushuk, 1985). Numerous polypeptides contribute to the formation of gluten, the viscoelastic protein responsible for the unique properties of wheat flour (Graybosch, 1992).

In terms of protein quality, gluten is a complex mixture of polymeric glutenin subunits and monomeric gliadins (Graybosch, 1992). The major proportion of the total protein (usually between 75 and 85 per cent), is contributed by the gliadin and glutenin components of the storage protein (Simmonds, 1981). Biochemical variation among wheat gluten proteins is extensive, and numerous investigators have studied the relationships between allelic variation at glutenin-encoded loci and wheat flour quality (Graybosch, 1992).

Improvements in grain protein percentage occasionally have been achieved by using unadapted genotypes as source of higher grain protein. In some cases, genetic factors for higher grain protein has been incorporated into locally adapted genotypes (Löffler & Busch, 1982).

2.2 Genotype and environmental influences on quality characteristics

Wheat quality factors may be divided into those largely inherited and those predominantly influenced by growing of environmental conditions (Nel, Agenbag & Purchase, 1998). While most breeding programmes emphasise the

importance of cultivar, and significant variation for quality traits exists among cultivars, the importance of the environment should not be overlooked. The environment, cultivar and their interaction all affect the milling and baking quality of wheat (Baenziger, Clements, McIntosch, Yamakazi, Starling, Sammons and Johnson, 1985).

Nel *et al.* (1998) reported that the most critical climatic factors affecting plant yield and grain quality in the Western Cape are those of temperature and rainfall.

For South Africa, Van Lill, Purchase, Smith, Agenbag & De Villiers (1995) reported a large variance for breadmaking characteristics such as protein content, mixograph dough development time and baking strength index, among winter wheat genotypes grown in the Free State, but Laubscher (1980) found that the effect of the cultivars on protein content and loaf volume is dominated by that of the environment for spring wheat cultivars in the Western and Southern Cape. Very little is thus known about the effect of the environment on the stability of genotypes in this area.

In the study conducted by Nel, *et al.* (1998) the environment contributed to 86.7% of the variation in hectolitre mass. Although significant, the contribution of cultivars to the variation in hectolitre mass was only 0.8%. Cultivar x environmental interaction was responsible for 12.5 % of the variation in hectolitre mass. Further, cultivars contributed only 0.1% to the variation in grain protein content. Although the contribution of environment to the variation in grain protein content (94.5%) was by far the largest, results also showed a significant cultivar x environment interaction. And, the environment contributed to 90.7% of the yield variation.

Jalaluddin & Harrison (1989) reported that test weight (hectolitre mass) is a function of kernel density and packing efficiency. Packing efficiency is a heritable trait associated with grain shape, whereas kernel density is more related

to the environment in which it is grown. Hectolitre mass will be affected by genotype x environment interaction.

Bhatt & Derera (1975) found significant genotype x environmental interactions for hectolitre mass, extraction, grain protein content, flour protein content, baking volume and flour colour. Terman (1979) also reported that various environmental factors greatly affect grain yield and grain protein content.

Fowler & De la Roche (1975b) also found that the environmental component for hectolitre mass is of major significance and as such should be given considerable emphasis. A significant environmental interaction was further found for thousand kernel mass, mixograph peak area and hardness. The environment was found to exert its largest influence on yield, protein content and protein-related parameters.

According to Pomeranz, Peterson & Mattern (1985), the influence of the environment was larger for thousand kernel mass and protein content, whereas for hardness, the influence of genotype was more important than the growth conditions.

In contrast to Pomeranz *et al.* (1985), Gaines *et al.* (1996) reported that location had much more influence on hardness than did cultivar adaptation. They further reported that the environment had a greater effect on hectolitre mass and breakflour yield than did cultivar adaptation, and that flour yield and mixograph mixing time was slightly influenced by environmental differences.
In a study conducted by Baenziger *et al.* (1985), it was found that flour yield and protein content showed highly significant differences among environments.

Gaines (1991) reported that year, location, cultivation customs and environmental and climatic conditions profoundly affected cultivar protein content and kernel texture.

Shuey (1975) studied the influence of environment on the colour and flour ash of 11 hard red spring wheat cultivars. Year, location and cultivar inconsistencies were observed for flour colour and flour ash.

Fenn, Lukow & Bushuk (1994) found that the genotype affected more of the quality charateristics of 1B/1R translocation containing wheats than did the environment.

Drier climates, especially during the grain fill period, should favour the production of larger, better filled, and harder kernels that tend to produce superior milling characteristics. Moister environments should produce softer kernels that generally produce less damaged starch during milling and lower water absorption (Gaines *et al.*, 1996). Differences among cultivars tend to be greater under optimum growth conditions

2.3 Quality analysis from diallel crosses

The technique of diallel crosses lends itself to detailed genetic analysis after only one generation. It can provide valuable knowledge about the nature of genetic variances and the magnitude of each of its components (Sayed, 1978).

The use of a diallel analysis as a means of studying genetic relationships among pure bred wheat lines is well established. However, the technique is seldom used for the purpose of studying wheat quality characteristics, presumably because some of the genetic factors contributing to these characteristics may not comply with the assumptions of the Hayman-Jinks model (Marais, 1982).

Research groups using the diallel analysis have so far undertaken various studies.

Levy & Feldman (1989) conducted a study on diallel crosses, including reciprocals. No significant differences in grain protein percentage were found

between the F2 crosses and their reciprocals, therefore it was concluded that reciprocals could be pooled with crosses.

The lack of information regarding the inheritance of grain filling rate and duration prompted a study by Mou & Kronstad (1994) to determine the relative magnitude of genetic components and combining ability estimates for the grain filling parameters. A 4 x 4 diallel cross of four winter wheat lines, excluding reciprocals, was used in this study.

Paroda & Joshi (1970) studied the combining ability for grain yield and components of yield in wheat using F2 generation data from a 6 x 6 diallel set. Although results were similar to those obtained earlier from F1 data, the F2 generation showed a marked decline in the magnitude of SCA variance. The decline in the estimate of SCA variance in the F2 can be attributed to the reduction of dominance from F1 to F2 generations. The F2 generation, however, can effectively be used for the identification of good GCA.

The F2 reciprocals are not expected to differ except in the presence of cytoplasmic/ maternal effects. Consequently, reciprocal differences in the F2 diallel are not expected to be detected as frequently as in the F1 diallel and the corresponding mean squares of the two diallels may in fact differ significantly. Estimates of the additive components are likely to be very similar for the F1 and F2 diallels except in the presence of genotype x environment interaction. The dominance component can differ between diallels, particularly between those based on the F1 and F2 families, as the coefficients of the dominance parameters differ considerably between these generations. Results show the consistency of these results across diallels. The ranking of the parental lines according to their GCA values are virtually the same for all the diallels. Genetic segregation, on the other hand, should make the variances of the F2 generation larger than those of the parental/F1 families and that is what was observed when the average variances were compared. Only the F2 diallel can be trusted to provide unbiased tests of the reciprocal effects under most situations. Clearly the F1

diallel is the most efficient for detecting and estimating the components of additive and dominant effects. However, its within-family variances do not provide any supplementary information on the genetic control of the trails owing to lack of segregation (Pooni, Kumar & Khush, 1993).

After considering the above mentioned problems, and those associated with the tests of reciprocal effects and of hybrid seed production, it was found that the F2 diallel was perhaps the most appropriate for analysing trials (Pooni *et al.*, 1993). If the base is a F2-population, two alleles with equal frequencies exist at each locus undergoing segregation, and the analysis is relatively simple (Wricke & Weber, 1986).

2.3.1 Combining ability

Because of the difficulties caused by correlation of characteristics in the parents, the estimation of GCA and SCA mean squares and effects are of importance to the breeder. Such information is useful for measuring hybrid performance in assessing the potential of a hybrid breeding programme (Baker, 1978).

Knowledge of the genetic systems controlling the quantitative characters is essential for the choice of the most effective and efficient selection and breeding procedures. It is necessary to evaluate the importance of epistatic effects, in particular the fixable additive and dominant type interaction components (Jian & Singh, 1978).

GCA is used to designate the average performance of a line in hybrid combination (Sprague & Tatum, 1942). A significant GCA indicates real differences between the additive effects of the parents. These differences are illustrated by the GCA effects. The GCA variances provide estimates of the sensitivity of the parental GCA effects to environmental variables.

SCA is used to designate those cases in which certain combinations do relatively better or worse than would be expected on the basis of the average performance of the lines involved (Sprague & Tatum, 1942). A significant SCA indicates real differences between the SCA effects (and therefore heterotic effects) of the parents involved. These differences are illustrated in a table of the SCA effects. The SCA variances provide estimates of the sensitivity of the heterotic effects to environmental influences.

In a fixed model analysis of data from single cross progeny in a diallel cross, the average performance of each progeny is broken into components relating to GCA (main effects) and to SCA (interactions). The best performing progeny may be produced by crossing the two parents having the highest GCA (Baker, 1978).

Phenotypic expression of quantitative characters is significantly influenced by environmental fluctuations. Genotype x environment interaction, depending upon their nature and magnitude, leads to a bias in the estimates of gene effects and combining ability for various characters sensitive to environmental modulations. Such traits are less amenable to selection (Sing, Paroda & Behl, 1986).

The analysis of variance for the combining ability of grain protein content showed that both GCA and SCA variances were highly significant. Thus, the grain protein content in wheat is determined by additive and non-allelic gene interaction but with the predominance of the additive gene action (Mihaljev & Kovacev-Djolai, 1978).

Sing *et al.* (1986) found that GCA effects played a more important role in thousand kernel mass and that grain yield was mainly under additive genetic control. Relatively higher magnitude of GCA x environments interaction as compared to SCA x environment interactions suggested a higher sensitivity of GCA to environments than that of SCA.

In contrast to this, Paroda and Joshi (1970) found that the GCA was significant for the components of yield and the SCA variances for thousand kernel mass.

Jian & Singh (1978) studied additive, dominance and additive x additive genetic variance in wheat for grain yield and its components, in two environments. The estimates of GCA variances were significant for grain number per ear and thousand kernel mass in both environments, and for grain yield under irrigated conditions. The estimates for SCA components was highly significant in both environments for grain yield and ear number, and in one environment for grain number per ear and thousand kernel mass. Considering these results, SCA variance components made major contributions to genetic variation in grain yield and ear number irrespective of the variations in environmental conditions. For thousand kernel mass, GCA and SCA variance components were significant under irrigated conditions and GCA variance components alone made a major contribution under non-irrigated conditions.

2.3.1.1 GCA to SCA ratio

Studying the GCA:SCA ratio can reveal the nature of the genetic variance. Should the GCA variance be larger in comparison with SCA variance, a higher ratio is eminent indicating the prevalence of the additive genes, and vice versa. Thousand kernel mass indicated almost equal effects of additive and non-additive genetic components. Yield per plant was the only character showing more non-additive than additive gene action (Sayed, 1978).

Mihaljev & Kovacev-Djolai (1978) found that for grain protein content the GCA variance was larger than the SCA variance, with the ratio GCA:SCA being 4.05. The relatitively higher magnitude of the GCA variance indicates the predominance of additive gene effects in the genetic control of the grain protein percentage.

2.3.2 Correlations

The characters observed in the individuals of a population can be correlated negatively or positively. In genetic studies the first problem will always be to distinguish between genetic and environmental causes of correlation (Aastveit & Aastveit, 1993).

Correlations are of interest for three main reasons:

- In connection with the genetic causes of correlation through the pleiotropic action of genes – pleiotropy is a common property of major genes, but as yet its effects in quantitative genetics has not been considered.
- In connection with the changes brought about by selection – it is important to know how the improvement of one character will cause simultaneous changes in the other characters.
- In connection with natural selection – the relationship between a metric character and fitness is the primary agent that determines the genetic properties of that character in a natural population (Falconer, 1981).

The genetic cause of correlations is mainly pleiotrophy. The degree of correlation arising from pleiotrophy expresses the extent to which two characters are influenced by the same genes. But the correlation resulting from pleiotrophy is the overall effect of all the segregating genes that affect both characters. The environment is a cause of correlation in so far as two characters are influenced by the same differences in environmental conditions. The assosiation between two characters that can be directly observed is the phenotypic correlation, thus the genetic and environmental causes of correlation. The genetic correlation is a correlation of the breeding values (Falconer, 1981).

If both characters have low heritabilities, then the phenotypic correlation is determined mainly by the environmental correlation: if the characteristics have

high heritabilities, then the genetic correlation is the important one (Falconer, 1981).

2.3.2.1 Milling characteristics

1 Grain protein

Protein content in wheat grain is an important constituent in the nutritional quality of wheat, and therefore knowledge of the genetic control of this character is essential for breeders to formulate efficient breeding and selection strategies for genetic improvement of wheat nutritional value (Mihaljev & Kovacev-Djolai, 1978).

Although the wheat grain protein content was shown to be genetically controlled and significant genotypic or varietal differences in this characteristic have been noticed, it is well known that the grain protein content is strongly affected by environmental factors and agricultural practices (Mihaljev & Kovacev-Djolai, 1978).

Levy & Feldman (1988) also found that genotype x environment interaction was highly significant for grain protein percentage, which is positively associated with large grains. Grain protein percentage was weakly, and in most cases non-significantly, correlated with spikelets per spike and grain yield.

The highly significant positive correlation between grain- and flour protein indicates that milling has essentially no effect on protein content (Baker *et al.*, 1971).

Bhatt & Derera (1975) also found that grain protein showed highly significant positive correlation with flour protein and baking volume at both genotypic as well as phenotypic levels. Grain protein exhibited highly significant positive correlations with baking score at genotypic and phenotypic levels.

2 Flour Protein

Protein quality and quantity are both considered primary factors in measuring the potential of a flour in relation to its end use. The quantitative measurements of crude protein is related to total organic nitrogen in the flour, whereas quality evaluations relate specifically to physiochemical characteristics of the gluten forming components (Mailhot & Patton, 1988).

Graybosch, Peterson, Moore, Stearns & Grant (1993) found that variation in flour protein contributed to a large portion of variation in dough handling and loaf characteristics. Baker *et al.* (1971) stated that any increase in protein content will result in a proportional increase in loaf volume, regardless of the baking method used.

According to Bhatt & Derera (1975), flour protein showed a highly significant positive correlation with baking score and baking volume at genotypic level, and significant and highly significant positive correlation with baking score and baking volume respectively on the phenotypic level. Flour protein gave a higher correlation with baking score and baking volume than did grain protein.

A large portion of the variation observed in flour quality may be attributed to variation in gluten protein content and composition (Bietz, 1988). Flour protein content and total gluten content generally are highly correlated with extensibility (Andrews & Skerritt, 1996).

Flour protein content is extremely important because all other flour properties are in some way a function of protein quality. Flour water absorption is a linear function of protein content within a variety of wheat, and mixing requirements, mixing tolerance, dough handling characteristics and loaf volume are highly correlated to protein content according to Finney & Shogren (1972).

Johnson & Swason (1942) found that protein content of the flour is positively correlated with the height of the mixogram curve at optimum consistency, while it is negatively correlated with the angle of slope. No significant correlation was demonstrated between protein content and time of development as measured by the peak time of the curve. At low protein levels the time of development may appear to be longer than at higher protein levels.

Peterson, Graybosh, Baeziger & Grombachter (1992) found that mixing time and tolerance, kernel weight and SDS sedimentation were significantly correlated to flour protein concentration, although the correlations were relatively low. Also, the phenotypic correlation between flour protein and mixing time was essentially unchanged ($r = 0.54$) when the high protein genotypes were dropped from the analysis.

A positive genetic correlation of kernel hardness with flour protein was found, although the phenotypic correlation was small and non-significant (Peterson *et al.*, 1992). Bhatt & Derera (1975) found an important positive correlation to exist between protein content and baking properties. Previous studies have generally shown little relationship between protein concentration and hardness (Pomeranz *et al.*, 1985).

Both environmental and genotypic factors are known to influence flour protein composition, however, the relative magnitude of genotypic, environmental and genotype x environment effects on hard red winter wheat flour protein composition remains unknown (Graybosch *et al.*, 1996). A morphological marker, namely black glumes, is convenient to recognise high protein percentage genotypes in wild tetraploid wheat (Levy & Feldman, 1988).

3 Bühler extraction

Flour of a wheat variety is obtained by Bühler-milling of a composite wheat sample (Marais & D'Appolonia, 1981a). A decrease in grain size causes a

decrease in milling quality due to a reduction in the proportion of endosperm that can be extracted as flour and an increase in the difficulty in doing so (Wrigley, Blumenthal, Gras & Barlow, 1994).

The process of milling did not have a significant effect on protein content, therefore it may not be necessary to measure both grain protein and flour protein (Bhatt & Derera, 1975).

4 Break flour yield

In the grading system, the smaller particles are separated according to size on sieves. As the wheat is broken open in the break system, a small amount of endosperm is reduced to flour particle size. This flour, called "break flour", is sifted out in the grading system (Bass, 1988).

Break flour yield was positively correlated with larger kernel size (Kosmolak & Dyck, 1981). Across environments, flour yield was highly correlated with hardness, sedimentation, percent protein and cookie diameter (Basset, Allan & Rubenthaler, 1989).

Gaines (1991) reported a negative correlation between break flour yield and flour protein content in red wheat.

5 Falling number

Falling number is used to evaluate preharvest sprouting which influences the loaf volume directly. A decrease in the falling number, indicates an increase in preharvest sprouting, accompanied by a higher percentage of germination. The higher the falling number, the less the α-amylase enzyme activity, thus the better the cultivar (Kosmolak & Dyck, 1981). Baker *et al.* (1971) found that α-amylase activity is a measure of gassing power.

The overall detrimental effects of germination result from the cumulative losses of grain yield, grain quality (grade), flour yield and flour quality. Protein content, break flour yield and SDS sedimentation decreased as germination increased. Deterioration in baking quality was shown by the decrease in farinograph water absorption and dough development time, and increase in mixing tolerance index during germination (Lukow & Bushuk, 1984).

Preharvest sprouting had a detrimental effect on baking quality. Loaf volumes decreased progressively with increased germination. Doughs became sticky and difficult to handle, and the crust and crumb colour became darker and the crumb grain became coarser (Lukow & Bushuk, 1984).

6 Flour colour

Flour colour has been important throughout the history of the milling industry. Colour has long been a criterion of flour quality. Today, many equate flour colour with quality, especially as related to flour grade or flour extraction (Shuey, 1975).

Colour measurements may be approached in two ways. The first approach is to measure whiteness, which primarily determines the extent of colour removal by bleaching compounds. The second approach largely ignores the whiteness and concentrates of the influence of the branny material in the flour by measuring reflectance with a light source in the green band of the light spectrum (Mailhot & Patton, 1988).

Significant correlations were found between flour pigment content, starch damage and extensigraph measurement (Baker *et al.*, 1971).
Bhatt & Derera (1975) found colour grade not to be correlated with any other traits and, therefore, should be considered as independent traits as far as selection strategies are concerned.

7 SDS sedimentation

In a breeding programme, a method is needed for quick and positive identification of new wheat cultivars with good bread-baking quality. Axford, McDermott & Redman (1978) introduced the sodium dodecyl sulphate sedimentation test (SDSS test) for estimating the bread-baking quality of wheat cultivars. As the SDSS test is a simple and rapid test and needs only a small sample of flour, it can be used by breeders to classify wheat for bread-baking purposes (De Villiers & Laubscher, 1995).

Axford *et al.* (1978) found a significant correlation between SDS sedimentation values and loaf volumes (the most important criterium of bread baking quality). There has also been evidence to indicate that SDS-sedimentation is the test that singularly gives the best prediction of bread baking potential and strength for hard wheats (Greenaway, Hurst, Neustadt & Zeleny, 1966).

A study was therefore undertaken by De Villiers & Laubscher (1995) to determine the relationship between the SDS sedimentation volume and the protein content and bread volume of wheat cultivars grown at different locations in the southern part of the Western Cape Province, in an attempt to determine whether the SDSS test could be used to predict the baking quality of new cultivars in a breeding programme. A significant positive correlation was found between SDSS values and the protein content as well as between the SDSS values and the loaf volumes. From this it is evident that cultivars with good baking quality (high protein content and bread volumes) have high SDSS values, whereas cultivars with poor baking quality (low protein content and bread volumes) have poor SDSS values.

Gröger, Oberforster, Werteker, Grausgruber & Lelley (1997) found a significant correlation between sedimentation volumes and protein content ($r = 0.73$), extensograph dough strength ($r = 0.59$), extensibility ($r = 0.6$) and all farinograph parameters, as well as all alveograph parameters.

Genotype means for SDS-sedimentation value, which reflect both protein quality and loaf volume potential were negatively correlated with the genotypic responses (*b*-values) (r = -0.57). This suggested that genotypes with lower loaf volume potential had higher *b*-values and thus were generally less stable across environments (Peterson *et al.*, 1992).

The aggregative behaviour of flour protein content can be assayed through use of SDS sedimentation tests (Graybosch *et al.*, 1996).

In hard wheats the 1B/1R translocation had substantial and consistent deleterious effects on SDS sedimentation volume (Dahliwal, Mares & Marchall, 1987).

8 Hectolitre mass

Hectolitre mass is considered an important prediction of flour yield. To be graded as suitable for breadbaking purposes, a minimum hectolitre mass for wheat of 74 kg ha $^{-1}$ is needed in South Africa (Nel, *et al.*, 1998).

Hectolitre mass of grain represents the mass of wheat per volume, and have been interpreted as a measure or kernel soundness. Fully mature, plump kernels, undamaged by disease or the environment, are high in test weight. The principle of this test is the packing of kernels in a container. Plump kernels pack more uniformly, giving rise to a higher hectolitre mass, whereas smaller kernels, usually more elongated, pack more randomly to give a lower mass (Dick & Matsuo, 1988).

A positive correlation was found between hectolitre mass and flour yield, which influences the number of loaves baked from an even mass of wheat. Observations made indicate that the environmental component (especially between florescence and harvest) has a major influence on hectolitre mass. This

is of major significance and as such should be given considerable emphasis in the evaluation of breeding material (Fowler & De la Roche, 1975b).

Grain yield and hectolitre mass are important economic characters of wheat, and selection for both traits is necessary. Therefore, knowledge of the genetic correlation between these two traits and their relative reactions to environment is important to plant breeders. Selection can be made simultaneously for these two traits since they are not negatively correlated (Jalaluddin & Harrison, 1989).

Grain yield differences within cultivars, as well as grain volume weight (hectolitre mass), were correlated in soft white winter wheat with sedimentation, kernel hardness, flour protein, flour moisture and cookie diameter (Basset *et al.*, 1989).

Gaines (1991) found that hectolitre mass was positively correlated with flour yield, and that cultivars with higher hectolitre mass produced less break flour.

Bhatt & Derera (1975) found test weight to be an independent trait since it was not correlated with any other trait studied.

9 Hardness

Hardness is one of the most important characteristics of wheat from the standpoint of milling and end-use properties such as in production of bread (Pomeranz & Mattern, 1988). Milling- and flour quality is often influenced by kernel hardness (Gaines *et al.*, 1996). Kernel size may modify hardness (Pomeranz *et al.*, 1985), but correlation between indirect indices of hardness and protein content were either very low or non-significant. Variation in hardness of winter wheat grown under widely different environmental conditions was found to be affected mainly by genotype (Pomeranz & Mattern, 1988) and to a small extent by environmental and growth conditions (Pomeranz *et al.*, 1985 ; Fowler & De la Roche, 1975b).

Starch damage increases with wheat endosperm hardness and is related to rate and level of water absorption and dough development characteristics, susceptibility of starch to amylolytic attach, and freshness retention of the baked bread (Pomeranz & Mattern, 1988).

The 1B/1R translocation has consistently harder grain, as evidenced by higher pearling resistance (Dahliwal *et al.*, 1987).

2.3.2.2 Rheological characteristics

Several physical testing devices measure various rheological properties of wheat flour doughs. Tests are usually performed on flour-water doughs and are widely employed in quality testing. Recording dough mixers such as the mixograph and farinograph, evaluate the mixing characteristics of gluten development in a dough. Since the mixing characteristics of a flour are usually related to the gluten quality measurements, they can be defined by the use of recording dough mixers in the selection and evaluation of experimentally milled wheat (Mailhot & Patton, 1988).

Recording dough mixers record the power that is required to mix a dough at constant speed or the resistance to mixing. The recorded curves yield information about changes in rheological properties during mixing (Bloksma & Bushuk, 1988).

Dahliwal *et al.* (1987) reported that the 1B/1R translocation has a deleterious effect on dough-development time. There is also a tendency towards reduced extensibility. Dough derived from such wheat often develops marked stickiness with high-speed mixing, and is associated with reduced dough strength and intolerance to over mixing.

1 Mixograph

The mixograph is an instrument that performs measurements on the dough during the mixing action. The mixograph was developed by Swanson and Working in 1933 and is still one of the most widely used instruments for physical dough testing. Parameters from the mixogram are used to classify wheat and to predict properties in the finished product (Wikström & Bohlin, 1996)

The rate of dough development classifies as a primary measurement of this instrument. Following a consideration of the complexity of procedure and a comparison of analysis utilising mixograph and farinograph data, mixograph peak time was selected as a measure of this factor (Fowler & De la Roche, 1975a).

A mixograph consist of a two-part curve, consisting of ascending and descending arms. High protein flours from hard winter and spring wheat produce curves with long mixing times and high peak values. Mixograph absorption is more subjective than farinograph absorption, but knowing flour protein content, moisture content and the wheat variety from which the flour was milled, one can apply Finney's equation to predict mixograph absorption. Absorption influences dough stiffness and the work input required. Curve width, especially during the ascending portion of the curve, is also affected by absorption. The ascending slope is an indication of the rate of dough development. Descending slopes are associated with the rate of dough breakdown and are relevant to the wheat variety, production environment, and flour protein content. Generally, the angle between the development and weakening slopes denotes a dough's mixing tolerance. Lower protein, soft wheat flours tend to break down rapidly after reaching a peak and is said to lack mixing tolerance (Walker & Hazelton, 1996). In the case of mixograph measurements, especially mixograph development time, the biochemical nature of the gluten protein is of considerable importance (Orth & Bushuk, 1972). Variability in mixing times among samples has been

shown to reside primarily in the protein fractions, and to be related to total protein, water solubles, glutenin, residue protein, and the gliadin/glutenin ratio (Bietz, Huebner & Wall, 1973).

Finney & Shogren (1972) found that flour absorption is a function of protein content, variety, flour moisture and environment. Water absorption increases with increasing flour protein content. The mixing requirements of flour containing 7.5 percent protein is much longer and mixing tolerance materially greater than those values of flours containing 11 – 13 percent protein. Mixing time, in general, decreases as protein content increases to about 12 percent, thereafter remaining approximately constant with flour protein increases. Mixing time obtained from the mixogram is a reliable index of loaf volume potential and protein quality.

Both phenotypic and genotypic correlations indicated that decreased mixing time was related to increased protein levels and kernel weight. The negative genetic correlation between protein and mixing time was a consequence of the typical shorter mixing time characteristics of high protein genotypes. While phenotypic correlations for mixing tolerance were low or non-significant, genotypic correlations indicated a positive relationship of mixing tolerance with mixing time and SDS-sedimentation values (Peterson *et al.*, 1992). Phenotypic correlations of genotype means can be used to examine relationships between the mixograph and bread making parameters, as well as flour and biochemical attributes (Graybosch *et al.*, 1996).

2 Farinograph

The farinograph was developed in 1930 (Bloksma & Bushuk, 1988). Although the farinograph has long been a standard tool to generate information concerning the mixing and absorption characteristics of flour, these measurements neither translate directly to baking test results nor always correspond with measurements

made by other types of recording mixers. The information is useful in comparing differences among flours (Walker & Hazelton, 1996).

Farinograph values include the arrival time when the top of the curve first intersects the 500 Brabender unit line as the water is being absorbed rapidly. Shorter arrival times result when protein levels (within a wheat variety) increase. The time required to reach a point of maximum dough consistency, before any indication of dough breakdown, is considered to be the dough's development or peak time. Occasionally a farinogram posses two peaks. The second peak is regarded as the true peak, and the first is sometimes called the false or hydration peak. The departure time is the time at which the top of the curve drops below the 500 BU line. A long departure time suggests a strong flour. Stability or tolerance is the difference in minutes between the arrival and departure times and is an indication of the flour's tolerance to mixing. The time to breakdown is defined as the time from the start of mixing to the time at which the curve has dropped by 30 BU from the peak point. The valorimeter value is a graphically determined, single-value, quality score and is based on a correlation of the peak time and the rate of breakdown. Absorption is the most widely accepted farinograph measurement. A flour's expected absorption can be estimated by its moisture and protein content (Walker & Hazelton, 1995). Lower absorption may be due to a lower protein content (Kosmolak & Dyck, 1981).

The farinograph method allows for dough development and a greater increased water-binding potential by the protein which should then become a major determining factor in water-absorption (Fowler & De la Roche, 1975a).

Fowler & de la Roche (1975b) suggested development time as a useful test for early generation selection in wheat. Farinograph development time was characterised by heterogeneous correlations with starch damage, but was highly positively correlated with extensigraph length and area (Baker *et al.*, 1971).

Dough strength characteristics (extensograph or farinograph) have been predominantly correlated with high molecular weight gluten subunit (HMW-GS) composition. Knowledge of the relationship between the low molecular weight gluten subunits (LMW-GS) and dough property is much more limited, even though these subunits represent the majority of the protein present in the glutenin complex (Andrews & Skerritt, 1996).

The 1B/1R translocation does not generally have a negative effect on farinograph water absorption (Dahliwal *et al.*, 1987).

2.3.2.3 Baking characteristics

1 Loaf volume

None of the milling and rheological measurements are capable of fully predicting the end performance of a flour. These measurements serve as indexes that, when properly interpreted, increase the probability of satisfactory performance. The ultimate criteria of quality in flours are its conformance to chemical and physical requirements plus its adherence to certain standards as established by a performance or baking test (Mailhot & Patton, 1988). The baking test is still the only reliable method for determining the breadmaking performance of wheat flour (Wikström & Bohlin, 1996).

In loaf volume, a complex of factors such as protein content, protein type and oxidation requirements come into play (Marais, 1982).

According to Fowler & De la Roche (1975a) the baking test is usually considered the final measure of wheat quality and as such the degree of association of other prediction tests with this test was given primary emphasis. Kernel hardness gave the highest correlation with loaf volume. Within a cultivar, the majority of variation in loaf volume can be attributed directly to variation in protein quantity

(content). When variability due to genetic differences was considered, the remainder of the quality measurements took on greater importance.

Differences in bread baking quality have usually been attributed to differences in protein quality. Dough development is the factor which is of primary importance in our interpretation of protein quality. Protein quality is considered a function of dough development with its manifestation in the baking test being procedure-dependant (Fowler & De la Roche, 1975a).

Wikström & Bohlin (1996) stated that there are several wheats with approximately the same protein content but with large differences in bread volume. The obvious conclusion is that the prediction capacity should be rather low. This was confirmed by results achieved from a partial least squares regression model, where protein alone explained only 55 percent of the variation in bread volume. This should be compared with the mixogram parameter build up, which alone explained 77.9 percent. If a new calibration was made where protein was included together with the mixogram parameters, the explained variation in bread volume increased to 92.8 percent.

Finney & Shogren (1972) concluded that loaf volume at the 13 percent protein level (protein quantity) increased as mixing time increased from about one minute to about three minutes. Beyond three minutes, loaf volume at 13 percent protein is approximately constant with increasing mixing time.

Baker *et al.* (1971) found that loaf volume was highly correlated with protein content, farinograph absorption and dough development time. Stronger flours, as measured by farinograph developmental time, resulted in greater loaf volumes. Loaf volume will increase with increasing strength to the point where the flour becomes to strong. Beyond this point, increases in strength will cause decreases in loaf volume.

The genetic as well as the phenotypic correlations between baking volume and baking score were found to be highly significant and positive (Bhatt & Derera, 1975).

2.3.2.4 Yield characteristics

1 Thousand kernel mass

Kernel size is usually reported as mass per 1000 kernels. In smaller kernels the ratio of endosperm to bran is smaller and low thousand kernel mass results in low hectolitre mass (Dick & Matsuo, 1988).

A low genetic correlation existed between thousand kernel mass and hectolitre mass. A significant phenotypic correlation but a low genetic correlation was found between grain yield and thousand kernel mass (Jalaluddin & Harrison, 1989). Thousand Kernel mass has been identified as a very reliable criterion for yield losses (Pretorius, 1983). The correlation coefficient between thousand kernel mass and protein content was not significant (Pomeranz *et al.*, 1985).

2. Yield

Until recent times, the perception amongst wheat growers that increases in yield can only be achieved at the cost of producing poor quality grain, has not been a serious deterrent to increasing yields, since the major determinant of profit has been yield rather than the premiums paid for quality. This is now changing as world markets move from being price to quality conscious (Anderson, Shackey & Shawkins, 1996).

Grain yield and grain protein percentage were negatively correlated ($r = -0.48$), and no single selection criterion proved of value in improving both traits simultaneously (Löffler & Busch, 1982). This relationship, however, can be broken if environmental factors, water supply and ground nutrients are

favourable (Cox, Qualset & Rains, 1985). Lorenzo (1985) reported that the association between grain protein concentration and biological yield was different for spring and winter wheat cultivars. He suggested that biomass yield could be used as a selection criterion in winter wheat to improve grain yield and grain protein concentration simultaneously, but not in spring wheat where a negative association between grain protein concentration and biological yield was observed (Costa & Kronstad, 1994).

2.3.3 Heritability

Duplication of factors that mask or inhibit effects of genes and the presence of minor or modifying genes make genetic analysis of quantitative characters difficult in polyploid plant species such as wheat (Bhatt, 1972).

Heritability is a measure of the ability of the plant breeder to recognise genetic differences among cultivars, and genetic variance indicates the potential for improvement in a population. Successful selection is dependent on a high heritability of characteristics. To use breeding techniques other than backcrossing for the improvement of quality and yield, a plant breeder must know the inheritance of quality traits and of the joint inheritance of quality and agronomic traits (Baker *et al.*, 1971). Thus, the extent to which response to selection for a given trait can be expected or observed is reflected by its heritability, which is a measure or the degree of correspondence between the phenotype and genotype. Because quality characteristics are phenotypic observations, the accuracy with which a particular set measures the genotypic value can be assessed by its heritability (O'Brien & Ronalds, 1987).

In general, the heritability for most quality traits is higher than those for yield (Fowler & De la Roche, 1975b).

Jalaluddin & Harrison (1989) found that the heritability of hectolitre mass was higher than that of grain yield, probably because hectolitre mass is comparitively

less complex, and the components of hectolitre mass are less vulnerable to environmental fluctutions in the normal range.

Baker *et al.* (1971) estimated heritability of quality characteristics as the ratio G / (G x E), where G was the component of variance due to average (genetic) differences among cultivars and E was the component due to deviations from average performance. The heritability estimates of these traits are presented below:

Grain protein	80%
Flour yield	66%
Flour protein	88%
Flour colour	62%
Starch damage	82%
Farinograph	
Absorption	80%
Development time	62%
Extensograph	
Length	47%
Resistance	48%
Area	71%
Baking volume	63%

Bhatt & Derera, (1975) found the heritabilities for hectolitre mass (66%), flour yield (75%), grain protein (72%), flour protein (78%) and flour colour (73%) were high to very high. Baking score (55%) and baking volume (59%) indicated moderate heritabilities.

Bhatt (1972) undertook a study to determine the inheritance of thousand kernel mass. The individuals in the population were normally distributed. Partial dominance of genes controlling high kernel mass was evident, and the additive component of variation was higher than the dominance component. This

indicated a good probability of success in selecting for higher thousand kernel mass in crosses.

O'Brien & Ronalds (1987) found low heritability estimates for the small-scale early generation measures for flour extraction and flour protein content. The estimates of protein quality, residue protein content and SDS volume were all high.

Protein quality of red winter wheat kernel is heritable with partial dominance of low protein (Leonard & Martin, 1963). Crude protein values segregate similarly to other quantitative characters (Ausemus *et al.*, 1967), because of the multiple genes controlling this trait (Haunold, Johnson & Schmidt, 1962).

The within-cross estimates varied between crosses, largely reflecting the reduced range for the various traits, but were generally high for SDS volume and protein content. The heritability of grain hardness was very high, both within individual crosses and for the data pooled over crosses (O'Brien & Ronalds, 1987).

The percentage heritability estimates for standard macro-measures showed that the farinograph water absorption was highly heritable, both within crosses and for data pooled over crosses (O'Brien & Ronalds, 1987).

2.3.4 Correlated response

If character X is selected, what will the change be in the correlated character Y? The expected response of Y, when selection is applied to another character X is called the correlated response. Consideration of correlated responses suggests that it might sometimes be possible to achieve more rapid progress under selection for a correlated character than from selection for the desired character itself. In other words, if character X has to be improved, another character Y can be selected and progress achieved through the correlated response of character X. This procedure is also known as indirect selection (Falconer, 1981).

If the genetic correlation of the characteristics is high, and there are no special circumstances affecting the heritability or the intensity of selection, it will make little difference in which environment the selection is carried out. But if the genetic correlation is low, it will be advantageous to carry out the selection in the environment for which the population is destined (Falconer, 1981).

CHAPTER 3

MATERIALS & METHODS

3.1 Experimental Materials

The chosen parents, and the reasons for use in the crosses, are listed below with their relevant agronomic, quality and disease resistance data (five cultivars and one advanced breeding line):

Palmiet-PCH 1

This cultivar possesses eyespot resistance, good yield, stem rust resistant genes (Sr 2 & Sr 24) and leaf rust resistant gene (Lr 24). However, this cultivar has poor quality characteristics regarding protein and extraction.

Kariega

This cultivar has good yield, stem rust resistance (Sr 24), leaf rust resistance (Lr 34), and yellow rust resistance (Yr 18 & Yr A). Furthermore this cultivar has excellent quality characteristics.

SST 57

This cultivar has a solid stem and resistance to eyespot. Excellent yield, resistance against leafrust, stemrust and yellowrust. It generally possesses reasonable quality.

Gamtoos

The cultivar was chosen for the good agrotype and the 1B/1R translocation. Stemrust gene (Sr 31) and yellow rust gene (Yr 9) are present. Poor quality is attributed due to the 1B/1R translocation.

Nantes

Nantes was the previous quality standard in the Western Cape. This cultivar has a moderate yield, leafrust resistance and yellowrust resistance (Yr 6).

W92-1

This advanced line has excellent protein content, with an extraction problem. The line has leaf rust resistance and stem rust resistance.

The parents were crossed using Griffing's diallel (Model 1, the experimental material is regarded as the population about which conclusions are being made and method 2: parents and one set of F2's are included but not reciprocals). Crosses were conducted during 1996, August to November, in the greenhouse at Bethlehem experimental farm. Crosses were made in only one direction, excluding reciprocals, because kernel characteristics such as kernel plumpness measurements, flour extraction and total flour protein content may be assumed to be the only function primarily of the mother plant's adaptability (Marais, 1982). See Table 3.1.

Parent lines were planted in two-litre pots filled with sand. The four plantings were made at weekly intervals to synchronise the available pollen for cross fertilisation. Temperatures of 18° C (night) and 22° C (day) were maintained in the greenhouse. The plants were watered by means of drip-irrigation. The length of an irrigation cycle depended on the growth-stage of the plants.

To generate F2 seed, the F1-seed, harvested from the 15 hybrid combinations during November 1996 were planted for seed multiplication in the greenhouse at Bethlehem during December 1996, under the same conditions as the parents. Nitrogen supplement was given weekly.

3.2 Trials conducted

Two different experiments were conducted:

3.2.1 Evaluation trial of parental cultivars

During the 1996 season, the six parents were planted at the Langgewens and Tygerhoek experimental farms. The trial was planted on a wheat on wheat land as this is representative of the way the farmers grow wheat under dry land conditions.

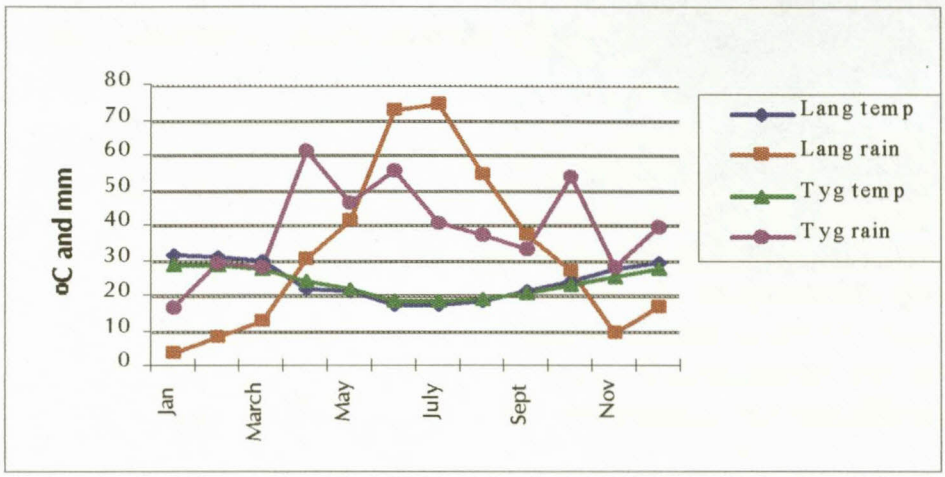


Figure 3.1 Average climatic data for Langgewens (Lang) and Tygerhoek (Tyg).

Langgewens is an experimental farm in the Swartland whereas Tygerhoek is in the Rûens area. Although both these localities are in the Western Cape, climatic differences occur. The rainfall patterns of these two localities are different: the Swartland receiving mostly winter rain, whereas the Rûens receives winter as well as early spring rains (Figure 3.1). The most important climatic data is for the months May to October during which spring wheat is grown. In these regions, wheat flower approximately 108 days after plant. During this time, and the following grain fill, temperatures are critical. During 1996, when the trial was conducted, normal temperatures and rainfall prevailed, correlating well with the average data. On average the wheat in the Rûens has a protein content of 0.75 % to 1% higher than in the Swartland due to the different soil types.

A randomised complete block design (RCBD) with four replications was used. The planting dates for Langgewens and Tygerhoek were 21/5/1996 and 24/5/1996, and the harvesting dates 27/11/1996 and 9/12/1996, respectively. Seedbeds were

prepared with 60-kg nitrogen and 13-kg phosphate per hectare before planting. At growth stage five and growth stage ten the trial was fertilised with 30 kg nitrogen per hectare. Tilt was sprayed to control rust infections, while Metasystox and Rogor were used for aphid infections. Weeds were controlled with Gleen, Buctril and Hoelon.

3.2.2 Diallel trial of parents and F2 progeny

Table 3.1 Summary of the crosses and parental lines used in the diallel analysis.

Entry	ID	Name
1	M2/M1	Kariega/Gamtoos
2	M3/M1	Palmiet/Gamtoos
3	M3/M2	Palmiet/Kariega
4	M4/M1	Nantes/Gamtoos
5	M4/M2	Nantes/Kariega
6	M4/ M3	Nantes/Palmiet
7	M5/M1	SST 57/Gamtoos
8	M5/M2	SST 57/Kariega
9	M5/M3	SST 57/Palmiet
10	M5/M4	SST 57/Nantes
11	M6/M1	W92-1/Gamtoos
12	M6/M2	W92-1/Kariega
13	M6/M3	W92- 1/Palmiet
14	M6/M4	W92-1/Nantes
15	M6/M5	W92-1/SST 57
16	M1	Gamtoos
17	M2	Kariega
18	M3	Palmiet
19	M4	Nantes
20	M5	SST 57
21	M6	W92-1

The F2 generation, harvested during March 1997 in the greenhouse at Bethlehem, together with the parents, was planted at Langgewens experimental farm during early June 1997. A F2 diallel was used in order to generate enough seed for a replicated planting at Langgewens. Again a randomised complete block design (Basset *et al.*, 1989; Ehdaie, Waines & Hall, 1988) with four replications was used. Plots consisted of three rows per entry. Rows were five metres in length with interrow and interplant spacing 37 cm and 5 cm, respectively. Seeds were sown 5 cm apart to minimise yield variation due to variation in sowing rates (Halloran, 1981).

According to the soil analysis, the nitrogen (N) need was 107 kg.ha $^{-1}$ and the potassium (P) need 13 kg.ha $^{-1}$. Before planting, the plots received 200 kg 4:1:0 per ha which amounts to 46 kg of N and 12 kg of P per hectare. At growth stage five and ten respectively, 110 kg.ha $^{-1}$ LAN was top-dressed which released 30 kg N.ha $^{-1}$ per dressing, resulting in a total N of 106 kg.ha $^{-1}$. Tilt was sprayed to control rust infections, while Metasystox and Rogor were used for aphid infections. Weeds were controlled with Gleen, Buctril and Hoelon.

3.3 Characteristics determined

The inheritance of milling and baking quality, like the inheritance of yield, is extremely complex. It is necessary to quantify the components of quality and to analyse the inheritance of each component separately (Poehlman, 1987). One kilogram of seed of each parental entry (1996), as well as the parents and F2 lines (1997), were submitted for the following quality evaluations:

3.3.1 Milling characteristics

3.3.1.1 Grain protein (AACC method 46-10) (GPC)

(only diallel trial)

The macro-Kjeldahl procedure was used (Marais & D'Appolonia, 1981b). To a weighed sample, sulphuric acid (H_2SO_4) was added. Selenium was used as catalyst. An organic compound was formed. Released ammonia is distilled in Boric acid, and

titrated in Potassium chloride (KCL). Nitrogen (N) was measured.

Crude protein = N x 5.7

3.3.1.2 Flour protein (AACC method 39-11) (FPC)

An infrared reflectance spectrophotometer was used. Calibrations were done using Kjeldahl data. The protein reading of the flour sample is given as a percentage.

3.3.1.3 Bühler extraction (AACC method 26-21A) (EX)

Bühler extraction reffers to test milling of wheat. The Bühler was calibrated at 76% extraction rate using the standard Betta. Hardness and moisture content of the sample was measured before milling to determine the amount of water required for the milled monster. White flour, reduction flour, bran and pollard were used for extraction calculations.

Extraction was calculated as:

$$\% \text{ extraction} = \frac{\text{Weight of flour through 118 } \mu\text{m sieve}}{\text{weight of total products}} \times 100$$

The Bühler milling score was calculated as:

Milling score: 100 - [(80- flour yield) + 50(flour ash - 0.30) + 0.48(milling time - 12.5) + 0.5(65 - % long parent) + 0.5(16 - first tempering moisture)] (Gaines *et al.*, 1996).

3.3.1.4 Break flour yield (BFY)

(only diallel trial)

The first three fractions of white flour, obtained during Bühler extraction, are referred to as break flour yield.

3.3.1.5 Falling number (AACC method 56-81B) (FN)

(only diallel trial)

This method is based on the unique ability of α -amylase to liquefy starch gel. Strength of the enzyme was measured by the falling number, defined as time in seconds required to stir and allow stirrer to fall a measured distance through a hot aqueous flour or meal gel undergoing liquefaction.

3.3.1.6 Flour colour (FCL)

Colour was measured with the "Maartin colour grader" instrument. The instrument was calibrated against a flour sample with a known colour (standard), where after the samples were read one by one against the standard.

3.3.1.7 SDS sedimentation (AACC method 56-61-A)

(only diallel trial)

The sedimentation test reflects differences in quality and quantity of gluten in wheat (or flour) and hence is a rough measure of baking strength. Sedimentation values can range from 20 or less for low-protein wheat and as high as 70 or more for high protein wheat with superior bread-baking strength.

The test was performed manually in a 100 ml cylinder filled with 50 ml water kept at 220 °C in a water bath. Four gram of flour was mixed with the water and shaken three times at regular time intervals. A lactic acid mixture was added to the flour mixture and inverted at regular time intervals. Six minutes after the third inversion, a reading was taken of the cylinder.

3.3.1.8 Hectolitre mass (HLM)

The analysis was done with the "Dicky John". Sufficient grain is placed in the hopper to ensure that when the grain flows into the quart kettle, it overflows. Excess seed is removed. The weight of the remaining seeds is recorded. This parameter was used to

estimate the expected flour after milling.

3.3.2 Rheological characteristics

3.3.2.1 Mixograph (AACC method 54-40-A) (MDT)

The mixograph measures and records resistance of a dough to mixing. A mixogram was recorded on paper during the length of the mixing action. The mixing curve (mixogram) indicates optimum development time, tolerance to overmixing, and other dough characteristics and estimates baking absorbtion. The mixograph has been used to study the effects of added ingredients on mixing properties, dough rheology, blending and quality control, and for evaluation of hard, soft and durum wheats.

3.3.2.2 Farinograph (AACC method 54-21)

(only evaluation trial)

The farinograph functions by measuring the resistance of dough, obtained from a flour and water mixture, against sigmoid-shaped mixing paddles turning at a 5.1:1 differential speed.

The farinograph measures and records resistance of a dough to mixing. It was used to evaluate absorption of flours and to determine stability and other characteristics of doughs during mixing.

3.3.3 Baking characteristics

3.3.3.1 Loaf volume (AACC method 10-9) (LFV)

The long fermentation bread baking method was used. This method provided a basic baking test for evaluating bread-wheat flour quality by a straight-dough process that employed long fermentation and in which all ingredients (flour, salt, yeast, water, sugar, malt, ammonium phosphate) were incorporated in the first mixing step. Ingredients may be combined in dry form, but efficiency and accuracy were

increased when solutions and suspensions were prepared in advance.

The volume of the baked bread was measured by rapeseed displacement within 10 minutes after removal from the oven.

3.3.3.2 Baking strength index (BSI)

(only experimental trial)

This predicted value ranges from 1 – 10. The index expresses actual loaf volume as a percentage of the volume that can be expected of a cultivar with acceptable baking quality. Betta is considered the standard and the BSI is calculated according to the formula (Van Lill & Purchase, 1995):

$$BSI = \frac{LFV_{\text{experimental flour sample at x percent FPC)}}\ (100)}{LFV_{\text{Betta at x percent FPC}}}$$

3.3.4 Yield characteristics

3.3.4.1 Thousand kernel mass (TKM)

The wheat sample should be clean and free from mechanical and insect damage for the best results. A thousand kernels are counted in a numerical grain counter, and weighed. The higher the mass, the better the plumpness of the kernels. This test is also used to estimate flour yield after milling.

3.3.4.2 Yield per plot

(only experimental trial)

Because of the negative correlation between seed yield and certain quality characteristics, yield tests should also be taken into account; therefore, the yield (g/plot) was also evaluated.

The same quality evaluation method as used for the parents was used to evaluate the F2 seed, together with the F2 set of parents, planted at Langgewens experimental farms during 1997. Estimations were that 700 g seed per plot, per replication would be necessary for similar quality evaluations as those done on the parents during 1996.

3.4 Statistical analysis

3.4.1 Evaluation trial of parental cultivars

The parental lines, planted at both Langgewens and Tygerhoek, were analysed according to the quality and yield data over the two localities.

3.4.1.1 Analysis of Variance (ANOVA)

An ANOVA was performed from which localities, cultivars and the locality and cultivar interactions can be seen. Genotype means can be compared using the LSD (0.05) procedure.

3.4.1.2 Correlation matrix

A correlation matrix, to calculate the phenotypic correlations, was performed for both Langgewens and Tygerhoek. The GENSTATS program was used to perform the analysis based on the formulas of Draper & Smith (1981).

Heredity and environment overlap extensively in the shaping of the phenotype. Phenotypic correlations between different characters result from combinations of genetic and environmental correlations (Rieger, Michaelis & Green, 1976).

$$rxy = \frac{Cov\ xy}{\sqrt{Vx.Vy}}$$

3.4.2 Diallel trial of parents and F2 progeny

The harvested F2 seed, together with the parental lines planted at Langgewens experimental farms, were analysed as a F2 diallel. Statistical analysis was performed on a GENSTAT programme.

3.4.2.1 Analysis of Variance (ANOVA)

Data was analysed for descriptive statistics and analysis of variance (ANOVA) (Gaines *et al.*, 1996). The ANOVA is used to evaluate the responses of each character within each experiment (Ehdaie *et al.*, 1988). The ANOVA was carried out for the F2 generation for each characteristic evaluated. The ordinary ANOVA is an additive model and therefore describes only the main effects effectively. ANOVA provides no insight into the particular patterns of genotypes or environments that give rise to interaction (Zobel, Madison & Gauch, 1988). Significance can be evaluated by an approximate chi-square test (Souza & Sunderman, 1992).

Analysis of variance for diallel cross method 4 (Wricke & Weber, 1986):

Source	d.f.	m.s.	E. (m.s.)	Variance component
GCA	k - 1	m_1	$\sigma^2_e + r\sigma^2_{sca} + r(k - 2)$ $r\sigma^2_{gca}$	$\sigma^2_{gca} = C(HS)$
SCA	k(k - 3) / 2	m_2	$\sigma^2_e + r\sigma^2_{sca}$	$\sigma^2_{sca} = C(FS) -$ 2C(HS)
Blocks	r – 1	m_3	-	-
Errors	$(r - 1)(k^2 - k - 1)/2$	m_4	σ^2_e	$\sigma^2_e \approx \sigma^2$

VF2 = the variance of F2. The genetic variance (Vg) is calculated by subtracting the environmental variance (Ve) from the total variance, i.e. Vg = VF2 - Ve. The

environmental Ve was calculated from the parental variances (Vp1, Vp2) and the F1 variance (VF1) by the formula:

Ve = ¼ Vp1 + ½ VF1 + ¼Vp2 (Levy & Feldman, 1988).

k = number of parents

$$HS = \text{half sib: } C(HS) = \frac{1 + F}{4}\sigma^2_A + \ldots\ldots$$

$$FS = \text{Full sib: } C(FS) = \frac{2 + F_m + F_f}{4}\sigma^2_A + \frac{(1 + F_m)(1 + F_f)}{4}\sigma^2_D + \ldots\ldots$$

F = inbreeding coefficient of the genotypes tested.

3.4.2.2 Combining abilities (general & specific)

The GCA and SCA, as well as the relationship between these two values, were evaluated.

In the combining ability analysis, the variety effects are considered in terms of GCA and SCA effects, such that:

$$V_{ij} = g_i + g_j + s_{ij}$$

for those diallel crossing methods in which reciprocal F2's are not included.

Source	D.F.	Sum of Squares	Mean Squares	Expectation of mean Squares
GCA	p-1	S_g	M_g	$\sigma^2 + (p+2)(1/p\text{-}1)\sum g_i^2$
SCA	p(p-1)/2	S_s	M_s	$\sigma^2 + 2/p(p\text{-}1)\sum_i\sum_j s_{ij}^2$
Error	M	S_e	M_e'	σ^2

Where:

$$S_g = \frac{1}{p+1}\left\{\sum_l (X_i + x_{ii})^2 - \frac{4}{p} X..^2\right.$$

$$S_s = \sum_{i \leq} \sum_j x_{ij}^2 - \frac{1}{P+2_i}\sum(X_i + x_{ii})^2 + \frac{2}{(p+1)(p+2)} X..^2$$

The mathematical model for the combining ability analysis is assumed to be

$$Xij = u + g_i + g_j + s_{ij} + \frac{1}{bc}\sum k \sum_l e_{ijkl}$$

i.j = 1, ..., p
k = 1, ..., b
l = 1, ..., c

u = population mean
$(g_i)g_l$ = gca
s_{ij} = sca

The effects may be estimated as follows:

For GCA effects:

$$g_l = \frac{1}{p+2}\left[X_i + x_{ii} - \frac{2}{p} X..\right]$$

The LSD between GCA was calculated as

$$LSD = q\,\alpha;t,f.\,\sqrt{S^2_E/r} \qquad (t = 0.5)$$

$q\alpha;t,f$ = α value at t treatment's degree of freedom and error's degrees of freedom

For SCA effects:

$$s_{ij} = x_{ii} - \frac{1}{p+2}[X_i + x_{ii} + X_j + x_{jj}] + \frac{2}{(p+1)(p+2)} X..$$

The LSD between SCA effects was calculated as

$$LSD = q\alpha;t,f.\,\sqrt{S^2_E/r} \qquad (t = 0.5)$$

q α;t,f = α value at t treatment's degree of freedom and error's degrees of freedom.

3.4.2.2.1 GCA:SCA

The GCA : SCA ratio indicates whether GCA or SCA effects are predominant and which factor plays a more important role in exercising genetic control. This ratio also indicates whether a character is mainly under the control of additive / non-additive (dominant) gene action (Sing *et al.*, 1986).

3.4.2.2.2 Additive gene action

The relative importance of GCA and SCA determining progeny performance should be assessed by estimating the components of variance and expressing them in the ratio:

$$2\sigma^2_g / (2\sigma^2_g + \sigma^2_s).$$

The closer this ratio is to unity, the greater the predictability based on general combining ability allone (Baker, 1978).

3.4.2.3 Genetic correlations

A phenotypic correlation matrix was calculated for all the quality and yield characters determined (see evaluation trial). A genetic correlation matrix was also performed on the F2 trial. Genetic correlations can arise from pleiotropy, linkage or introduction of genes involved into a population (Rieger *et al.*, 1976).

3.4.2.4 Heritability

Heritability is in fact a regression coefficient of genotypic values (G) on phenotypic values (P). It is defined as the ratio of genotypic to phenotypic variance (Wricke & Weber, 1986), thus the portion of phenotypic variation among individuals due to genetic differences among them. Broad and narrow sense heritability was determined.

The broad sense heritability is the extent to which the genotype influences the phenotype, and is therefore calculated from the ratio of the total genetic variance to the phenotypic variance according to the formula:

$h^2 = \sigma^2_G / \sigma^2_P = V(G) / V(P)$.

The broad sense heritability of grain protein percentage was calculated according to the formula:

$h^2 = (Vg / VF2)$

The narrow sense heritability expresses the extent to which the phenotypes are determined by the genes transmitted from the parents, and was estimated from the ratio of the additive portion of the genetic variance to the phenotypic variance according to the formula:

$h^2 = \sigma^2_A / \sigma^2_P$

Where $\sigma^2_A = 2\,\sigma^2_{GCA}$

The variance components were calculated according to Griffing (1956(b)):

$\sigma^2_G = 2\,\sigma^2_{GCA} + 2\,\sigma^2_{SCA}$

Where: $\sigma^2_{GCA} = \dfrac{MS_{GCA} - MS_{SCA}}{p-2}$ $\qquad \sigma^2_{SCA} = MS_{SCA} - MS_E$

$\sigma^2_P = \sigma^2_G + 2\,\sigma^2_E$

3.4.2.5 Correlated response

The response of a correlated character can be predicted if the genetic correlation and the heritabilities of the two characteristics are known. Direct response to selection is

when selection is applied directly to the desired characteristic. Indirect selection is the response obtained for one characteristic when selection was applied to another characteristic, resulting in an indirect response.

Let R_X be the direct response of the desired character (if selection were directly applied); and let CR_X be the correlated response of character X resulting form selection applied to the secondary character Y. The merit of indirect selection relative to that of direct selection may then be expressed as the ratio of the expected responses, CR_X/R_X.

Then $$\frac{CR_X}{R_X} = \frac{i_Y h_Y r_A \sigma_{AX}}{i_X h_X \sigma_{AX}}$$

$$= r_A \frac{i_Y}{i_X} \frac{h_Y}{h_X}$$

Where r_A = genetic correlation between X and Y

h = $\sqrt{h^2}$ = direct selection (Falconer, 1981).

i = selection intensity.

A tabulated i value can be used according to the selection intensity, but because this is just used for predictions and comparisons only, the value was taken as 1 in all the calculations.

If the same intensity of selection can be achieved when selecting for character Y as when selecting for character X, then the correlated response will be greater than the direct response if $r_A\ h_Y$ is greater than h_X. Therefore indirect selection cannot be expected to be superior to direct selection unless the secondary character has substantially higher heritability than the desired character and the genetic correlation between the two is high; or unless a substantially higher intensity of selection can be applied to the secondary character.

CHAPTER 4

RESULTS & DISCUSSION

4.1 Evaluation trial of parental cultivars

4.1.1 ANOVA

An analysis of variance was performed on all the milling, rheological, baking and yield characteristics across localities (Tables 4.1 and 4.2).

Locality had a significant influence on most of the characteristics (FPC, EX, FCL, MDT, FA, LFV, BSI, TKM, and yield - Table 4.5). These results agree with previous findings by Bhatt & Derera (1975), Terman (1979) and Fowler & De La Roche (1974b). HLM, FST and FDT were not influenced by the environment. The lack of influence of locality on HLM is contrary to the results of Fowler & De La Roche (1974b) and Gaines *et al.* (1996) who reported a major significance of environment. This difference may be explained by the fact that

(i) the environments in this study were more diverse

(ii) some or all the cultivars used in this study had a narrower range of adaptation.

The effect of cultivar was significant for all the characteristics, except FCL. Cultivar and location interaction was significant for all the characteristics, except EX, FCL, MDT and TKM. This was in contrast with findings by Bhatt & Derera (1975) who found significant genotype x environment interactions for EX, and Shuey (1975) who reported significant location and cultivar inconsistencies for FCL. Fowler & De La Roche (1974b) however, reported a significant cultivar x location interaction for TKM.

Because most of the quality characteristics are polygenic, the environment plays a significant role. Some cultivars, however, are more stable over environments, and as such should be used more often in breeding programmes, as they will give a stable yield irrespective of the environment in which they are grown.

Table 4.1 Analysis of variance for quality characteristics across localities

Characteristics		Milling				Rheological				Baking		Yield	
Source	D.F.	FPC	EX	FCL	HLM	MDT	FA	FST	FDT	LFV	BSI	TKM	YIELD
Loc.Rep stratum													
Locality	1	14.74**	69.12**	14.30**	0.16 ns	1.17*	104.73**	11.9 ns	0.07 ns	74419**	133.34*	25.96**	18484695**
Residual	6	0.31	0.18	0.46	1.19	0.09	0.52	3.46	0.45	657	12.21	0.579	112621
Loc.Rep.Cult stratum													
Cultivar	5	1.83**	24.01**	2.35 ns	6.01**	0.71**	13.78**	29.9**	1.18*	11180**	99.55**	103.5**	186359**
Loc.Cult	5	2.21**	1.29 ns	1.98 ns	3.34**	0.09 ns	3.90**	10.85*	1.55**	7465**	23.43*	3.185 ns	385576**
Residual	30	0.37	0.56	0.84	0.14	0.04	0.5	4.25	0.32	1365	5.66	1.247	32272

Table 4.2 Standard errors and coefficients of variation of the different quality and yield characteristics determined

	Milling								Rheological								Baking				Yield			
	FPC		EX		FCL		HLM		MDT		FA		FST		FDT		LFV		BSI		TKM		YIELD	
	s.e.	cv %	s.e.	Cv%	s.e.	cv%	s.e.	cv%	s.e.	cv%	s.e.	cv%	s.e.	cv%	s.e.	cv%	s.e.	cv%	s.e.	cv%	s.e.	cv%	s.e.	cv%
Loc.Rep	0.23	1.9	0.18	0.2	0.28	18.8	0.17	0.2	0.12	4.5	0.29	0.5	0.76	8.2	0.27	5.3	10.5	1.0	1.43	1.3	0.31	0.8	137.0	6.8
Loc.Rep.Cult	0.61	5.0	0.74	1.1	0.92	62.1	0.37	0.5	0.19	6.8	0.7	1.1	2.06	22.4	0.58	11.1	36.9	3.4	2.38	2.1	1.12	2.8	179.6	8.9

4.1.1.1 Comparison of data for the two localities

The averages of the characteristics of each locality are shown in Figures 4.1 to 4.4. The cultivars performed significantly better at Langgewens with regards to the EX and yield, whereas at Tygerhoek the FPC, LFV and TKM were significantly higher. From this data it is evident that the temperature and rainfall plays a significant role in quality characteristics. Drier climates give rise to better FPC which is usually correlated with a higher LFV, whereas increased yield is probably the result of higher rainfall.

The cultivars were compared separately for the two localities, and data is summarised in Tables 4.3 and 4.4. A cultivar with a high value for the important characteristics, and stability over environments, should be used in breeding programmes. The following assumptions can be made from this data:

Milling characteristics

FPC: At Langgewens, the only significant difference between cultivars was that of Palmiet (with the highest value) and W92-1(the poorest protein value). Nantes and Gamtoos performed second and third best, respectively. At Tygerhoek, Nantes performed the best, significantly better than Palmiet and W92-1, whereas SST 57, with the second highest value, showed a significantly better FPC than Palmiet. Gamtoos had the third best FPC. None of the cultivars were stable over environments for FPC. In the ANOVA 4.1.1 it is shown that locality had a significant influence on FPC.

EX: At Langgewens, SST 57 and Kariega (with the same EX values) were significantly better than all the other cultivars. Palmiet, followed by Nantes, showed a significantly higher EX than Gamtoos. At Tygerhoek, Kariega and SST 57 (0.5% lower than Kariega) again showed the highest EX values, significantly better that W92-1, Nantes and Gamtoos. Palmiet had the third highest EX value. Although the environment showed significant EX interaction, SST 57 and Kariega proved to have a consistent high value over environments for this trait.

FN: The falling number should exceed 250 seconds to be acceptable as a bread wheat. At Langgewens all the cultivars had high FN values. At Tygerhoek the FN of Nantes (121) indicates a major problem. Starch properties were affected, but the protein are still unaffected.

FCL: Kariega performed significantly better than Palmiet and SST 57, with no significant differences between the other cultivars at Langgewens. Gamtoos and Nantes respectively had the second and third best FCL. At Tygerhoek Kariega again performed the best with significantly better values than Nantes and SST 57, followed by Palmiet and W92-1. For FCL (usually significantly influenced by the environment) Kariega again showed a high, stable, value across localities.

HLM: At Langgewens, Gamtoos performed significantly better than all the cultivars, except SST 57 (second best value). SST 57 and Palmiet had significantly higher values than W92-1. At Tygerhoek, SST 57 performed significantly better than the other cultivars, whereas Gamtoos and Kariega, performed significantly better than Nantes. Although previous results showed HLM not to be influenced by the environment, SST 57 and Gamtoos was the only cultivar showing good HLM values over both environments.

Rheological characteristics

MDT: Palmiet, followed by Kariega, had significantly higher values than the other cultivars at Langgewens. SST 57 had the third highest value. At Tygerhoek, Kariega followed by SST 57 had significantly higher values than all the cultivars except Palmiet, which in turn performed significantly better than Nantes and Gamtoos. MDT showed environmental interactions. Although Kariega showed the highest MDT value, SST 57, W92-1 or Nantes should rather be used in crosses. These cultivars were stable across environments and possessed a development time of 2.4 to 2.9 which falls within the acceptable range for mixograph mixing time.

FA: At Langgewens the water absorption of Gamtoos and Nantes was significantly higher than all the other cultivars, and Palmiet had significantly higher values than SST 57. At Tygerhoek, Gamtoos again showed the highest water

absorption, significantly better than all the other cultivars. Kariega showed the second highest value, with SST 57 and Nantes third. No significant differences were observed between the remaining cultivars. This high, stable values of Gamtoos can be the result of the 1B/1R translocation, because the quality characteristics of 1B/1R translocation cultivars are affected more by the genotype than the environment (Fenn *et al.*, 1994). This translocation is stable across environments, even though FA is influenced by the environment. In this regard the stability of Gamtoos is a good trait. Dahliwal *et al.* (1987) reported that the translocation does not generally have a negative effect on water absorption. Because of the other negative effects of this translocation on the quality of wheat, this cultivar should rather not be used to improve quality characteristics, except in a cross where only the FA of an otherwise outstanding line should be improved.

FST: At Langgewens, Kariega had significanlty higher values than SST 57 and W92-1. Gamtoos had the second highest value, with Nantes and Palmiet third. Gamtoos had significantly better values than W92-1 at both Langgewens and Tygerhoek. At Tygerhoek, Kariega followed by SST 57 had the second and third highest values. Again because of the effect of the 1B/1R translocation in Gamtoos, Kariega, also stable over environments, should rather be used as a parent in crosses.

FDT: Nantes had significantly higher values than W92-1 at Langgewens. Palmiet followed by Kariega had the second and third highest values, but no significant differences occurred. SST 57 had significantly better values than al the cultivars except Kariega (second highest value) at Tygerhoek. Gamtoos had the third highest value.

Baking characteristics

LFV: At Langgewens Palmiet performed significantly better than SST 57, W92-1 and Gamtoos, and Kariega (second) performed significantly better than SST 57 and Gamtoos. Nantes had the third highest value but not significantly better than the remainder of the cultivars. At Tygerhoek, Nantes performed significantly better than Palmiet, W92-1 and Gamtoos, whereas Kariega, followed by SST

57 performed better than W92-1 and Gamtoos. Nantes' high loaf volume could be the result of the enhanced gassing power due to the α-amilase activity. Loaf volume is significantly influenced by environmental fluctuations, and none of the cultivars showed stability for this trait. Palmiet, Kariega and Nantes were the three best cultivars over both localities. This data is linked to variation in FPC.

BSI: Palmiet performed significantly better than Nantes, SST 57 and Gamtoos, and Kariega followed by W92-1 performed better than SST 57 and Gamtoos at Langgewens. Also at Tygerhoek, Palmiet had the higest value, which was significantly better than SST 57, W92-1 and Gamtoos, with Kariega significantly better than W92-1 and Gamtoos. Nantes had the third highest value. Palmiet followed by Kariega showed stable and high values over environments even though this character is environmentally sensitive.

Yield characteristics

TKM: Kariega performed significantly better than all other cultivars, except W92-1 at both Langgewens and Tygerhoek. W92-1 and Palmiet performed significantly better than all the remaining cultivars at Langgewens and all the remaining cultivars except SST 57 at Tygerhoek. For improvement of this trait, Kariega, followed by Palmiet should be used.

Yield: At Langgewens Kariega, SST 57 and Gamtoos (no significant differences between them) yielded significantly higher than Palmiet, W92-1 and Nantes, with Nantes being significantly better than the remaining two lines. At Tygerhoek, Palmiet had a significantly higher yield than all the cultivars, Gamtoos and W92-1 yielded significantly better than Nantes and SST 57, whereas Kariega yielded significantly better than Nantes. All of the cultivars proved to be adapted to one of the two environments, lower or higher rainfall, but not one cultivar proved stable across both environments.

In planned crosses Kariega, SST 57 and Palmiet should be used to improve quality characteristics because of their stability over environments, which indicates that the genotype plays a more important role in the expression of these traits.

A comparison of the averages of the quality data for all the cultivars over two localities

Figure 4.1 Milling characteristics

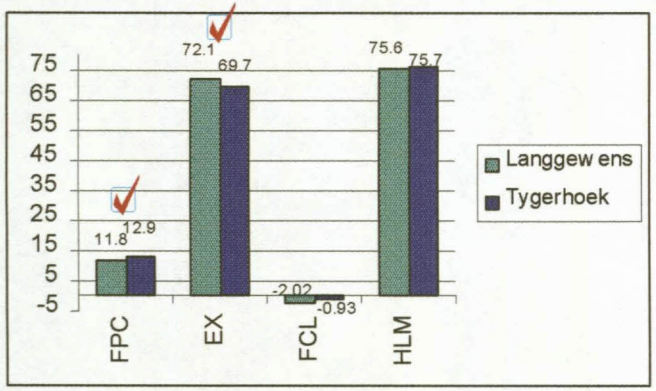


Figure 4.2 Rheological characteristics

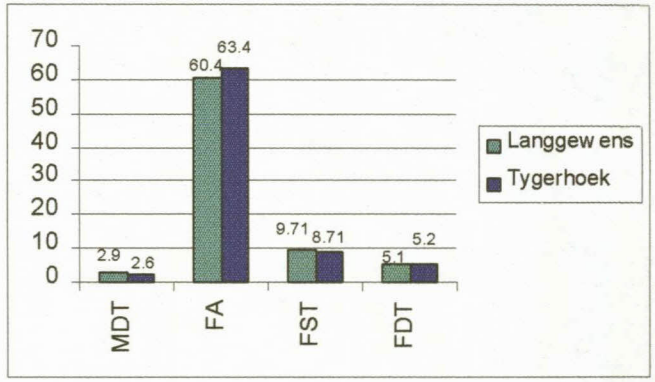


Figure 4.3 Baking chatacteristics

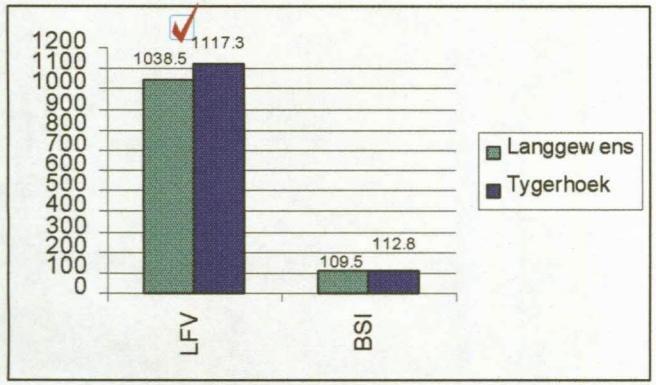
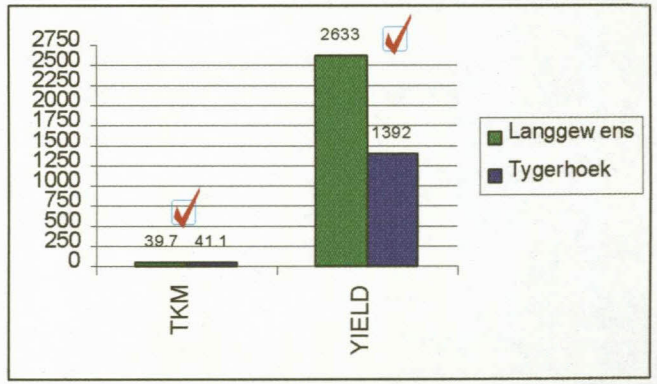


Figure 4.4 Yield characteristics



Significant differences at p = 0.05 ✓

Table 4.3 Quality and yield data of cultivars and one line at Langgewens

Characteristics	Palmiet	SST 57	Kariega	W 92-1	Nantes	Gamtoos
Milling						
FPC	12.7	11.5	11.8	10.8	12	11.9
EX	71.8	74.6	74.6	70.7	71.7	69.5
FN	367	394	425	385	400	375
FCL	-1.2	-1.1	-3.5	-1.8	-2.4	-2.8
SDS	84	80	94	90	95	72
HLM	75.6	76.1	75.4	74.7	75.4	76.5
Rheological						
MDT	3.4	2.9	3.2	2.8	2.8	2.6
FA (absorption)	60.6	58.7	60	59.4	62	62.1
FST (stability)	9.6	7.9	13.6	6.3	9.6	11.3
FDT (development)	5.6	4.8	5.4	4.4	5.7	4.7
Baking						
LFV	1125	990	1071	1049	1057	975
BSI	115	105	113	112	110	102
Yield						
TKM	41	37.5	44.2	42.4	36.2	36.6
Yield per plot	2293	2896	2991	2221	2509	2890

Table 4.4 Quality and yield data of cultivars and one line at Tygerhoek

Characteristics	Palmiet	SST 57	Kariega	W 92-1	Nantes	Gamtoos
Milling						
FPC	11.8	13.1	12.9	12.3	14.1	13.1
EX	70	71	71.5	69.4	69	67.3
FN	345	359	334	304	121	300
FCL	-1.7	-0.3	-2.3	-0.9	-0.2	-0.8
SDS	92	83	94	92	93	72
HLM	75.8	77.4	76.1	75.7	73.2	76.2
Rheological						
MDT	2.8	2.9	3	2.5	2.4	2.1
FA (absorption)	62.2	63	63.1	62.5	63	66.6
FST (stability)	8.3	9.6	9.9	7.1	6	11.1
FDT(development)	4.6	6.2	5.6	4.6	4.9	5.2
Baking						
LFV	1095	1116	1146	1068	1175	1104
BSI	117	112	115	110	114	110
Yield						
TKM	42.3	41	46.1	44.2	36.8	36.4
Yield per plot	1711	1259	1372	1389	1218	1405

Table 4.5 The LSD (0.05) for the different traits over localities, as well as the locality and cultivar interactions

	Milling				Rheological				Baking			Yield
	FPC	EX	FCL	HLM	MDT	FA	FST	FDT	LFV	BSI	TKM	YIELD
Loc	0.97	0.74	1.17	0.71	0.53	1.24	3.22	1.16	44.3	6.05	1.32	580.6
Cult	1.25	1.53	1.88	0.77	0.39	1.44	4.22	1.16	75.7	4.88	2.29	116.5
Cult x Loc	1.25	1.53	1.88	0.77	0.39	1.44	4.22	1.16	75.7	4.88	2.29	116.5

Analysis was done for data over two localities. The variables FLN and SDS were not included due to problems with homogeneity, and to ensure a reliable analysis, the variances of the cultivars were used.

4.1.2 Correlation matrix

Table 4.6 shows the correlation matrix for all the characteristics determined at the Langgewens experimental farm. A significant positive correlation existed between LFV and MDT (0.914*), FDT (0.826*) and BSI (0.876*) respectively. This implies that when breeding for an increase in MDT, FDT and BSI, an increased loaf volume will also be obtained. This is in agreement with findings from Finney & Shogren (1972) that loaf volume increased as mixing time increased at the 13 % protein level, and Baker *et al.* (1971) who reported a high correlation between loaf volume and FDT.

At Tygerhoek experimental farm (Table 4.7) a positive correlation existed between MDT and EX (0.975***) implicating a longer mixing time with a higher flour extraction. A positive correlation was also observed between HLM and FN (0.951**). Both these characteristics are sensitive to the environment, and poor environmental conditions will result in a decrease in HLM as well as FN. A negative correlation was found between yield and FPC (-0.847*) which implies that a higher protein content results in a lower yield. Löffler & Busch (1982) and Costa & Kronstad (1994) reported this traditional negative correlation between yield and protein content.

There were no similarities between correlations for the two environments. One very clear example is the high negative correlation between yield and flour protein content at Langgewens, while at Tygerhoek the same correlation value was 0.027. This again emphasises that correlations tend to be environment specific, especially for polygenic traits, and that correlations should not be taken as indicator of selection direction across environments.

In general, for the parental trial it can be said that there were no consistent correlations between characteristics across environments, and that parents should be selected on the ground of good average performance across localities.

For FPC there was no consistent performance of cultivars across localities, but Palmiet and SST 57 respectively, performed the best. For EX, Kariega and SST 57 performed consistently at both localities. Kariega also had a consistent FCL across localities. For HLM, SST 57 proved to be the most consistent over environments. Kariega was again very consistent for MDT. Gamtoos was the best cultivar for both FA and FST, but due to the 1B/1R translocation the use of Gamtoos as a parent should be avoided. Kariega, also stable for FST over environments should rather be used. For loaf volume there was no constently better cultivar. Palmiet was stable for BSI, and Kariega for TKM. There was, however, no stable yielding cultivar.

As was expected with predominantly polygenic traits, there were large genotype and environmental interactions. In spite of this, some cultivars still stood out , and should be considered as parents in a breeding programme. These cultivars were Kariega, Palmiet and SST 57.

Table 4.6 A correlation matrix for quality and yield characteristics at Langgewens

	HLM	TGM	EX	FPC	FCL	MDT	FA	FST	FDT	LFV	BSI	YIELD	FN	SDS
HLM	1													
TGM	-0.651 ns	1												
EX	-0.047 ns	0.341 ns	1											
FPC	0.41 ns	-0.209 ns	-0.03 ns	1										
FCL	-0.06 ns	-0.041 ns	0.216 ns	0.077 ns	1									
MDT	-0.275 ns	0.561 ns	0.467 ns	0.577 ns	0.373 ns	1								
FA	-0.037 ns	-0.003 ns	0.284 ns	0.775 ns	-0.078 ns	0.654 ns	1							
FST	0.339 ns	0.182 ns	0.249 ns	0.443 ns	-0.698 ns	0.224 ns	0.471 ns	1						
FDT	0.29 ns	-0.462 ns	-0.61 ns	0.51 ns	-0.619 ns	-0.224 ns	0.416 ns	0.435 ns	1					
LFV	-0.385 ns	0.444 ns	0.24 ns	0.652 ns	0.16 ns	0.914*	0.826*	0.262 ns	0.11 ns	1				
BSI	-0.769 ns	0.697 ns	0.245 ns	0.215 ns	0.196 ns	0.806 ns	0.54 ns	-0.003 ns	-0.167 ns	0.876*	1			
YIELD	0.649 ns	-0.153 ns	0.457 ns	-0.027 ns	-0.436 ns	-0.253 ns	-0.073 ns	0.651 ns	-0.007 ns	-0.409 ns	-0.588 ns	1		
FN	-0.242 ns	0.343 ns	0.699 ns	-0.311 ns	-0.468 ns	0.043 ns	0.216 ns	0.48 ns	-0.189 ns	0.039 ns	0.15 ns	0.534 ns	1	
SDS	-0.809 ns	0.48 ns	0.363 ns	-0.097 ns	-0.115 ns	0.42 ns	0.516 ns	0.037 ns	-0.078 ns	0.591 ns	0.787 ns	-0.349 ns	0.583 ns	1

ns = non significant

* = 0.05

Table 4.7 A correlation matrix for quality and yield characteristics at Tygerhoek

	HLM	TGM	EX	FPC	FCL	MDT	FA	FST	FDT	LFV	BSI	YIELD	FN	SDS
HLM	1													
TGM	0.368 ns	1												
EX	0.325 ns	0.762 ns	1											
FPC	-0.503 ns	-0.608 ns	-0.218 ns	1										
FCL	-0.26 ns	-0.687 ns	-0.358 ns	0.694 ns	1									
MDT	0.343 ns	0.758 ns	0.975***	-0.356 ns	-0.48 ns	1								
FA	0.569 ns	0.054 ns	0.497 ns	0.333 ns	0.204 ns	0.406 ns	1							
FST	0.786 ns	0.007 ns	0.019 ns	-0.137 ns	-0.263 ns	0.043 ns	0.611 ns	1						
FDT	0.152 ns	-0.607 ns	-0.707 ns	0.318 ns	0.17 ns	-0.717 ns	0.138 ns	0.631 ns	1					
LFV	-0.552 ns	-0.3 ns	0.174 ns	0.808 ns	0.257 ns	0.107 ns	0.328 ns	-0.177 ns	-0.003 ns	1				
BSI	-0.21 ns	0.312 ns	0.519 ns	-0.21 ns	-0.581 ns	0.648 ns	-0.066 ns	-0.151 ns	-0.491 ns	0.394 ns	1			
YIELD	0.205 ns	0.291 ns	-0.007 ns	-0.847*	-0.741 ns	0.199 ns	-0.494 ns	0.102 ns	-0.15 ns	-0.532 ns	0.494 ns	1		
FN	0.951**	0.574 ns	0.433 ns	-0.726 ns	-0.483 ns	0.487 ns	0.377 ns	0.648 ns	-0.06 ns	-0.649 ns	-0.025 ns	0.428 ns	1	
SDS	-0.509 ns	0.586 ns	0.513 ns	-0.148 ns	-0.364 ns	0.512 ns	-0.393 ns	-0.717 ns	-0.812 ns	0.23 ns	0.576 ns	0.131 ns	-0.269 ns	1

ns = non significant

* = 0.05

** = 0.01

*** = 0.001

4.2 Analysis of the diallel trial of parents and F2 progeny

4.2.1 ANOVA

An ANOVA was performed for the complete block design, and is shown in Table 4.8. A significant effect was found for replications for GPC, BFY, FCL, SDS, HLM, MDT and TKM. A significant genotype effect was shown for, GPC, EX, BFY, HLM, MDT, LFV and TKM.

The average for four replications of the parental lines and crosses are summarised in Figures 4.5 to 4.18.

Milling characteristics

GPC: Nantes performed the best of the parental lines, significantly better than W92-1. Palmiet had the second best value, followed by Kariega and SST 57 jointly third. No significant differences were observed between the other parental lines. The best performing cross was W92-1/Gmt, followed by Nts/Gmt, Nts/Kar, Nts/Pmt and SST 57/Pmt. All these crosses had the same or higher values than Nantes. SST 57/Kar had the lowest value, significantly lower than W92-1/Gmt. The other crosses showed no significant differences. The lowest F2 value showed a 0.5% higher value than that of the lowest parental line. Even though W92-1 showed the poorest GPC, in a cross with Gamtoos in the F2, it performed the best of all the progeny.

FPC: Again, Nantes showed the highest value, significantly better than W92-1. Palmiet and Kariega came in second and third. W92-1/Nts and Nts/Kar showed the highest F2 values (0.1% better than the best parental value), followed by Nts/Gmt, SST 57/Kar and W92-1/Gmt. Again, no significant differences were observed between the F2 values. W92-1 showed the lowest value, but in a cross with Nantes, the progeny performed better than both the parents.

EX: Kariega showed the highest parental value, significantly better than Palmiet and Gamtoos. SST 57 had the second highest value, followed by W92-1. Nts/Kar and SST 57/Kar showed the best F2 values, significantly better than

Nts/Gmt, W92-1/Gmt and W92-1/Kar. SST 57/Nts performed second best. Kariega had the best parental and overall value. Kariega's high values were present in the crosses as well.

BFY: Kariega had the best value, significantly better than al the parental lines, except Nantes with the second highest value. SST 57 followed in third place. The cross Nts/Kar performed the best, 0.9% higher than SST 57/Kar with the second highest value. Nts/Kar was significantly better than 50% of the F2-crosses. Nts/SST 57 had the third highest value. All three these crosses had a higher value than the best parental line, Kariega.

FN: Again, Kariega performed the best (parents and F2 progeny). SST 57 and Gamtoos had the same value, followed by W92-1. No significant differences were observed between parental lines. Pmt/Kar, Nts/Pmt, SST 57/Nts and W92-1/Pmt were the best F2 lines. No significant differences were observed between the F2 lines either.

FCL: SST 57 had the best parental value, significantly better than Palmiet. Kariega and Gamtoos were second and third respectively. W92-1/SST 57 had the best value (0.1% better than SST 57), followed by SST 57/Nts, SST 57/Kar and Nts/Kar. No significant differences were obtained in the F2 population.

SDS: Kariega had the highest value, significantly better than al the other parental lines. Nantes and Palmiet were second and third respectively. Nts/Kar was the best F2 cross, significantly better than all the other crosses, even the second best cross namely W92-1/Nts. Nts/Kar was 8.5% lower than Kariega.

HLM: Palmiet and W92-1 jointly had the highest value, followed by Kariega with SST 57 in third place. The F2 Nts/Pmt had the highest value (0.1 % better than Palmiet and W92-1) followed by Nts/Kar. Nts/Pmt was significantly better than W92-1/Gmt and W92-1/Nts.

Rheological characteristics

MDT: The variation between the parents varied from 2.3 to 2.8, a significant difference. Palmiet and SST 57 jointly had the highest value, followed by Kariega. W92-1 and Nantes jointly had the third best value. Gamtoos had the lowest value. The F2 crosses varied even more. W92-1/Gmt had the lowest

value of 2.2 and Kar/Gmt had the highest value of 2.9 (0.1 higher than the highest parent).

FA: Gamtoos was the best performing parent, followed by Palmiet and W92-1. Nantes had the lowest value. The crosses involving Gamtoos had the highest values as well, but less than Gamtoos. SST 57/Gmt performed the best, followed by W92-1/Gmt and Pmt/Gmt. W92-1/SST 57 had the lowest value.

FST: Kariega, followed by Gamtoos and SST 57 were the three best performing parental lines. W92-1 showed the lowest value. SST57/Gmt was the best performing F2 cross, 0.8 % better than Kariega. Nts/Gmt followed by SST 57/Pmt had the second and third best values respectively.

FDT: Again Kariega had the highest value, followed by Nantes, with Palmiet and SST 57 jointly third. SST 57/Pmt showed the highest F2 value, and W92-1/Nts had the lowest value.

Baking characteristics

LFV: Nantes had the highest value, followed by Kariega and SST 57. No significant differences were observed. W92-1/Nts followed by Nts/Kar gave the highest F2 values, higher than Nantes and Kariega, followed by Nts/Gmt. Between the F2 lines, no significant differences were observed.

TKM: W92-1 had the highest value, significantly better than SST 57, Gmt, and Nts. Kariega followed by Palmiet had the second and third highest values. W92-1/Pmt had the highest value, significantly higher than Nts/Gmt, SST 57/Nts and W92-1/Gmt. SST 57/Kar followed with Pmt/Kar third.

Yield: W92-1 had the best yield, followed by Gamtoos and SST 57. A combination of these parental lines gave the best performing F2 progeny. W92-1/SST 57 had the highest yield, 1.92 ton.ha $^{-1}$ more than W92-1. W92-1/Kar followed by W92-1/Gmt ranked second and third respectively.

Nantes, Kariega, Palmiet and SST 57 performed very well for all the characteristics which are considered to be important. Either Nantes or Kariega were involved as parent in almost all the best performing F2 combinations. Although the progeny was

F2, some heterosis was still evident, especially for loaf volume, where the Nts/Kar cross performed significantly better than both parents.

Gamtoos again showed high FA and FST values. The F2 crosses containing Gamtoos as a parent also showed high FA and FST.

Table 4.8 Analysis of variance of quality and yield characteristics of the parents and F2 progeny

Characteristics		Milling								Rheological	Baking	Yield
Source	D.F.	GPC	FPC	EX	BFY	FN	FCL	SDS	HLM	MDT	LFV	TKM
Blocks	3	3.25**	0.62 ns	0.47 ns	6.95**	2042.45 ns	4.37**	2.2**	4.39**	0.33**	487.45 ns	24.93**
Genotypes	20	0.49**	0.41 ns	4.73**	1.29**	1234.78 ns	0.64 ns	0.16 ns	3.23**	0.10**	4868.16**	15.48**
Error	60											

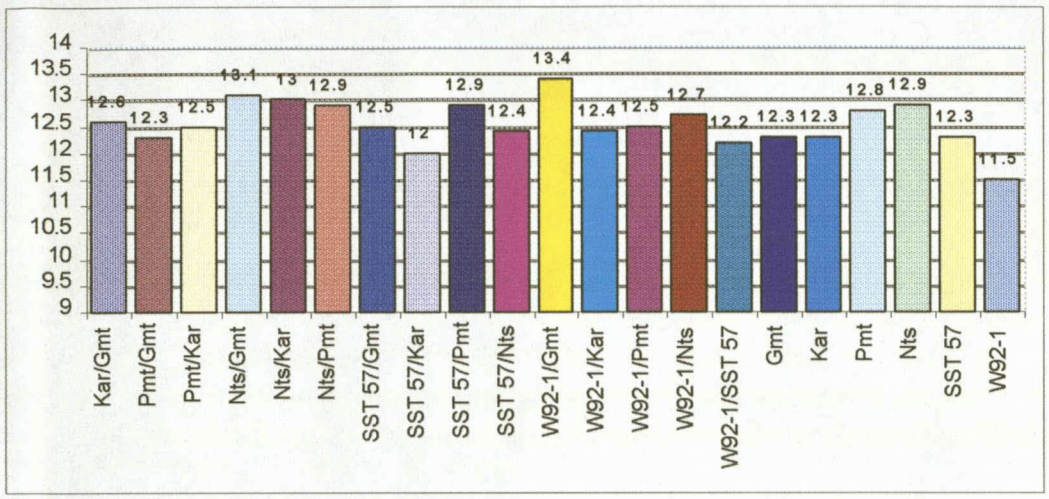
* p = 0.01

** p = 0.05

The averages of the different triats over four replications, including parental lines and the F2 generation:

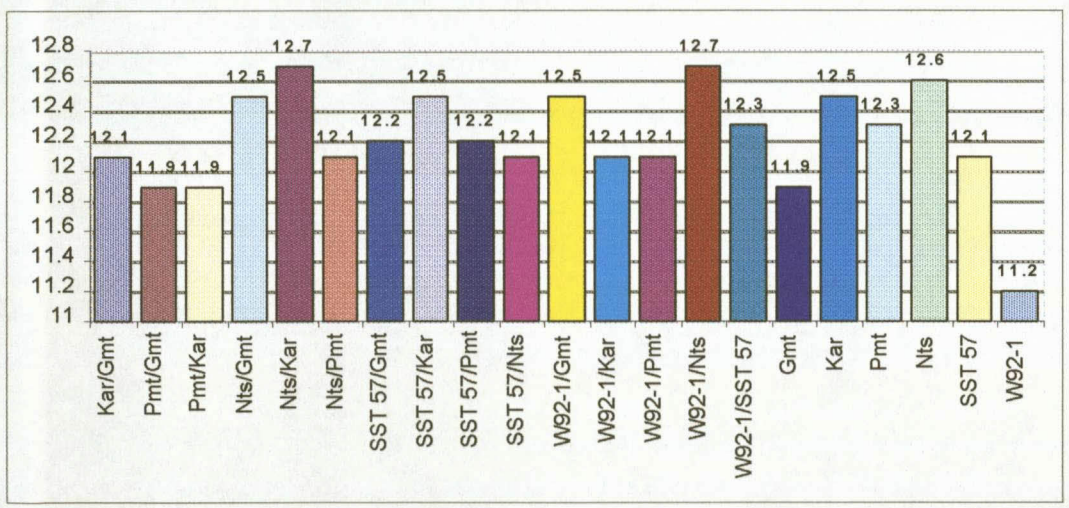
Milling characteristics

Figure 4.5 Grain protein content (GPC)



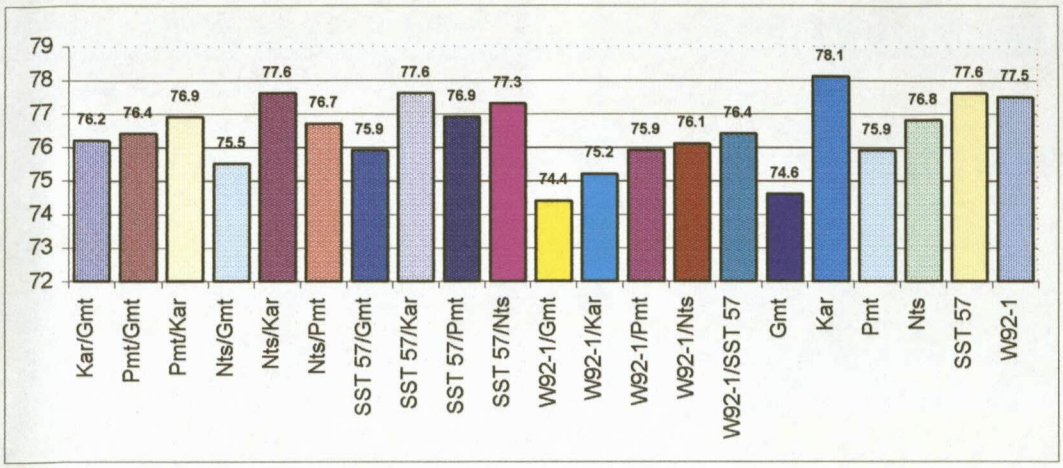
LSD (0.05) = 1.24

Figure 4.6 Flour protein content (FPC)



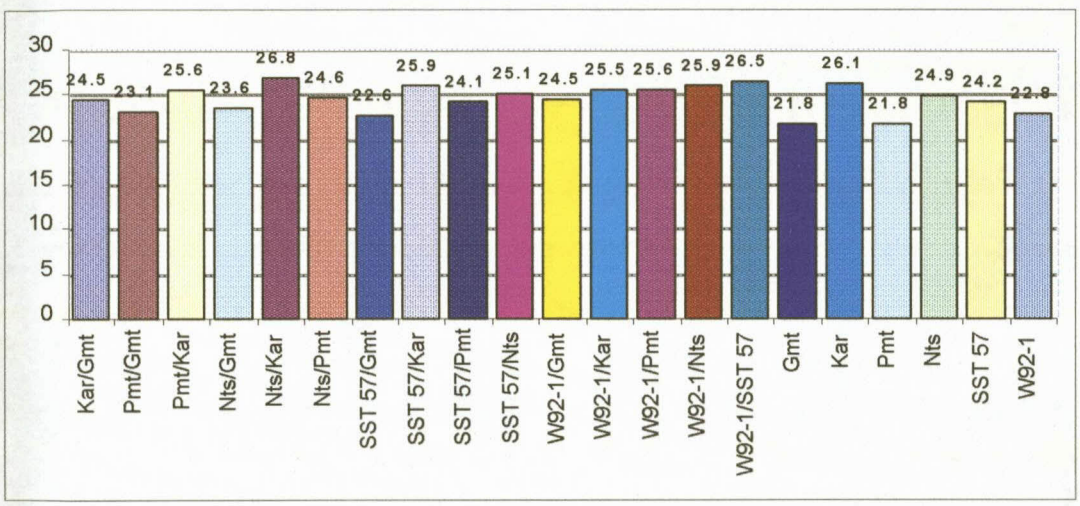
LSD (0.05) = 1.35

Figure 4.7 Extraction (EX)



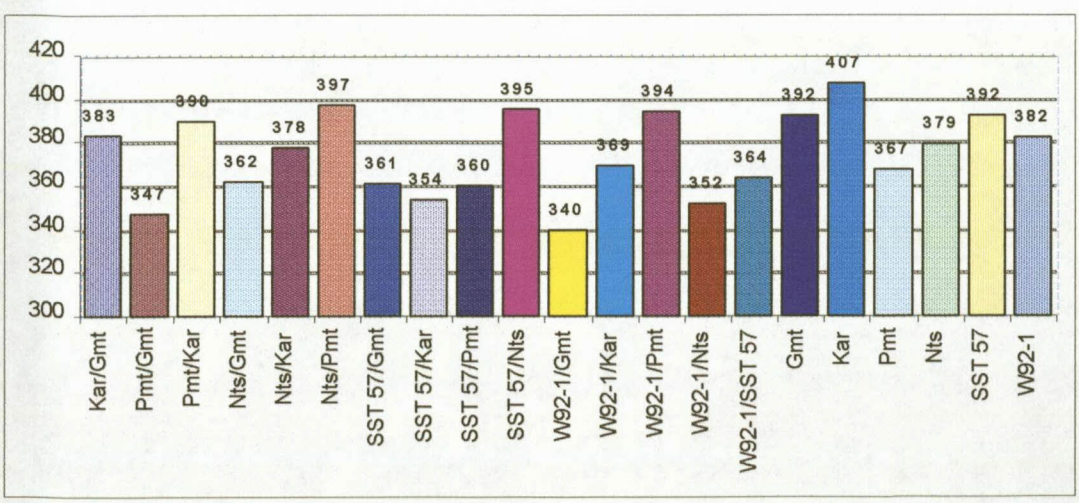
LSD (0.05) = **1.76**

Figure 4.8 Break flour yield (BFY)



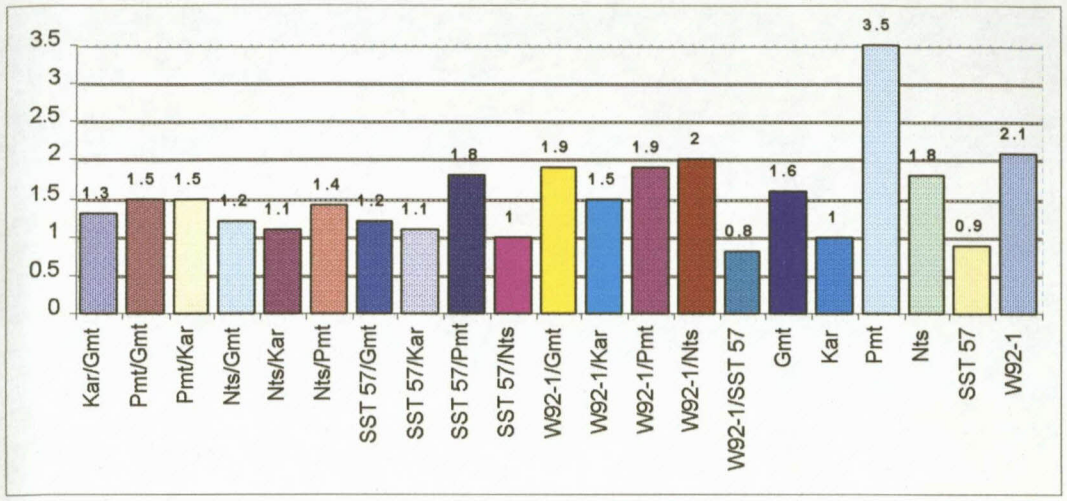
LSD (0.05) = **1.37**

Figure 4.9 Falling number (FN)



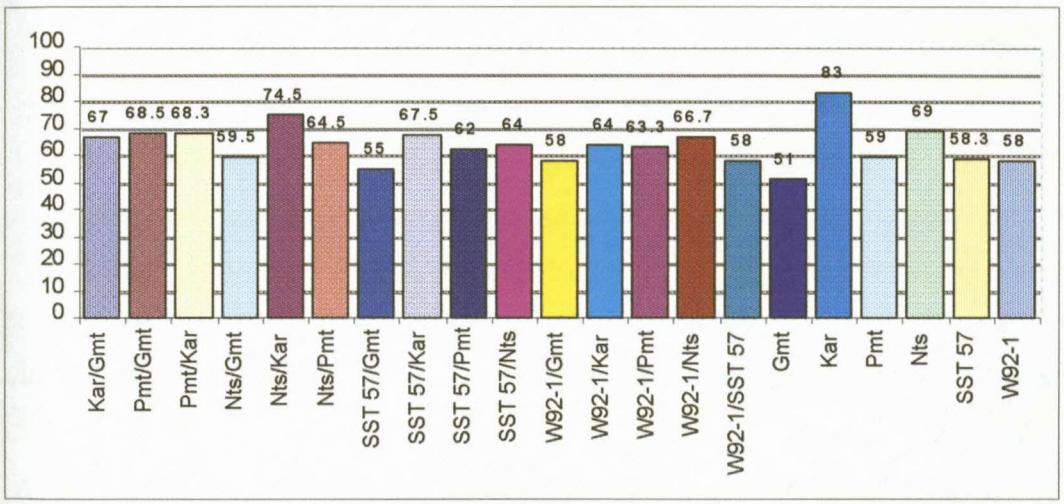
LSD (0.05) = **73.1**

Figure 4.10 Flour colour(FCL)



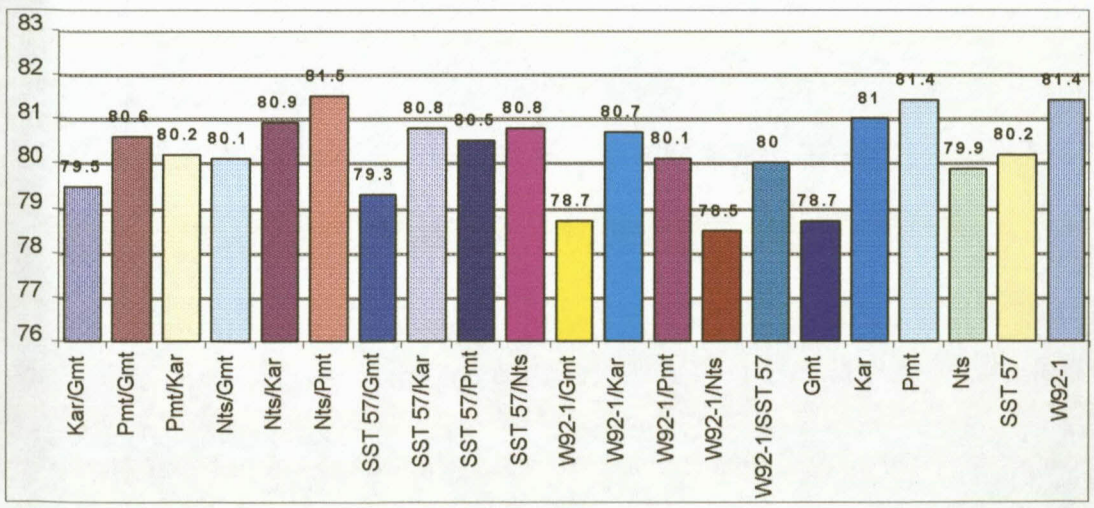
LSD (0.05) = 2.13

Figure 4.11 SDS sedimentation (SDS)



LSD (0.05) = 0.99

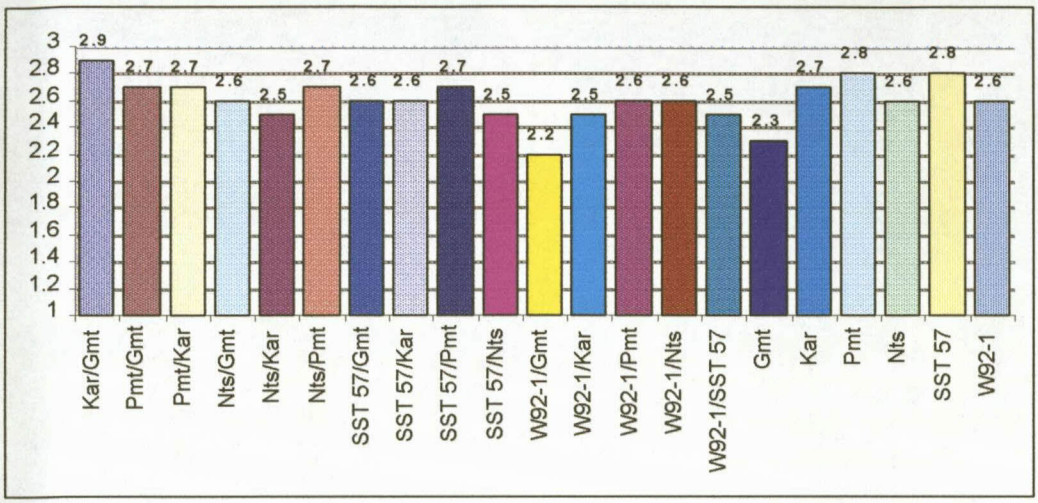
Figure 4.12 Hectolitre mass (HLM)



LSD (0.05) = 2.77

Rheological characteristics

Figure 4.13 Mixograph development time (MDT)



LSD (0.05) = **0.44**

Figure 4.14 Farinograph absorbtion (FAB)

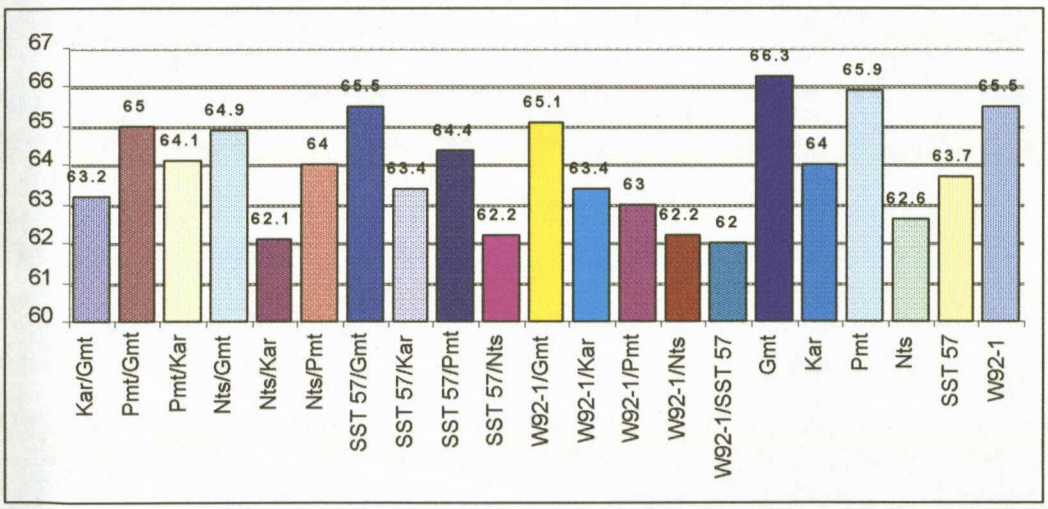
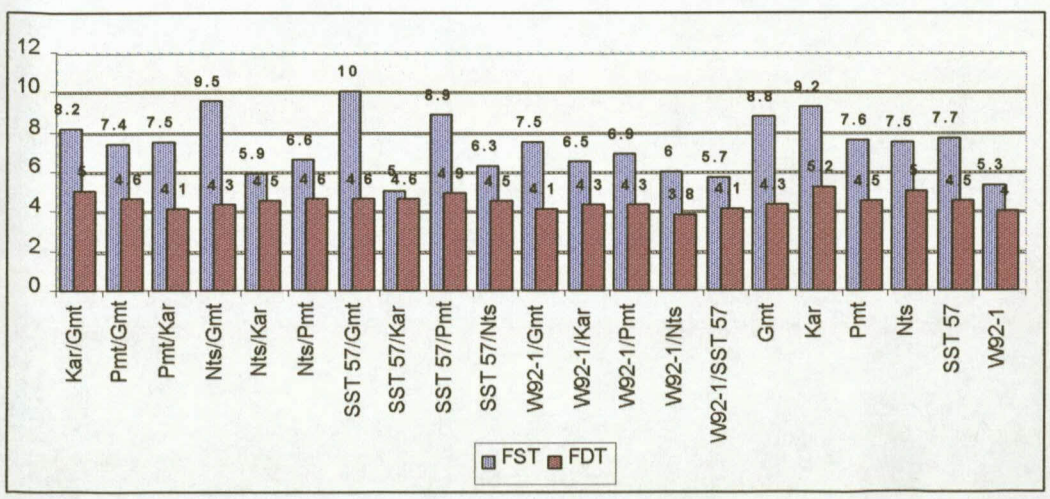
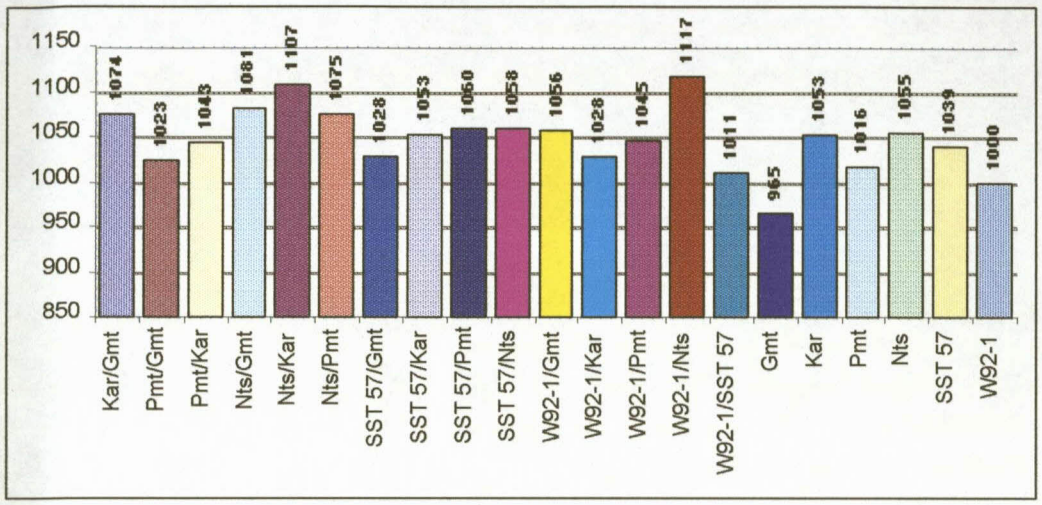


Figure 4.15 Farinograph stability (FST) and development time (FDT)



Baking characteristics

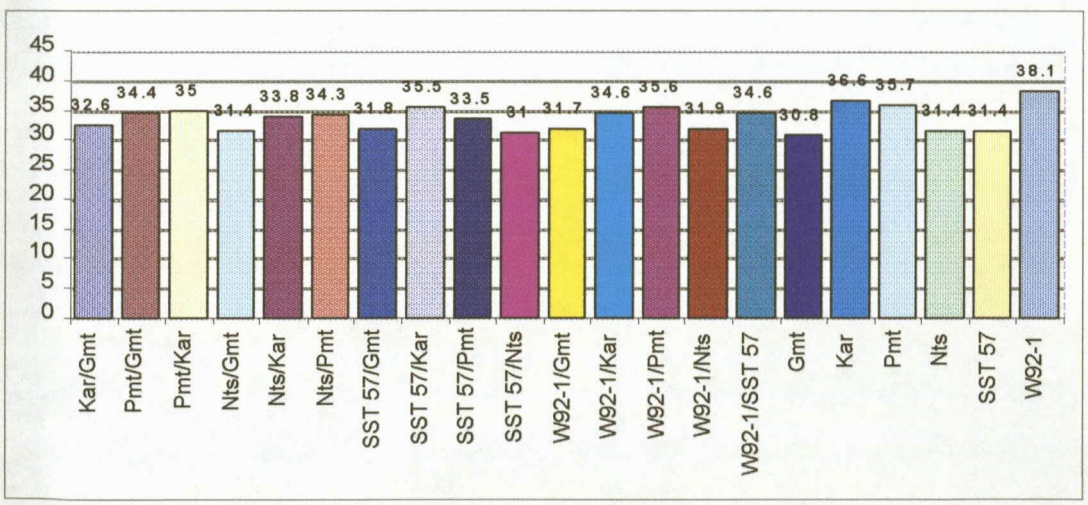
Figure 4.16 Loaf volume (LFV)



LSD (0.05) = **117.1**

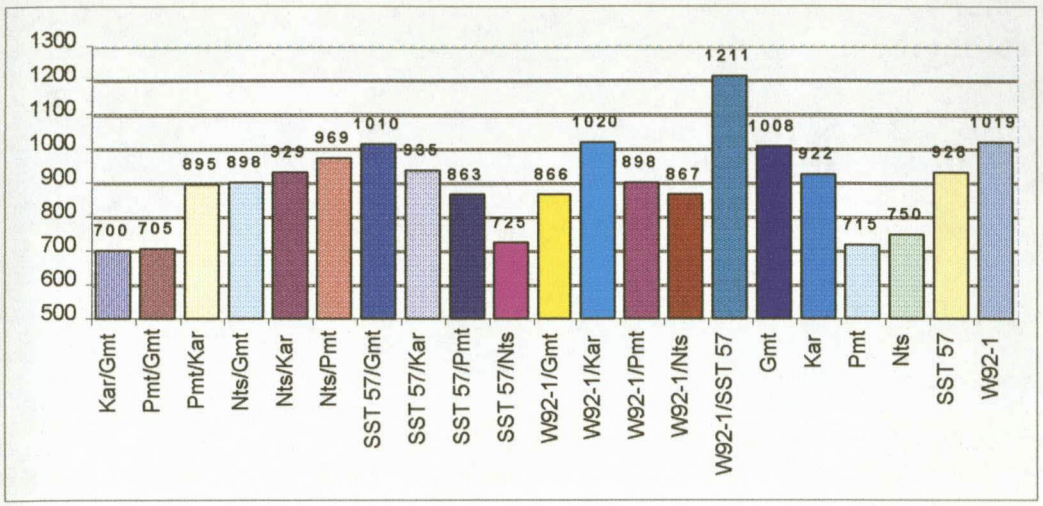
Yield characteristics

Figure 4.17 Thousend kernel mass (TKM)



LSD (0.05) = **3.73**

Figure 4.18 Yield



The traits that have no LSD value (FAB, FST, FDT & yield), were not included in the ANOVA. These traits had more than 10 % missing values and would influence the accuracy of the analysis.

4.2.2 The Diallel analysis of parents and F2 progeny trial

4.2.2.1 ANOVA

An ANOVA of the combining ability of the different quality traits was performed and is shown in Table 4.9. GCA was significant for all the traits except FN, FCL and SDS. This is in agreement with data presented by Mihaljev & Kovacev-Djolai (1978) showing a highly significant GCA for grain protein content, Sing *et al.* (1986) and Jain & Sing (1978) who reported a significant GCA for TKM, and a report by Paroda *et al.* (1970) indicating that GCA was significant for yield. This indicates that the above-mentioned traits are controlled mainly through additive gene action.

SCA was significant for FN, HLM and LFV. Highly significant SCA was evident for EX, BFY and MDT. In contrast to this, Paroda *et al.* (1970) reported a significant SCA for TKM, and Jain & Sing (1978) reported a significant SCA for grain yield. The SCA could be an indication of heterotic effects in the above mentioned traits.

Table 4.9 Analysis of variance of the combining ability of the different quality and yield characteristics

Characteristics		Milling								Rheological	Baking	Yield
Source	D.F.	GPC	FPC	EX	BFY	FN	FCL	SDS	HLM	MDT	LFV	TKM
GCA	5	0.23**	0.14*	3.09**	6.95**	181.1 ns	0.35 ns	0.02 ns	1.55**	0.043**	2052.8**	12.1**
SCA	15	0.09 ns	0.09 ns	0.55**	1.28**	351.2*	0.09 ns	0.05 ns	2.12*	0.02**	938.6*	1.12*
Error	60											

* p = 0.01

** p = 0.05

ns = not significant

4.2.2.1.1 General combining ability of the quality traits

In Table 4.10 the GCA effects of the quality traits are listed.

Milling characteristics

GPC: Nantes showed the best combining ability for GPC, followed by Palmiet and Gamtoos. No significant differences occurred between the parental lines for this trait. W92-1 showed the poorest combining ability.

FPC: Again, Nantes was the best combiner, followed by Kariega, with SST 57 in third place. Again no significant differences occurred between entries, and W92-1 gave the lowest value.

EX: Kariega showed the best combining ability, followed by SST 57. Both these lines were significantly better than Gamtoos, Palmiet and W92-1. Nantes had the third highest value.

BFY: Kariega again showed the highest value, significantly better than all the other parental lines. Nantes was the second best combiner, followed by W92-1. Both these lines were significantly better than Palmiet and Gamtoos.

FN: Kariega was the best general combiner, followed by Palmiet and Nantes. No significant differences were observed between the parents.

FCL: W92-1 had the highest GCA, followed by Palmiet and Nantes. Again no significant differences were observed.

SDS: Gamtoos proved to be the best combiner, followed by SST 57 and Kariega. No significant differences were observed between these lines.

HLM: Palmiet was the best general combiner, followed by Kariega, with SST 57 third. Palmiet and Kariega had a significantly better HLM than Gamtoos.

Rheological characteristics

MDT: Again Palmiet showed the best combining ability, followed by Kariega and SST 57. Palmiet had a significantly higher value than Gamtoos

Baking characteristics

LFV: Nantes was the best combiner for loaf volume, significantly better than Gamtoos. Kariega was the second best combiner, followed by SST 57.

Yield characteristics

TKM: Kariega showed the best combining ability, followed by W92-1 and Palmiet. All three these lines were significantly better than SST 57 and Gamtoos.

To produce the best progeny, parental lines with the highest GCA for a specific trait should be used.

Kariega proved to be the best general combiner for the following characteristics: EX, BFY, FN, LFV and TKM, and second best for FPC, HLM and MDT. To improve any of these characteristics, Kariega should be one of the parental lines.

Nantes was the best combiner for the characteristics: GPC and FPC, and second best for BFY and LFV.

Palmiet was the best combiner for HLM and MDT and second best GPC, FCL and FN.

SST 57 was the second best combiner for EX and SDS.

Gamtoos proved to be the best general combiner for SDS and MDT.

W92-1was the best combiner for FCL and second best for TKM.

Table 4.11 contains the variances of the GCA of al the quality traits, which indicates the sensitivity of the parental GCA effects to the environment.

Baking characteristics

GPC: Nantes' GCA effects were the most significantly affected by the environment, followed by W92-1. Palmiet was less affected by the environment, but both these cultivars can be used to improve this trait.

FPC: The GCA effects of W92-1, followed by Nantes, were the most sensitive to the environment. Kariega was affected less by the environment, but both Nantes and Kariega can be used to improve this trait.

EX: The GCA effects of Gamtoos were most sensitive, followed by Kariega. Even though Kariega showed a high interaction, this cultivar should still be used because cultivars not so much affected by the environment showed a poor GCA.

BFY: Again, the GCA effects of Gamtoos and Kariega were the most sensitive to environmental influences. SST 57 showed the least environmental effect, but only the fourth best general combiner. Nantes should rather be used in these crosses.

FN: GCA effects of Kariega, followed by that of W92-1 were the most environmentally sensitive. Palmiet should be used in crosses to increase FN.

FCL: The GCA effects of W92-1 followed by SST 57 were most sensitive to the environment. Palmiet and Nantes are the best parents to improve this trait.

SDS: The GCA effects of Palmiet followed by Gamtoos were, respectively, most sensitive to environmental variables. The environmental effect was small enough to still use Gamtoos in these crosses.

HLM: Gamtoos' GCA effects, followed by Palmiet showed the highest sensitivity. Kariega should rather be used as parent as it is less influenced by the environment.

Rheological characteristics

MDT: Again the sensitivity of the GCA effects of Palmiet and Gamtoos came in first and second, but still the sensitivity was low. Palmiet can be used to improve this trait.

Baking characteristics

LFV: The environment influenced the GCA effects of Nantes the most, followed by Gamtoos. Therefore SST 57 should rather be used to improve this characteristic.

Yield characteristics

TKM: Again, the GCA effects of Gamtoos were the most sensitive to environment, followed by that of Kariega. Palmiet should rather be used to improve this trait.

Table 4.10 GCA effects of quality and yield characteristics

	Milling								Rheological	Baking	Yield
Parents	GPC	FPC	EX	BFY	FN	FCL	SDS	HLM	MDT	LFV	TKM
W92-1	-0.2159	-0.1956	-0.4044	0.4356	-6.1656	0.3244	0.0134	-0.1297	-0.0674	-9.0833	1.0914
SST 57	-0.1209	0.0244	0.6196	0.0439	-0.2750	-0.2362	0.0231	0.0125	0.0406	-4.8958	-0.7849
Nantes	0.2459	0.1641	0.2320	0.4389	0.6937	0.0203	-0.0075	0.0694	-0.0486	27.4792	-1.0049
Palmiet	0.1272	-0.0581	-0.1463	-0.7379	0.9062	0.1193	-0.0963	0.5059	0.0875	-6.2083	1.0792
Kariega	-0.0766	0.1266	0.6436	1.2137	7.9969	-0.2097	0.0166	0.3109	0.0660	9.6979	1.1339
Gamtoos	0.0403	-0.0613	-0.9445	-1.3941	-3.1563	-0.0182	0.0506	-0.7691	-0.0781	-16.9896	-1.5149
LDS (0.05)	0.46	0.6	0.65	0.51	26.98	0.79	0.37	1.02	0.164	43.21	1.38

Table 4.11 Variances of GCA of all the quality traits

	Milling								Rheological	Baking	Yield
Parents	GPC	FPC	EX	BFY	FN	FCL	SDS	HLM	MDT	LFV	TKM
W92-1	0.0466	0.0383	0.1636	0.1898	38.0150	0.1053	0.0002	0.0168	0.0045	82.5068	1.1911
SST 57	0.0146	0.0006	0.3839	0.0019	0.0756	0.0558	0.0005	0.0002	0.0017	23.9691	0.6161
Nantes	0.0605	0.0269	0.0538	0.1926	0.4813	0.0004	0.0001	0.0048	0.0024	755.1049	1.0098
Palmiet	0.0162	0.0034	0.0214	0.5445	0.8213	0.0142	0.0093	0.2560	0.0077	38.5433	1.1646
Kariega	0.0059	0.0160	0.4143	1.4731	63.9499	0.0440	0.0003	0.0967	0.0044	94.0497	1.2856
Gamtoos	0.0016	0.0038	0.8921	1.9436	9.9620	0.0003	0.0026	0.5915	0.0061	288.6458	2.2940

4.2.2.1.2 Specific combining ability of the quality traits

Table 4.12 contains the SCA effects of the quality traits for all the crosses. The SCA effect is an indication of the heterotic (interaction) effect for a specific trait. Although Paroda & Joshi (1970) found a marked decline in the magnitude of the SCA in the F2 population, good results was still obtained.

Milling characteristics

GPC: The cross W92-1/Gmt showed the best SCA, significantly better than Pmt/Gmt, Pmt/Kar, Nts/Pmt, SST 57/Gmt, SST 57/Kar, W92-1/Pmt, SST 57/Nts, and W92-1/Nts. SST 57/Pmt and Nts/Gmt were second and third best specific combinations, significantly better than Pmt/Gmt. W92-1 showed a poor GCA, but a high SCA insuring heterotic effects in its progeny.

FPC: W92-1/Gmt again was the best specific combination, followed by W92-1/SST 57 and W92-1/Nts. W92-1/Gmt had significantly better combining ability than Kar/Gmt, Pmt/Gmt, Pmt/Kar, Nts/Pmt, SST 57/Nts and W92-1/Kar, whereas W92-1/SST 57 was significantly better than Pmt/Kar. Again W92-1 in combination with Gamtoos showed heterotic effects. This combination can be used to improve the grain and flour protein content in the hybrid.

EX: Pmt/Gmt was the best specific combination, followed by SST 57/Kar and Nts/Kar. Pmt/Gmt was significantly better than al the combinations, except SST 57/Kar. SST 57/Kar was significantly better than W92-1/Gmt, W92-1/Kar and W92-1/Pmt. Palmiet and Gamtoos showed the lowest GCA. This combination (Pmt/Gmt) can, however, produce superior progeny for this trait.

BFY: The best combination was W92-1/Pmt. This combination again showed a significantly better combining ability than all the other combinations, except W92-1/SST 57, which is the second best combination, significantly better than all the remaining combinations except W92-1/Gmt with the third highest combining ability. W92-1/Gmt was a significantly better combination than Kar/Gmt, Pmt/Gmt, Nts/Gmt, SST 57/Gmt, SST 57/Kar, SST 57/Pmt and SST 57/Nts.

FN: The best combination was Nts/Pmt, followed by SST 57/Nts and W92-1/Pmt. Nts/Pmt and SST 57/Nts were significantly better than SST 57/Kar, SST 57/Pmt, W92-1/Nts and W92-1/Gmt. W92-1/Pmt was significantly better than SST 57/Kar and W92-1/Nts.

FCL: W92-1/Gmt was the best specific combination, followed by SST 57/Pmt and SST 57/Kar. W92-1/Gmt and SST 57/Pmt were significantly better than Pmt/Gmt and W92-1 /SST 57.

SDS: W92-1/Pmt was the best combination. Nts/Kar was the second best combination, followed by W92-1/Kar. Both W92-1/Pmt and Nts/Kar were significantly better than Pmt/Kar, Nts/Gmt, Nts/Pmt, W92-1/Gmt and W92-1/Nts.

HLM: Pmt/Gmt, followed by Nts/Gmt and Nts/Kar were the best three specific combinations. Pmt/Gmt was significantly better than Palmiet/Kar, W92-1/Gmt and W92-1/Nts, whereas Nts/Kar and Pmt/Kar were significantly better than Pmt/Kar and W92-1/Nts.

The best specific combination to produce progeny with desirable milling characteristics, was Nts/Kar.

Rheological characteristics

MDT: Kar/Gmt had the best combining ability, significantly better than all the other crosses. Nts/Gmt was the second best combination, significantly better than SST 57/Kar, W92-1/Gmt and W92-1/Kar. The third best combination, Pmt/Gmt, was significantly better than W92-1/Gmt.

Kar/Gmt proved to be the best specific combination to improve both rheological characteristics simultaneously in superior progeny.

Baking characteristics

LFV: W92-1/Nts was the best specific combination, significantly better than Pmt/Gmt, Pmt/Kar, SST 57/Nts, W92-1/Kar and W92-1/SST 57. W92-1/Gmt and Kar/Gmt were second and third respectively. W92-1/Gmt was significantly better than W92-1/Kar and W92-1/SST 57, and Kar/Gmt were

significantly better than W92-1/Kar. The combination W92-1/Nts can be used to develop desirable progenies for LFV.

Yield characteristics

TKM: SST 57/Kar proved to be the best combination, followed by Pmt/Gmt and W92-1/SST 57. SST 57/Kar was significantly better than Kar/Gmt, Pmt/Kar, SST 57/Pmt, SST 57/Nts, W92-1/Gmt, W92-1/Kar, W92-1/Pmt and W92-1/Nts. Pmt/Gmt was significantly better than Kar/Gmt, Pmt/Kar, SST 57/Nts, W92-1/Gmt, W92-1/Kar and W92-1/Nts. W92-1/SST 57 was significantly better than W92-1/Gmt and W92-1/Nts. Kariega proved to be the best parent for both GCA and SCA to improve this trait. SST 57/Kar proved to be the best cross to improve TKM.

Table 4.13 contains the variables of the SCA of all the quality traits, which indicates the sensitivity of the parental SCA effects to the environmental variables.

Milling characteristics

GPC: Gamtoos' SCA effects were the most affected by the environment, followed by W92-1.

FPC: The SCA of W92-1 was affected most, followed by Gamtoos.

EX: For this trait, W92-1 and Kariega's SCA was affected most.

BFY: Again W92-1 showed the highest sensitivity to the environment, followed by Palmiet.

FN: SST 57 and Nantes' SCA was affected most by the environment.

FCL: Again, the SCA of W92-1 was affected the most, followed by Gamtoos.

SDS: Nantes showed the highest environmental effect, followed by W92-1.

HLM: Nantes' SCA was affected most, followed by W92-1.

Rheological characteristics

MDT: The interaction between Gamtoos and the environment was the highest, followed by Kariega.

Baking characteristics

LFV: W92-1 and Nantes' SCA effects were affected the most by the environment.

Yield characteristics

TKM: Once more, the environment affected SCA effects of W92-1 and Nantes' SCA the most.

The SCA of W92-1 seems to be the most affected by the environment.

Table 4.12 SCA effects for quality and yield characteristics

	Milling								Rheological	Baking	Yield
Crosses	GPC	FPC	EX	BFY	FN	FCL	SDS	HLM	MDT	LFV	TKM
Kar/Gmt	0.1280	-0.1996	0.0322	0.1002	3.8737	0.1428	0.1692	-0.3351	0.3014	34.3036	-0.6574
Pmt/Gmt	-0.4007	-0.1399	1.0721	-0.2397	-7.2857	-0.5862	-0.0179	0.6449	0.0799	-1.0402	1.1723
Pmt/Kar	-0.1088	-0.4027	-0.0161	0.4939	7.0612	0.0303	-0.1339	-0.8851	-0.0392	-7.7277	-0.8511
Nts/Gmt	0.3055	0.2129	-0.2313	-0.0499	-9.5732	-0.1872	-0.2317	0.5315	0.0910	24.0223	0.2314
Nts/Kar	0.1174	0.2001	0.2631	0.5297	-9.4013	-0.2799	0.3674	0.5115	-0.0696	21.3348	0.4529
Nts/Pmt	0.0187	-0.1652	0.2205	0.3188	21.3643	-0.1247	-0.1098	0.6815	0.0254	6.9911	0.5626
SST 57/Gmt	0.0224	0.0276	-0.2438	-0.7049	-10.1045	-0.0057	-0.0123	-0.2367	0.0768	2.6473	0.4614
SST 57/Kar	-0.1607	0.1648	0.5258	0.0372	-27.5076	0.1608	0.0717	0.2583	-0.1174	0.9598	1.4879
SST 57/Pmt	0.3605	0.0495	-0.0170	0.2138	-14.6670	0.4068	0.0846	-0.2866	-0.0389	24.3661	-0.4074
SST 57/Nts	-0.1432	-0.2627	0.1096	-0.0254	20.3455	0.0368	0.1008	0.4774	-0.1025	-10.0714	-0.7608
92-1/Gmt	0.6223	0.5226	-0.7198	0.8783	-24.9638	0.4837	-0.1276	-0.6445	-0.2402	35.5848	-1.5399
92-1/Kar	-0.0207	-0.1077	-1.4680	0.6945	-11.2170	-0.1175	0.1789	0.4455	-0.1174	-20.6027	-0.8758
92-1/Pmt	0.0555	0.1445	-0.8571	1.9720	12.2237	0.1212	0.3692	-0.4945	-0.0559	13.5536	-0.1836
92-1/Nts	0.2518	0.1898	-0.1014	0.4478	-16.4388	-0.0573	-0.1895	-1.7479	0.0055	52.6161	-1.6696
92-1/SST 57	-0.0463	0.2870	-0.2589	1.4153	-4.0951	-0.6233	0.0749	-0.0432	-0.0340	-21.5089	0.6554
LDS (0.05)	0.55	0.6	0.79	0.61	32.6	0.96	0.45	1.24	0.198	52.23	1.66

Table 4.13 Variances of SCA of all the quality and yield characteristics

	Milling								Rheological	Baking	Yield
Parents	GPC	FPC	EX	BFY	FN	FCL	SDS	HLM	MDT	LFV	TKM
W92-1	0.0742	0.0591	0.7910	1.7881	158.5238	0.0446	0.0308	0.7843	0.0139	922.6999	1.2380
SST 57	0.0049	-0.0015	0.0236	0.5884	238.3141	0.0264	-0.0187	-0.0858	0.0031	-62.2579	0.5411
Nantes	0.0080	0.0075	-0.0318	0.0979	192.3247	-0.0855	0.0359	0.8749	0.0010	634.0678	0.6261
Palmiet	0.0366	0.0112	0.4031	1.0359	93.1427	0.0161	0.0177	0.2996	-0.0018	-131.9139	0.2945
Kariega	-0.0228	0.0233	0.5453	0.2060	121.0992	-0.0841	0.0289	0.1576	0.0261	175.5709	0.7264
Gamtoos	0.1247	0.0477	0.3651	0.2961	83.4211	0.0393	-0.0010	0.1225	0.0372	403.3604	0.7518

4.2.2.1.3 GCA:SCA ratio for the quality characteristics

In Table 4.14 the calculated values for the GCA: SCA ratio, are listed. This ratio reveals whether the different characters show an additive or non-additive gene action. A GCA:SCA ratio with a value greater than one, indicates additive gene action, whereas a GCA:SCA ratio with a value lower than one indicates dominant gene action. A much higher SCA to GCA is an indication of over dominance.

In descending order, the following characteristics showed additive gene action, implicating that these characteristics can be improved through selection procedures. Less environmental interactions are found for the additive gene action. TKM (10.8), EX (5.62), BFY(5.43), FCL(3.89), HLM (2.77), GPC(2.56), LFV(2.19), MDT(2.15) and FPC (1.56). Mihaljev & Kovacev-Djolai (1978) also found predominance for additive gene effects for grain protein percentage. Sayed (1978) found TKM to have equal effects of additive and non-additive gene action.

The remainder of the characteristics showed very little variation between the GCA and SCA, except in the case of SDS (0.40) and FN (0.52) where the SCA were much higher, which could implicate over-dominance or non-additive gene action. In contrast to this, Sayed (1978) reported yield to be the only character with more non-additive than additive gene action.

Table 4.14 GCA : SCA ratio as determined from the mean squares for the quality characteristics

Quality characteristic	GCA	SCA	GCA:SCA
Milling characteristics			
Grain protein (GPC)	0.23	0.09	2.56
Flour protein (FPC)	0.14	0.09	1.56
Buhler extraction (EX)	3.09	0.55	5.62
Break flour yield (BFY)	6.95	1.28	5.43
Falling number (FN)	181.10	351.20	0.52
Flour colour (FCL)	0.35	0.09	3.89
SDS sedimentation	0.02	0.05	0.40
Hectolitre mass (HLM)	1.55	0.56	2.77
Rheological characteristics			
Mixograph (MDT)	0.043	0.02	2.15
Baking characteristics			
Bread volume (LFV)	2052.80	938.60	2.19
Yield characteristics			
1000 kernel mass (TKM)	12.10	1.12	10.80

4.2.2.1.4 Additive gene action

Table 4.15 shows the estimation of the components of variance expressed as a ratio. The closer the ratio is to one, the greater the prediction of general combining ability (additive gene action) alone.

The predictability of TKM (0.96), EX (0.92) and BFY (0.92), are mostly based on the GCA. FCL (0.89), HLM (0.85), GPC (0.84), MDT (0.81) LFV (0.81) and FPC (0.76) showed equally high values, indicating that GCA plays an important role in these characters as well. These characters are easier to improve through selection procedures. The remainder of the characteristics predictability was based on both GCA and SCA. SDS showed the lowest value (0.44), followed by FN (0.51) indicating that of all the characteristics, SCA had the most significant influence on these

characteristics. The environment plays a fundamental role in these characteristics. This is in agreement with GCA:SCA ratio's.

Table 4.15 Aditive gene action determined for the quality characteristics

Quality characteristic	Aditive gene action
Milling characteristics	
Grain protein (GPC)	0.84
Flour protein (FPC)	0.76
Buhler extraction (EX)	0.92
Break flour yield (BFY)	0.92
Falling number (FN)	0.51
Flour colour (FCL)	0.89
SDS sedimentation	0.44
Hectolitre mass (HLM)	0.85
Rheological characteristics	
Mixograph (MDT)	0.81
Baking characteristics	
Bread volume (LFV)	0.81
Yield characteristics	
1000 kernel mass (TKM)	0.96

4.2.2.2 Phenotypic and Genetic correlations

Table 4.16 shows the phenotypical correlation matrix between the different quality characteristics of the parents and F2 progeny. Significant positive correlations were observed between the following characteristics:

HLM was significantly correlated with TKM (0.651**), EX (0.572**) and MDT (0.475*). This correlation implies that a selection for a higher HLM will simultaneously increase the TKM, EX and MDT under favourable environmental conditions. These findings are in agreement with that of Fowler & De la Roche (1975b) and Gaines (1991) who reported a positive correlation between HLM and EX.

GPC was highly significantly correlated with LFV (0.663**) and FPC (0.616**). An improvement in GPC will result in an improved LFV and FPC. Bhatt & Derera (1975) reported that grain protein sowed highly significant positive correlation with flour protein, and Baker *et al.* (1971) also reported a positive correlation between grain and flour protein.

SDS showed significant correlations with LFV (0.557**), EX(0.596**), BFLY(0.616**) and FPC(0.452*). The SDS tests can be performed in early generations, and these correlations can be handy in predictions of superior lines with regard to LFV, EX, BFLY and FPC. These results are in agreement with Axford *et al.* (1978) who found a significant correlation between SDS and LFV. De Villiers & Laubscher (1995) reported a significant correlation between SDS, and LFV and FPC.

BFY and LFV (0.509*) were significantly correlated. EX was correlated with MDT (0.539*). FPC and LFV (0.567**) were significantly correlated. This is in agreement with findings by Baker *et al.* (1971), who stated that any increase in protein content will result in a proportional increase in loaf volume. FCL and MDT (0.578**) was significantly correlated. Bhatt & Derera (1975) found FCL not to be correlated with any other trait. The above findings indicate that any improvement in one of the

characteristics will simultaneously improve the other characteristic without specifically selecting for that trait.

Significant negative correlations existed between TKM and GPC(-0.437*). In contrast to these findings, Levy & Feldman (1988) found a positive association between grain protein and larger grains, whereas Pomeranz *et al.* (1985) reported that the correlation between TKM and protein content was not significant. EX and FCL (-0.439*) were also found to be negatively correlated. The negative correlations indicate that an increase in the one trait will result in a decrease in the other trait. Such a negative correlation between two important quality traits can cause a delay in the progress of a breeding programme, which can be both time and cost consuming.

Table 4.17 shows the genetic correlations between the different quality characteristics of the parents and F2 progeny.

With genetic correlations the influence of the environment on the values is eliminated. This means that correlations are based on the genotype and not the environment. It is therefore a true correlation, which will be consistent across environments. If both characters have low heritabilities, the phenotypic correlation is determined chiefly by the environment; if the characters have high heritabilities, the genetic correlation is the more important one. As was expected, the number of significant phenotypic correlations were significantly more than significant genetic correlations, as it was already shown in the previous trials that the correlations are influenced to a large extent by the environment.

Three significant positive correlations were observed between SDS and FN (0.858*), MDT and HLM (0.815*) and LFV and FPC(0.824*) indicating that an increase in one of these characteristics will result in an increase of the associated characteristic as well, irrespective of environmental influences. In the phenotypic correlation matrix these correlations were positive as well, but non-significant. The high genetic correlation between protein content and the loaf volume again emphasises the strong relationship between these two characteristics.

Table 4.16 The phenotypical correlation matrix for quality characteristics of the parents and F2 progeny

HLM	1										
TKM	0.651**	1									
FN	0.358^{ns}	0.144^{ns}	1								
GPC	-0.156^{ns}	-0.437*	-0.248^{ns}	1							
SDS	0.36^{ns}	0.383^{ns}	0.313^{ns}	0.139^{ns}	1						
BFY	0.087^{ns}	0.212^{ns}	0.016^{ns}	0.024^{ns}	0.616**	1					
EX	0.572**	0.344^{ns}	0.374^{ns}	-0.245^{ns}	0.596**	0.261^{ns}	1				
FPC	-0.056^{ns}	-0.22^{ns}	-0.302^{ns}	0.616**	0.452*	0.402^{ns}	0.119^{ns}	1			
FCL	-0.179^{ns}	0.118^{ns}	-0.233^{ns}	0.114^{ns}	-0.245^{ns}	-0.170^{ns}	-0.439*	-0.3^{ns}	1		
MDT	0.475*	0.395^{ns}	0.377^{ns}	-0.087^{ns}	0.314^{ns}	-0.123^{ns}	0.539*	-0.148^{ns}	0.578**	1	
LFV	-0.035^{ns}	-0.187^{ns}	-0.179^{ns}	0.663**	0.557**	0.509*	0.249^{ns}	0.576**	0.229^{ns}	0.083^{ns}	1
	HLM	**TKM**	**FN**	**GPC**	**SDS**	**BFY**	**EX**	**FPC**	**FCL**	**MDT**	**LFV**

ns = non significant

* = 0.05

** = 0.01

Table 4.17 The genetic correlation matrix for quality characteristics of the parents and F2 progeny

HLM	1										
TKM	0.682 ns	1									
FN	0.594 ns	0.260 ns	1								
GPC	0.142 ns	-0.380 ns	0.224 ns	1							
SDS	0.634 ns	0.460 ns	0.858 *	0.124 ns	1						
BFY	0.513 ns	0.470 ns	0.498 ns	-0.295 ns	0.804 ns	1					
EX	0.680 ns	0.220 ns	0.709 ns	-0.069 ns	0.688 ns	0.746 ns	1				
FPC	0.321 ns	-0.273 ns	0.777 ns	0.528 ns	0.690 ns	0.434 ns	0.676 ns	1			
FCL	-0.075 ns	0.339 ns	-0.688 ns	-0.033 ns	-0.348 ns	-0.181 ns	-0.626 ns	-0.702 ns	1		
MDT	0.815 *	0.514 ns	0.704 ns	-0.010 ns	0.459 ns	0.222 ns	0.637*	0.239 ns	-0.449 ns	1	
LFV	-0.607 ns	-0.037 ns	0.530 ns	0.519 ns	0.728 ns	0.642 ns	0.607 ns	0.824 *	-0.220 ns	0.086 ns	1
	HLM	**TKM**	**FN**	**GPC**	**SDS**	**BFY**	**EX**	**FPC**	**FCL**	**MDT**	**LFV**

ns = non significant

* = 0.05

4.2.2.3 Heritability

In Table 4.18 the broad and narrow sense heritabilities, as well as the direct response to selection, are tabulated. Heritability of a trait is important to a plant breeder, because it reflects that trait's response to selection. The direct response of a character is an indication of the progress made when selection is directly applied to that character (with and without the influence of the environment).

The narrow sense heritability (phenotypic variance due to additive genetic variability) differed from as high as 0.7089 for TKM to 0 for SDS and FN. Bhatt (1972) reported that for TKM heritability the additive component was higher than the dominance component. This indicates a good success in selecting for higher TKM. High narrow sense heritabilities were also found for EX (0.5373), BFY (0.5247), FCL (0.3962) and HLM (0.3059). Selections for these traits to produce superior progeny are much easier because the environmental effects are non-significant. A higher response to selection occurs in traits with a high narrow sense heritability value.

From the direct response to selection based on the narrow sense heritabilities, it is evident that the best results can be expected when selecting for TKM (84% response) followed by BFY (0.74) and EX (0.73). FCL, HLM and GPC also showed responses higher than 0.50.

The broad sense heritabilities (phenotypic response for which genetic differences are responsible) where relatively high for most of the characteristics. BFY (0.9761) had the highest value, followed by EX (0.9096), TKM (0.8762), MDT (0.7394), HLM (0.6729), LFV (0.6126), GPC (0.5699) and FN (0.4047). Broad sense heritability is not a true indication of the heritability of a characteristic, because the environment plays a significant role in the expression of these genes.

Bhatt & Derera (1975) also found that HLM and EX had a high heritability.
In contrast to findings in this study, O'Brien & Ronalds (1987) reported a high heritability for SDS and protein content, and Bhatt & Derera (1975) found a high heritability for FPC, GPC and FCL.

The direct response to selection based on the broad sense heritabilities again showed that BFY (0.99), EX (0.95) and TKM (0.94) had high responses to selection. MDT (0.86), HLM (0.82), LFV (0.78) and GPC (0.75) also showed high responses. In contrast to direct responses to narrow sense heritabilities, FN showed a high response to broad sense heritabilities (0.64). Overall, all the characteristics except FCL (0.12) showed higher response to direct selection where the environment also plays a role in expression of the genes.

Table 4.18 Broad and narrow sense heritability and direct response to selection estimates for quality and yield characteristics.

Trait	Narrow Sense	Direct response	Broad Sense	Direct response
Milling characteristics				
Grain protein (GPC)	0.2939	0.54	0.5699	0.75
Flour protein (FPC)	0.1400	0.37	0.3756	0.61
Buhler extraction (EX)	0.5373	0.73	0.9096	0.95
Break flour yield (BFY)	0.5247	0.74	0.9761	0.99
Falling number (FN)	0*	0*	0.4047	0.64
Flour colour (FCL)	0.3962	0.63	0.0141	0.12
SDS sedimentation	0*	0*	0.1153	0.34
Hectolitre mass (HLM)	0.3059	0.55	0.6729	0.82
Rheological characteristics				
Mixograph (MDT)	0.2145	0.46	0.7394	0.86
Baking characteristics				
Bread volume (LFV)	0.2289	0.78	0.6126	0.78
Yield characteristics				
1000 kernel mass (TKM)	0.7089	0.84	0.8762	0.94

* These characters showed negative narrow sense heritabilities.

4.2.2.4 Indirect response to selection

If the same intensity of selection can be achieved when selecting for character Y as when selecting for character X, then the correlated response will be greater than the direct response if $r_A h_Y$ is greater than h_X. Therefore indirect selection cannot be expected to be superior to direct selection unless the secondary character has a substantially higher heritability than the desired character. The circumstances most likely to render indirect selection superior to direct selection are chiefly concerned with technical difficulties in applying selection directly to the desired character (Falconer, 1981).

The indirect responses to selection are showed in Table 4.19 and Table 4.20 for the narrow and broad sense heritabilities respectively. Calculations was done for both narrow and broad sense heritabilities due to the negative narrow sense heritability values that occurred for some of the characteristics measured.

1. Expected indirect selection based on narrow sense heritabilities

GPC: When GPC increase with one unit, an increase can be expected in FPC (0.77) and LFV (0.59). Both these values are higher than the direct response to selection, and should rather be improved through indirect selection. The other characters showed little or negative responses to the selection for this trait.

FPC: When selecting for a one unit higher FPC, predicted increases in LFV are 0.05 units higher than selection applied to GPC. All the other characters are increased more when selecting for FPC, except GPC.

EX: A one unit increase in EX will increase FPC with 1.32, LFV with 0.93 and MDT with 1.01units. These values are higher than direct response to selection's values, therefore it is better to increase FPC, LFV and MDT through indirect selection. BFY showed similar responses for direct or indirect response, whereas TKM, HLM and GPC showed low or negative values.

BFY: A one-unit increase in BFY should increase FPC (0.84), EX (0.74), HLM (0.67) and LFV (0.97). Again these values are higher than direct response values and should rather be improved through indirect selection. BFY had a negative influence on GPC (-0.39).

FCL: When FCL increase with one unit, all the characteristics should decrease, except MDT, which should increase with 0.4 units.

HLM: When HLM is increased by one unit, MDT should increase with 0.97, LFV with 0.73 and FPC with 0.66 units. Higher values are again obtained through indirect selection for these three characters. A 0.45 increase in TKM is predicted, the highest response of TKM to indirect selection. All the other traits are influenced positive except for FCL (-0.7).

MDT: A selection for MDT also showed a positive selection to all the traits except FCL (-0.33), but only HLM showed a higher indirect than direct response value.

LFV: When LFV is increased by one unit, FPC increase by 1.05 units, much higher than when direct selection is applied. TKM and FCL showed negative values and none of the other values showed higher values than direct response to selection.

TKM: When selecting for TKM, HLM (1.03) and MDT (0.93) showed higher indirect than direct response values. Selecting for this character however, has a negative effect on GPC (-0.59), FPC (-0.61) and LFV (-0.7).

None of the above indirect selections showed high response to selection for TKM and GPC, therefore to improve these characters, selection should be applied directly. Because of the negative correlation between FCL and all the characteristics except MDT, direct selection would be better to improve this character.

None of the selected characters could improve all the other characters simultaneously, therefore specific selection procedures should be used to improve specific quality characteristics.

2. Expected indirect selection based on broad sense heritabilities

In general the values of the indirect selection for the broad and narrow sense heritabilities correlated very well, therefore only the characters with negative narrow sense heritabilities namely FN and SDS are discussed.

GPC: When GPC increase with one unit, FN (0.27) and SDS (0.28) increased. All these values are lower than direct response to selection.

FPC: An increase in FPC increased FN (0.75), SDS (1.25) and MST (0.07). Indirect selection can rather be used to increase FN and SDS.

EX: A one-unit increase in EX increased FN (1.06) and SDS (1.93). To improve these characters indirect selection should rather be used.

BFY: An increase in BFY will simultaneously increase both these characters, and the indirect values are higher than the direct responses to selection.

FN: A one-unit increase in FN should result in a 0.81 unit increase in FPC and 1.61 in SDS. Both these values are higher than those predicted by direct response. A decrease of –3.69 units are expected for FCL. All the other characters showed positive correlations, but lower than for direct response.

FCL: Both these characters responded negatively when FCL was selected.

SDS: An increase in SDS showed a high decrease in FCL of -0.99 units. This character should rather be increased through direct selection. All the other characters showed an increase when selecting for SDS, but much less than would be achieved through direct selection.

HLM: Selection for a one unit increase in HLM increased FN (0.77) and SDS (1.53). Again indirect selection was better to improve these characters.

MDT: When selecting for MDT, FN (0.95) and SDS (1.16) showed higher responses than for direct selection.

LFV: An increase of one-unit in loaf volume will increase FN (0.65) and SDS (1.68).

TKM: Through selection for TKM, FN (0.38) and SDS (1.27) can also be improved.

Indirect selection would be best to select for SDS and FN.

Close agreement between observed and predicted correlated responses, cannot always be expected, particularly if the genetic correlation is low. There are two reasons for the low predictability and the inconsistency of correlated responses. The first is the low precision of estimates of the genetic correlation in the base population. The second is the sensitivity of genetic correlations to gene frequency changes. Genetic correlation and therefore the genetic response, can change rapidly during the course of the selection (Falconer, 1981).

Table 4.19 Expected indirect selection based on the narrow sense heritabilities

Secondary characters to which selections are applied (Y)

	GPC	FPC	EX	BFY	FCL	HLM	MDT	LFV	TKM
GPC		0.36	-0.09	-0.39	-1.18	0.44	0.01	0.46	-0.59
FPC	0.77		1.32	0.84	-1.18	0.66	0.36	1.05	-0.61
EX	-0.05	0.35		0.74	-0.54	0.51	0.40	0.40	0.25
BFY	-0.22	0.22	0.75		-0.16	0.39	0.14	0.42	0.58
FCL	-0.03	-0.42	-0.73	-0.21		-0.07	-0.33	-0.17	0.45
HLM	0.14	0.22	-1.27	0.67	-0.09		0.68	0.39	1.03
MDT	0.01	0.24	1.01	0.35	0.40	0.97		0.09	0.93
LFV	0.59	0.64	0.93	0.97	-0.29	0.73	0.08		-0.07
TKM	-0.24	-0.12	0.19	0.40	0.25	0.45	0.28	-0.02	

= Reciprocal selections made

FN and SDS were not included in this table because indirect selection response cannot be predicted from negative narrow sense heritabilities.

Table 4.20 Expected indirect selection based on the broad sense heritabilities

Secondary characters to which selections are applied (Y)

	GPC	FPC	EX	BFY	FN	FCL	SDS	HLM	MDT	LFV	TKM
GPC		0.43	-0.12	-0.39	0.18	-0.01	0.06	0.15	0.01	0.54	-0.47
FPC	0.65		1.05	0.70	0.81	-0.14	0.38	0.43	0.41	1.05	-0.36
EX	-0.05	0.43		0.77	0.47	-0.08	0.24	0.58	0.61	0.50	0.22
BFY	-0.23	0.27	0.72		0.32	-0.18	0.28	0.43	0.19	0.51	0.45
FN	0.27	0.75	1.06	0.77		-0.13	0.46	0.77	0.95	0.65	0.38
FCL	-0.21	-3.6	-5.43	-1.50	-3.69		-0.99	-0.52	-3.25	-1.45	2.67
SDS	0.28	1.25	1.93	2.3	1.61	-0.12		1.53	1.16	1.68	1.27
HLM	0.13	0.24	0.79	0.62	0.46	-0.01	0.26		0.85	0.43	0.78
MDT	0.01	0.21	0.71	0.26	0.52	-0.06	0.18	0.78		0.08	0.56
LFV	0.50	0.65	0.74	0.81	0.43	-0.03	0.32	0.48	0.09		-0.04
TKM	-0.31	-0.18	0.22	0.50	0.18	0.04	0.17	0.60	0.47	-0.03	

= Reciprocal selections made

SUMMARY

CHAPTER 5

1. The objective of this study was to select environmentally stable parental lines, and to determine the heritability of quality characteristics, the correlation between these characteristics, the combining ability of these quality characteristics, and the selection response.

2. A parental trial was planted at two diverse environments namely Langgewens and Tygerhoek, to determine the influence of environment on the different quality traits and parents. Locality had a significant influence on most of the characteristics (FPC, EX, FCL, MDT, FA, LFV, BSI, TKM and yield) whereas HLM, FST and FDT were not influenced by the environment.

3. A correlation matrix performed on the collected data from the two localities showed that correlations tend to be environment specific. There were no consistent correlations between characteristics across environments.

4. As expected, locality had a significant influence on most of the quality characteristics. Parents should be selected on average performance across localities. Kariega, SST 57 and Palmiet showed the least interaction with the environment and should therefore be considered as parents. Gamtoos was the best parent for FA and FST, but because of the 1B/1R translocation's negative effect on quality, this cultivar should be avoided as a parental line to improve quality.

5. At Langgewens a diallel trial was conducted, on the parents and the F2 progeny, to determine the correlations, heritability, combining ability and selection response of the different quality characteristics.

6. Significant effects were found over the four replications for some of the quality characteristics. From this trial, Palmiet, Kariega, Nantes and SST 57 were found to perform very well. Nantes and Kariega were involved in almost all the best performing F2 combinations and even though the progeny was F2, some heterosis was still evident.

7. Significant GCA was found for all the traits except FN, FCL and SDS. SCA was significant for FN, HLM and LFV, which could be an indication of heterotic effects in these traits.

8. To produce the best progeny, parental lines with the highest GCA for a specific trait should be used. High GCA effects is an indication of additive gene action, which again indicates high heritability. Kariega, Nantes, SST 57 and Palmiet proved to be the best cultivars to improve the different quality and yield characteristics.

9. The best specific combination to produce progeny with desirable milling characteristics was Nts/Kar, whereas Kar/Gmt proved to be the best specific combination to improve the rheological characteristics simultaneously. W92-1/Nts can be used to develop desirable progenies for LFV. SST 57/Kar proved to be the best combination to improve TKM. The SCA of W92-1 proved to be mostly influenced by the environment.

10. The GCA:SCA ratio was calculated to determine whether a character shows more additive or non-additive gene action. The following characteristics showed additive gene action: TKM, EX, BFY, FCL, HLM, GPC, LFV, MDT and FPC. The remainder of the characteristics showed very little variation between additive and non-additive gene action, except for FN, where the SCA was much higher.

11. To further confirm the above findings, the additive gene action was determined. Results were in agreement with previous findings, stating that TKM, EX and BFY was mainly under additive control, FCL, HLM, GPC, LFV, MDT and FPC showed mainly additive but also non-additive gene action and FN and SDS were under non-additive genetic control.

12. A phenotypic correlation matrix was performed to determine whether a positive or negative correlation exists between the quality and yield characteristics. Significant positive correlations were observed between HLM and TKM, EX and MDT, GPC and LFV and FPC, SDS and LFV, BFY and LFV, EX and MDT, FPC and LFV and FCL and MDT. This implies that selecting for one of these traits will simultaneously improve the other traits in a desirable environment. None of these correlations correlated with findings in the parental trial. Significant negative correlation existed between TKM and GPC and EX and FCL, implying a selection for one trait will influence the other trait negatively.

13. A genetic correlation matrix was also performed. Significant positive genetic correlations were observed between SDS and FN (0.858*), MDT and HLM (0.815*) and LFV and FPC (0.824*) indicating that an increase in one of these characteristics will result in an increase of the other character as well, irrespective of the environment. In the phenotypic correlation matrix these correlations were positive as well, but non-significant.

14. The broad and narrow sense heritability was calculated for the quality and yield characteristics. The narrow sense heritability varied from as high as 0.7089 for TKM to 0 for SDS and FN. These findings again indicate a good success in selecting for higher TKM. The broad sense heritabilities were relatively high for most of the characters, indicating a significant environmental influence in the non-additive or heterotic effects of these genes.

15. Indirect selection was calculated to find out whether it is possible to achieve more rapid progress through selection for a correlated response than from selection for the desired character itself. None of the indirect selections showed high response to selection for TKM and GPC, therefore to improve these characters, selection should be applied directly. Direct selection would be better to improve FCL, because of the negative correlations with the characteristics. None of the indirect selected characters could improve all the other characters simultaneously, but selection for HLM and MDT improved all the characteristics except FCL. Direct selection procedures should rather be used to improve specific quality characteristics. Indirect selection would be best to select for SDS and FN.

Key Words:

Wheat, quality, diallel analysis, parental lines, F2 generation, environmentally stable, combining ability, heritability, correlations, response to selection.

OPSOMMING

HOOFSTUK 5

1. Die doel van hierdie studie was om ouerlyne te selekteer wat stabiel is oor omgewings, en om die oorerflikheid van kwaliteitseienskappe, die korrelasies tussen hierdie eienskappe, die kombineervermoë van hierdie eienskappe en die indirekte responsie op seleksie te bepaal.

2. 'n Ouerproef is op twee diverse lokaliteite naamlik Langgewens en Tygerhoek geplant, om die invloed van die omgewing op die kwaliteitseienskappe te bepaal. Omgewing het 'n betekenisvolle invloed op die meeste van die eienskappe gehad (FPC, EX, MDT, FA, LFV, BSI, TKM en opbrengs). HLM, FST en FDT is nie deur die omgewing beïnvloed nie.

3. 'n Korrelasiematriks is uitgevoer op die versamelde data van die twee lokaliteite. Die resultate toon dat korrelasies omgewing-spesifiek is. Daar was geen konstante korrelasies tussen eienskappe oor omgewings nie.

4. Soos verwag het die omgewing 'n groot invloed op die meeste kwaliteitseienskappe gehad. Ouers moet geselekteer word op grond van die gemiddelde data oor omgewings. Kariega, SST 57 en Palmiet het die minste interaksies met die omgewing getoon, en moet daarom as ouers oorweeg word. Gamtoos was die beste ouer vir FA en FST, maar as gevolg van die negatiewe effek wat die 1B/1R translokasie op kwaliteit het, moet hierdie cultivar eerder as ouer vermy word in kruisings om kwaliteit te verbeter.

5. Op Langgewens is 'n dialeel analise uitgevoer op die ouer en F2 nageslag om die korrelasies, oorerflikhede, kombineervermoë en indirekte respons op seleksie van die verskillende kwaliteitseienskappe te bepaal.

6. Vir sommige kwaliteitseienskappe is betekenisvolle verskille oor die vier replikasies verkry. Vanuit hierdie proef is gevind dat Palmiet, Kariega, Nantes en SST 57 die beste gevaar het. Nantes en Kariega was 'n ouer in byna al die beste F2 kombinasies, en selfs al was die nageslag F2's, was heterose steeds sigbaar.

7. Betekenisvolle GCA is gevind vir al die kenmerke, behalwe FN, FCL en SDS. SCA was betekenisvol vir FN, HLM en LFV, wat kan dui op heterose in hierdie eienskappe.

8. Om die beste nageslag te verseker, moet die ouers met die beste GCA vir 'n spesifieke eienskap gebruik word. Hoë GCA is 'n aanduiding van aditiewe geenwerking, wat verder op hoë oorerflikheid dui. Kariega, Nantes, SST 57 en Palmiet is die beste cultivars om die verskillende kwaliteit- en opbrengs-eienskappe te verbeter.

9. Die beste spesifieke kombinasie om nageslag met die verlangde maaleienskappe te verkry is Nts/Kar. Kar/Gmt is die beste spesifieke kombinasie om die reologiese eienskappe gelyktydig te verbeter. W92-1/Nts kan gebruik word om verlangde nageslag vir LFV te verkry, terwyl SST 57/Kar die beste kombinasie is om TKM te verbeter. Die SCA van W92-1 word die meeste deur die omgewing beïnvloed.

10. Die GCA:SCA ratio is bereken om vas te stel of 'n karakter meer aditiewe of nie-aditiewe genewerking toon. Die volgende eienskappe het additiewe genewerking getoon: TKM, EX, FCL, HLM, GPC, LFV, MDT en FPC. Die oorblywende eienskappe het min variasie tussen additiewe en nie-additiewe geenaksie getoon, behalwe vir FN, waar die SCA baie hoër was.

11. Om die bogenoemde bevindinge verder te bevestig, is die aditiewe genewerking bereken. Resultate was in ooreenstemming met vorige bevindigs naamlik dat TKM, EX en BFY hoofsaaklik onder aditiewe beheer is, dat FCL, HLM, GPC, LFV, MDT en FPC hoofsaaklik aditief maar ook nie-aditiewe genewerking besit en dat FN en SDS onder nie-aditiewe genetiese beheer staan.

12. 'n Fenotipiese korrelasie matriks is uitgevoer om vas te stel of 'n positiewe of negatiewe korrelasie tussen die kwaliteit- en opbrengs-eienskappe bestaan. Betekenisvolle positiewe korrelasies is verkry tussen HLM en TKM, EX en MDT, GPC en FPC, SDS en LFV, BFY en LFV, EX en MDT, FPC en LFV en FCL en MDT. Dit impliseer dat wanneer vir een van die eienskappe geselekteer word, die ander ook sal verhoog in 'n gunstige omgewing. Nie een van die korrelasies stem ooreen met die ouerproef nie. Betekenisvolle negatiewe korrelasies is gevind tussen TKM en GPC en EX en FCL, wat impliseer dat seleksie vir een van hierdie eienskappe die ander negatief sal beïnvloed.

13. 'n Genetiese korrelasiematriks is ook uitgevoer. Betekenisvolle positiewe korrelasies is gevind tussen SDS en FN (0.858*), MDT en HLM (0.815*) en LFV en FPC(0.824*) wat beteken dat 'n toename in enige van hierdie eienskappe 'n toename in die ander tot gevolg sal hê ongeag die invloede van die omgewing. In die fenotipiese korrelasie matriks was hierdie korrelasies ook positief, maar nie betekenisvol nie.

14. Die breë en nou sin oorerflikheid is ook bereken vir die kwaliteit- en opbrengs-eienskappe. Die nou-sin oorerflikheid het gevarieër van so hoog as 0.7089 vir TKM tot 0 vir SDS en FN. Hierdie bevindinge dui weereens op 'n goeie sukses wanneer vir hoër TKM geselekteer word. Die breë sin oorerflikheid was relatief hoog vir die meeste van die eienskappe wat dui op betekenisvolle omgewings invloede in die nie-aditiewe of heterotiese effekte van hierdie gene.

15. Indirekte seleksie is bereken om te bepaal of dit moontlik is om vinniger vordering te maak deur te selekteer vir 'n gekorreleerde eienskap in plaas van direk vir die verlangde eienskap. Geen een van die indirekte seleksies het hoë respons getoon vir TKM en GPC nie, dus moet hierdie eienskappe eerder deur direkte seleksies verbeter word. Direkte seleksies sal ook beter wees om TKM te verhoog, as gevolg van die negatiewe korrelasie met die ander eienskappe. Geen van die indirek geselekteerde eienskappe kon al die ander eienskappe gelyktydig verbeter nie, maar 'n seleksie vir HLM en MDT het 'n verhoging in al die ander eienskappe tot gevolg gehad, gehalwe FCL. Direkte seleksie is dus beter om spesifieke eienskappe te verbeter. Indirekte seleksie sal egter die beste wees om vir 'n verhoging in SDS en FN te selekteer.

CHAPTER 6

CONCLUSIONS

The first objective of this study was to identify suitable parental lines that are stable over environments, which can be used to produce superior progeny in the Western Cape, because the choice of the correct parent is extremely important when breeding for improved quality and yield characteristics. The fact that most quality characteristics are under polygenic control, and therefore significantly influenced by the environment, makes this decision even more difficult. As was expected, locality, cultivar or locality x cultivar interaction had a significant influence on all the quality characteristics.

Correlations can be used as a tool to establish relationships (positive or negative) between characteristics. No consistent correlations were found between characteristics across environments, therefore this can not be used as a guideline over environments. However, some cultivars were more stable over environments, therefore parents should be selected on good average performance across localities. From this study three stable cultivars namely Kariega, SST 57 and Palmiet were identified to improve quality characteristics. No stable yielding cultivar was identified. Seeing that Palmiet's quality is unexceptable for the baking and milling industry, Kariega and SST 57 should rather be used as crossing block parents to improve quality characteristics. Gamtoos proved to be the best parental line to improve both FA and FST. Due to the 1B/1R translocation's negative assosiation with quality this cultivar should be used to a limited extent in crosses where quality needs to be improved. In an otherwise outstanding line where only the FA of FST proves to be a problem, Gamtoos can be considered as a parent.

From the averages of the parental and F2 trial, the same trend as in the parental trial was evident. Again Kariega, Palmiet and SST 57, but also Nantes, performed very well for the important characteristics. Kariega or Nantes was further involved as parent in almost all the best performing F2 combinations. Again Gamtoos showed high FA and FST values. The F2 crosses containing Gamtoos as a parent also possessed high FA and FST values, indicating that Gamtoos can be used to increase these characteristics in crosses.

Seeing that Kariega and Gamtoos are stable across environments, and produce superior progeny, these cultivars should be used in the crossing block. Gamtoos should be used to a limited extent due to the 1B/1R translocation. When breeding cultivars suitable for a specific environment, SST 57 and Nantes should also be considered as parental lines.

The GCA and SCA of measured characteristics were determined. From these results, the GCA:SCA ratio was calculated to predict the additive gene action. Highly significant GCA effects were evident for the following traits: GPC, FPC, EX, BFY, HLM, MDT, LFV and TKM, indicating that these traits are mainly under additive genetic control. Therefore good selection response is possible for these characteristics. High significant SCA for EX, BFY and MDT also occurred indicating possible heterotic effects in these traits. These characteristics will therefore have a low heritability with a poor selection response. From the GCA:SCA ratio, the following characteristics showed additive gene action, in other words less environmental influences and easier progress through selection: TKM, EX, BFY, FCL, HLM, GPC, LFV, MDT and FPC. In the case of SDS and FN, the SCA was much higher, which indicated non-additive gene action or over dominance. The success rates when selecting for these characteristics would be much lower.

The additive gene action was calculated as further conformation of the previous results from the GCA:SCA ratio. This calculation gave a more precise value between

0 and 1. The closer the value is to one, the higher the additive component in the specific trait. From this results, TKM, EX and BFY are almost entirely based on GCA effects indicating a good success when selecting for these characteristics. In the case of FCL, HLM, GPC, MDT, LFV and FPC, GCA still play a major role, but SCA also has an influence on the expression of these characteristics. In the case of SDS and FN, SCA had the most significant influence. The environmental influences on these characteristics are fundamental and progress through selection can not be achieved as effectively as with GCA characteristics.

To produce superior progeny, the parental lines with the highest GCA for a specific trait should be used. Overall, Kariega proved to be the best general combiner, followed by Palmiet, with Nantes in the third place. Crosses between these cultivars should produce good quality progeny.

The genetic and phenotypic correlations between the different quality and yield characteristics were evaluated. Significant positive and negative phenotypic correlations were observed between the characteristics, which indicated that an increase in one characteristic will simultaneously increase with selection of characteristics which are positively correlated, but only in a specific environment. Characteristics negatively correlated indicate that an increase in one characteristic will result in a decrease of the other. Therefore the genetic correlations, where the effect of the environment is eliminated, are more important to the plant breeder. As was expected, a smaller number of significant genetic correlations were observed: SDS and FN, MDT and HLM and LFV and FPC were positively correlated indicating that an increase in one of the characteristics will influence the other positively irrespective of the environment in which the plants are grown. These genetic correlations will give better results for achieving a simultaneous increase in quality characteristics.

The broad and narrow sense heritability, as well as the direct response to selection was calculated for the quality characteristics, because this is an indication of the progress made when selection is directly applied. According to the narrow sense heritabilities and the direct response to selection, good success will be achieved when selecting for TKM, EX, BFY, FCL, HLM and GPC. These characters all possess more GCA than SCA as indicated earlier. High responses will be achieved through selection for these characteristics. Environmental influences are non-significant.

Characteristics with high SCA had a very low heritability due to the influence of the environment. EX, TKM, MDT, HLM, LFV, GPC and FN had the highest broad sense heritability values.

Selection should rather be applied to characteristics with a high heritability indicating little environmental interference, for instance TKM, EX, BFY, FCL, HLM and GPC. The other characteristics with low heritability, should be increased by other means of selection. Therefore the indirect response to selection was investigated to determine whether selection for one characteristic could simultaneously increase the characteristics difficult to improve through direct selection. To calculate the indirect response to selection, the heritabilities and genetic correlations were taken into account.

Calculations were done on the narrow and broad sense heritabilities due to the negative narrow sense heritability values that occurred for some of the characteristics. In general, the values between the two calculations correlated very well. TKM and GPC should rather be improved through direct selection because the indirect selection gave lower responses. FCL had a negative correlation with all the characteristics and should rather be selected directly as well. FN and SDS should, however, be increased through indirect selection because higher values are obtained than when direct selection is applied. To improve a few quality characteristics simultaneously, HLM should be used, because an increase in this

character increased all the other measured characteristics (between 0.14 and 0.97) except FCL (-0.07). HLM is further easy to improve due to a high heritability and response to selection. Also when selecting for MDT, the indirect response was positive for all the characteristics except FCL. Selection for MDT has limitations however, because MDT should not be increased above 2.5 min, as this is the optimum value required by the baking and milling industry. FPC should rather be selected than GPC because FPC was negatively correlated with less of the other characteristics.

Even though the Western Cape is traditionally a low protein environment, and although most quality characteristics are under polygenic control, it is possible to improve quality characteristics through traditional breeding and selection techniques. The results from this study indicate that, by using the correct breeding parents, superior progeny, that is well adapted across different environments, can be obtained. Further, selecting for the correct quality characteristics will ensure progress and because of genetic correlations and indirect selection procedures, more than one characteristic can be improved simultaneously.

ABBREVIATION LIST

BFY	=	Break flour yield
BSI	=	Baking strength index
CR	=	Correlated response
D.F.	=	Degree's of freedom
E	=	Environment
EX	=	Extraction
FA	=	Farinograph water absorption
FDT	=	Farinograph development time
FST	=	Farinograph stability
FCL	=	Flour colour
FN	=	Falling number
FPC	=	Flour protein content
G	=	Genotipe
GCA	=	General combining ability
Gmt	=	Gamtoos
GPC	=	Grain protein content
HLM	=	Hectolitremass
h^2	=	Heritability
h	=	$\sqrt{h^2}$ = direct response to selection
i	=	selection intensity
Kar	=	Kariega
LFV	=	Loaf volume
LSD	=	Least significant difference
MDT	=	Mixogram development time
MS	=	Mean squares
NS	=	Non-significant
Nts	=	Nantes

Pmt	=	Palmiet
R	=	Direct response (= $i\sigma ph^2$)
r_A	=	Genetic correlation between characters X and Y
SCA	=	Specific combining ability
SDS	=	Sodium dodecyl sulfate sedimentation test
TKM	=	Thousand kernel mass
σ	=	Standard deviation

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Appendix Table 1: Parental lines planted at Langgewens 1996

ENTRY	NAME	REP	HLM	TKM	FN	SDS	FLY	FPC	FCL	MDT	FDT	FST	FA	LFV	BSI	YIELD
1	PALMIET	1	75.8	41.1	362	86.0	73.2	12.3	-1.0	3.5	5.6	8.8	60.7	1110	117	2326
2	PALMIET	2	75.4	41.1	342	85.0	70.7	13.5	-1.2	3.2	5.5	10.7	60.8	1165	115	2296
3	PALMIET	3	75.8	40.4	384	0.0	71.7	12.5	-1.3	4.0	5.7	10.0	60.1	1130	115	2562
4	PALMIET	4	75.3	41.2	378	85.0	71.4	12.5	-1.2	3.0	5.7	8.8	60.8	1095	112	1986
5	SST 57	1	75.8	38.3	392	82.0	74.4	11.1	-2.2	2.7	4.7	7.8	58.6	980	106	2645
6	SST 57	2	75.7	35.7	394	80.0	74.5	11.2	1.6	2.8	5.5	8.5	57.9	965	104	3292
7	SST 57	3	76.2	37.8	386	80.0	74.5	11.6	-1.9	3.1	4.3	8.0	59.1	995	105	2940
8	SST 57	4	76.7	38.2	402	77.0	74.0	12.0	-1.7	2.8	4.5	7.4	59.0	1020	106	2707
9	KARIEGA	1	76.0	44.5	426	95.0	74.4	12.0	-3.0	3.3	6.0	14.0	60.0	1105	115	2906
10	KARIEGA	2	75.2	43.4	439	92.0	74.7	11.6	-2.4	3.5	5.5	14.5	60.7	1055	110	3254
11	KARIEGA	3	75.0	42.3	426	95.0	75.1	11.6	-2.4	3.0	5.0	11.6	60.5	1075	114	2605
12	KARIEGA	4	75.2	46.7	408	92.0	74.1	11.6	-3.7	2.8	5.0	14.2	59.1	1050	111	3200
13	W 92-1	1	74.4	42.4	392	95.0	70.7	11.0	-1.2	3.2	4.3	6.2	60.0	1015	111	2287
14	W 92-1	2	74.5	43.6	388	90.0	71.3	9.9	-1.7	2.7	4.3	6.3	59.0	990	115	2456
15	W 92-1	3	74.9	42.2	386	88.0	70.5	10.9	-2.4	2.7	5.0	6.8	60.1	1040	114	2204
16	W 92-1	4	74.8	41.5	372	87.0	70.2	11.5	-1.9	2.5	4.0	6.0	58.6	1005	107	1936
17	NANTES	1	75.2	35.0	372	95.0	71.7	12.3	-2.2	3.0	5.5	9.6	62.1	1050	108	2339
18	NANTES	2	75.7	38.5	414	94.0	70.5	11.6	-2.3	2.7	5.4	6.8	60.6	1035	110	3026
19	NANTES	3	75.0	35.0	409	95.0	71.6	11.4	-3.5	3.0	6.5	13.0	63.2	1040	111	2220
20	NANTES	4	75.8	36.3	404	95.0	72.9	12.6	-1.6	2.6	5.4	9.0	62.0	1105	112	2451
21	GAMTOOS	1	77.0	37.6	342	70.0	69.2	10.8	-2.3	2.6	4.4	5.0	61.8	950	105	2906
22	GAMTOOS	2	76.2	34.5	392	70.0	69.9	12.5	-3.3	2.6	3.9	13.0	62.0	990	101	2920
23	GAMTOOS	3	76.6	37.6	372	74.0	69.1	11.7	-2.8	2.5	5.2	11.0	62.0	955	101	2608
24	GAMTOOS	4	76.0	36.8	393	74.0	69.6	12.5	-2.9	2.5	5.2	16.0	62.4	1005	102	3125

Appendix Table 2: Parental lines planted at Tygerhoek 1996

ENTRY	NAME	REP	HLM	TKM	FN	SDS	FLY	FPC	FCL	MDT	FDT	FST	FA	LFV	BSI	YIELD
1	PALMIET	1	75.8	41.8	352	90.0	70.8	11.8	-1.3	2.8	3.5	7.0	61.7	1055	117	1833
2	PALMIET	2	75.2	42.1	336	93.0	69.5	10.8	-3.2	3.0	5.0	9.0	61.3	1070	118	1776
3	PALMIET	3	76.2	43.4	366	92.0	69.7	12.4	-1.6	2.6	5.0	8.5	62.7	1105	113	1673
4	PALMIET	4	75.9	42.0	325	92.0	70.0	12.1	-0.6	2.9	5.0	8.5	63.2	1150	119	1560
5	SST 57	1	76.8	40.1	389	90.0	72.3	13.4	0.5	2.7	5.0	8.0	63.2	1130	111	1408
6	SST 57	2	77.0	41.1	365	86.0	71.8	12.3	0.0	2.8	6.6	9.0	62.0	1105	114	1359
7	SST 57	3	77.9	41.4	301	80.0	69.4	13.7	-0.6	3.0	7.0	10.8	63.3	1125	110	1081
8	SST 57	4	77.8	41.2	382	76.0	70.3	12.8	-1.0	2.9	6.0	12.0	63.4	1105	111	1187
9	KARIEGA	1	75.9	46.8	342	93.0	71.6	12.4	-2.8	3.0	6.0	8.5	62.8	1095	112	1482
10	KARIEGA	2	76.1	44.7	322	95.0	70.9	13.1	-0.2	3.0	4.8	7.5	63.8	1200	120	1325
11	KARIEGA	3	76.3	46.9	312	92.0	71.9	12.8	-2.4	2.9	6.6	15.0	63.3	1110	112	1405
12	KARIEGA	4	75.9	46.0	358	95.0	71.5	13.3	-1.8	3.0	5.0	8.5	62.6	1180	117	1276
13	W 92-1	1	75.8	45.1	312	90.0	68.7	12.9	-1.9	2.5	4.2	7.2	62.5	1100	110	1534
14	W 92-1	2	75.9	43.7	336	94.0	69.4	11.9	-0.7	2.5	4.2	6.6	62.6	1080	113	1515
15	W 92-1	3	75.4	43.6	305	90.0	69.2	11.8	-0.8	2.5	4.8	8.0	61.9	1030	108	1305
16	W 92-1	4	75.6	44.5	261	95.0	70.1	12.5	-0.2	2.5	5.0	6.5	63.1	1060	108	1202
17	NANTES	1	72.9	36.7	83	95.0	68.1	14.9	0.2	2.3	5.0	6.0	63.5	1195	113	1267
18	NANTES	2	73.0	36.4	125	92.0	69.4	14.4	-0.5	2.5	4.4	5.5	63.0	1205	115	1273
19	NANTES	3	73.9	36.9	118	92.0	69.0	14.3	-0.4	2.5	5.8	6.5	63.7	1190	114	1267
20	NANTES	4	72.8	37.1	120	92.0	69.4	12.8	0.2	2.4	4.4	6.0	62.0	1110	112	1063
21	GAMTOOS	1	76.2	36.3	264	76.0	66.9	13.2	0.0	2.0	5.5	12.0	66.2	1090	108	1528
22	GAMTOOS	2	76.3	37.2	329	70.0	68.1	13.8	-2.2	2.1	5.0	12.5	66.1	1160	113	1460
23	GAMTOOS	3	76.4	35.8	315	95.0	67.1	12.9	0.0	2.0	4.9	10.0	68.1	1135	114	1254
24	GAMTOOS	4	76.0	36.2	290	68.0	67.2	12.5	-1.0	2.4	5.2	10.0	66.0	1030	105	1377

Appendix Table 3: Parental and F2 lines planted at Langgewens 1997

ENTRY	NAME	REP	HLM	TKM	FN	GPC	SDS	BFY	EX	FPC	FCL	MDT	FA	FST	FDT	LFV	Yield
1	Pmt/Gmt	1	80.4	34.0	348	11.7	57	22.0	76.6	11.3	2.3	2.7	65.85	6.0	4.0	960	705
2	Nantes		81.5	33.3	386	12.3	73	24.8	77.5	12.2	1.9	2.5				1030	750
3	W92-1		80.9	36.6	389	11.3	60	23.0	77.8	10.9	1.7	2.7	65.35	5.3	3.5	1005	1038
4	SST57/Kar		81.4	35.5	392	11.9	70	26.0	77.9	13.5	0.5	2.7				1105	890
5	W92-1/Pmt		81.4	37.8	363	11.5	65	26.6	76.0	11.8	0.6	2.8				995	993
6	Kariega		81.6	36.1	414	12.0	83	25.7	78.3	12.3	1.5	2.9				1020	902
7	SST57/Pmt		80.4	34.6	386	12.3	65	24.6	77.3	11.9	1.0	3.1				1015	863
8	W92-1/Kar		81.2	33.3	378	12.4	68	28.1	75.1	12.6	1.2	2.5				1050	1020
9	Pmt/Kar		80.9	35.6	392	12.4	70	25.7	77.4	11.6	1.7	2.7	63.70	8.0	4.1	1035	1009
10	Nts/Pmt		81.9	33.7	422	12.7	65	23.8	77.5	11.8	3.2	2.6	64.40	7.2	4.5	1045	893
11	Nts/Gmt		80.1	32.1	367	13.2	60	23.8	74.5	12.8	1.9	2.4	65.00	10.0	4.4	1100	1018
12	Gamtoos		78.8	30.9	424	12.2	52	21.7	74.8	12.2	1.8	2.4				960	1102
13	W92-1/Gmt		77.5	29.4	257	13.1	59	24.9	73.2	12.3	2.3	2.4				1090	780
14	W92-1/Nts		77.3	31.6	383	12.8	67	25.6	76.9	12.4	2.7	2.6				1145	1008
15	SST57		79.6	29.9	376	12.5	60	24.6	77.2	12.1	0.9	2.7				1135	946
16	Kar/Gmt		78.2	31.5	398	13.4	71	24.6	76.4	12.7	1.5	2.9				1100	700
17	Nts/Kar		81.5	35.3	407	12.5	74	26.3	77.5	12.1	0.7	2.5				1065	929
18	SST57/Gmt		80.1	31.7	373	12.4	57	22.2	75.9	12.2	1.7	2.7	65.00	11.5	4.2	1030	1020
19	W92-1/SST57		80.2	34.3	379	12.6	57	25.7	76.9	12.9	0.0	2.5	62.55	6.0	4.3	1070	1211
20	SST57/Nts		80.4	31.0	389	12.6	64	25.0	77.3	12.2	0.9	2.5	62.55	5.5	4.5	1080	730
21	Palmiet		79.5	31.7	395	13.6	58	22.2	74.8	12.5	2.1	2.7	66.15	9.5	4.7	1055	715
22	SST57/Nts	2	81.5	31.3	418	12.5	64	25.2	77.3	12.5	0.9	2.6	61.85	7.2	4.5	1080	720
23	Pmt/Kar		79.1	34.7	399	12.3	68	25.5	76.7	12.1	0.8	2.7	63.05	7.0	4.2	1095	780
24	Nts/Pmt		81.9	35.2	365	12.5	60	24.1	76.4	12.2	1.0	2.7	63.00	7.0	4.5	1110	1039
25	Gamtoos		78.5	30.6	368	12.0	53	22.0	73.7	11.7	1.2	2.2	66.85	10.5	4.5	980	914
26	W92-1		81.8	39.3	395	11.6	60	22.6	77.5	11.2	2.4	2.8	65.00	6.0	4.0	970	1000
27	SST57/Gmt		78.5	32.0	306	12.1	50	22.4	75.7	11.7	0.7	2.5	65.00	8.0	4.5	1080	999
29	Pmt/Gmt		80.8	34.1	306	11.8	64	22.5	75.5	11.7	0.3	2.7	65.00	8.0	4.5	1005	705
30	W92-1/Gmt		80.1	34.2	332	12.0	55	24.7	75.0	12.3	1.2	2.2	63.00	7.5	3.5	1005	952
32	W92-1/Nts		81.9	34.6	334	12.1	65	26.1	76.2	11.4	0.9	2.5	61.90	5.0	3.5	1075	725
33	SST57		81.6	33.8	368	11.4	58	24.2	77.6	11.3	-1.2	3.0	61.95	6.5	4.4	1005	910
34	Nts/Gmt		79.5	31.5	346	13.0	60	23.9	75.7	12.2	0.4	2.7	63.00	12.0	4.0	1070	777
35	SST57/Kar		80.0	38.7	328	12.6	62	26.8	75.4	12.2	1.4	2.2	62.60	5.8	3.8	1090	980

36	W92-1/Pmt		80.6	35.3	400	12.1	66	25.1	78.2	11.8	1.3	2.6	63.00	7.0	5.0	1080	803
37	Kariega		81.7	37.6	428	12.1	82	26.6	77.9	13.6	0.1	2.8	63.00	9.0	5.0	1090	942
38	Kar/Gmt		80.6	34.0	356	11.6	68	24.9	76.0	11.7	0.1	2.8	63.00	7.5	4.9	1025	
39	SST57/Pmt		81.6	36.2	368	12.0	61	23.6	76.4	11.6	0.8	2.2	64.05	6.0	4.5	1030	
40	W92-1/SST57		80.8	36.5	341	11.1	55	26.7	76.4	12.1	0.2	2.6	61.25	5.8	3.5	995	
41	Palmiet		83.4	38.1	334	11.3	57	21.4	75.7	12.3	0.8	3.0	65.45	6.0	3.5	930	
43	Nts/Pmt	3	82.5	34.0	382	13.2	68	24.8	76.5	12.3	-0.9	2.7	64.70	5.5	5.0	1080	
44	Nts/Gmt		80.4	31.1	383	13.2	63	23.4	76.2	12.4	0.6	2.6	66.40	8.3	4.4	1050	
45	SST57/Gmt		80.1	31.7	390	12.3	55	23.0	75.8	12.3	-0.3	2.7	65.70	9.8	4.6	975	
46	SST57		80.7	31.4	412	12.5	57	23.7	77.7	12.2	1.9	2.9	65.00	7.5	4.5	940	
47	Gamtoos		79.0	30.7	381	12.3	48	22.0	75.2	11.5	1.8	2.5	65.00	10.0	4.0	950	
48	Kar/Gmt		79.8	33.2	392	12.2	62	24.3	76.1	11.6	1.1	3.1	62.55	8.0	5.0	1055	
49	W92-1/Kar		79.5	34.2	369	12.7	58	21.2	74.0	11.6	0.9	2.9	62.90	8.0	5.2	1005	
51	W92-1/Nts		76.2	29.6	339	13.3	68	26.1	75.2	13.3	0.8	2.5	62.40	7.0	4.0	1130	
52	Nantes		78.3	29.5	372	13.5	65	25.0	76.0	12.9	1.6	2.7	62.60	7.5	5.0	1080	
53	W92-1/SST57		79.6	33.3	386	12.3	60	26.8	76.3	11.7	1.6	2.5	61.25	5.0	4.0	965	
54	SST57/Nts		80.6	30.6	377	12.2	64	25.0	77.4	11.7	1.2	2.5	62.10	6.2	4.5	1015	
55	SST57/Kar		80.7	32.9	358	12.3	73	25.7	78.0	12.5	0.5	2.9	63.00	7.0	5.0	1020	
56	W92-1/Pmt		77.8	32.5	376	13.0	60	26.9	74.3	12.4	3.6	2.5	62.00	5.6	4.0	1030	
57	W92-1/Gmt		77.8	29.4	378	15.1	60	24.6	74.3	13.2	3.2	2.2	66.85	6.0	4.7	1100	
58	Nts/Kar		80.7	33.3	389	13.4	76	27.6	77.7	13.7	1.0	2.5	63.00	6.7	4.8	1140	
59	Pmt/Kar		79.5	33.2	415	13.1	70	25.3	77.4	12.2	1.4	2.9	65.45	8.0	4.2	1080	
60	SST57/Pmt		79.1	29.9	307	13.9	62	24.4	76.1	13.0	1.9	2.7	64.05	10.7	5.3	1095	
61	Palmiet		80.7	33.8	355	13.5	63	21.9	75.7	12.8	2.4	2.8	65.75	7.0	5.4	1050	
63	Pmt/Gmt		80.5	33.3	413	13.3	88	25.8	78.0	13.0	-0.4	3.0	64.10	8.3	5.2	1100	
64	Kar/Gmt	4	79.2	31.7	385	13.3	65	24.3	76.1	12.2	2.3	2.7	64.05	9.0	5.2	1115	
65	SST57		79.0	30.3	410	12.7	58	24.4	77.9	12.8	1.9	2.5	64.00	9.0	4.5	1075	
66	W92-1/SST57		79.4	34.3	348	12.6	60	26.8	75.9	12.5	1.4	2.5	62.95	6.0	4.4	1015	
67	Nts/Pmt		79.7	34.2	419	13.3	65	25.8	76.5	12.2	2.1	2.6	63.70	6.8	5.0	1065	
68	Nts/Gmt		80.3	30.7	352	13.1	55	23.3	75.5	12.6	1.7	2.5	65.05	7.5	4.5	1105	
69	Pmt/Gmt		80.8	36.1	391	12.4	65	22.1	75.5	11.7	1.2	2.3				1025	
71	SST57/Kar		81.2	34.8	339	11.9	65	25.1	78.9	11.8	1.8	2.5	64.05	7.0	5.0	995	
72	Pmt/Kar		81.2	36.5	354	12.1	65	25.8	76.1	11.5	1.2	2.5	64.00	9.0	4.0	960	
73	W92-1		81.6	38.3	362	11.7	55	22.7	77.1	11.5	2.2	2.4	66.00	4.5	4.5	1025	
74	Nts/Kar		80.6	32.8	338	13.1	74	26.5	77.6	12.4	1.5	2.6	61.25	5.0	4.1	1115	

75	Gamtoos		78.6	30.9	394	12.6	49	21.6	74.6	12.0	0.7	2.0	66.90	6.0	4.5	970	
76	SST57/Gmt		78.3	31.8	373	13.1	58	22.6	76.0	12.5	2.2	2.6	66.10	10.5	5.0	1025	
77	SST57/Pmt		80.8	33.4	379	13.4	60	23.9	77.7	12.3	2.8	2.7	65.00	10.0	5.0	1100	
78	Palmiet		82.1	39.0	382	12.9	58	21.5	77.5	11.7	1.3	2.6	66.40	8.0	4.5	1030	
79	W92-1/Pmt		80.7	36.9	385	13.4	60	26.5	74.9	12.3	2.1	2.3	64.00	8.0	4.0	1075	
80	W92-1/Gmt		79.4	33.7	392	13.5	58	23.9	74.9	12.0	1.8	2.0	65.40	9.0	3.9	1030	
81	Kariega		79.8	36.0	378	12.7	85	26.0	78.0	11.7	1.3	2.4	65.00	9.3	5.3	1050	
83	W92-1/Kar		81.3	36.2	361	12.1	66	27.2	76.6	12.0	2.5	2.0	63.95	5.0	3.4	1030	