QUALITY ASSESMENT AND CHARACTERIZATION OF HYBRID WHEAT IN SOUTH AFRICA

BY

ELAINE VAN EEDEN

Thesis submitted in accordance with the requirements for the Magister Scientiae Agriculturae degree

DEPARTMENT OF PLANT SCIENCES

(DIVISION OF PLANT BREEDING)

UNIVERSITY OF THE FREE STATE

BLOEMFONTEIN

2009

PROMOTOR: PROF. M. T. LABUSCHAGNE

ACKNOWLEDGEMENTS

All the honor to my Heavenly Father for it was through His will and strength that I completed this study and I am thankful for the privilege to do so.

My sincere gratitude to the following persons, companies and institutions:

Monsanto/Sensako for the opportunity, time and financial support to undertake this study. Sensako quality laboratory for their assistance in determining the quality data. A special word of appreciation to Mr. J. Cilliers for the determination of the quality data and valuable input. All my colleagues at Sensako for their support and understanding.

My supervisor, Prof. M.T. Labuschage for her guidance, help and advice in the completion of this study. Furthermore I am thankful for the financial support which was supplied by the National Research Foundation for the first part of my studies.

Mr. D. Exley and Dr. A. Barnard at the ARC Small Grains Institute for their help and advice regarding statistical analysis and sprouting information supplied.

To all the people who helped me become a plant breeder today by creating the opportunities for me and whom motivated and inspired me to further my studies (Dr. H.A. Van Niekerk, Prof. M.T. Labuschagne, Dr. F.P. Koekemoer, Dr. J.D. Theunissen).

My friends (Amali, Mrs Estelle Mann, Vernize, Mr Tobi Roux, ect.) and family who encouraged me to complete this study. In lovable memory of my mother (Lettie) and sister (Winelle) who both passed away during the writing of this study.

My in-laws, Mr. Al Van Eeden, Mrs. Erika Van Eeden, brother-in-law Josef Van Eeden and husband Freek who looked after my two-year old boy every day of the week, while I was writing my thesis. It would not have been possible without your help and encouragement. My boy Albert and husband Freek, for their love, support and patience during the time of my studies.

LIST OF TABLES AND FIGURES

CONTENTS

CHAPTER 1

INTRODUCTION

Wheat is the world's leading cereal grain and most important food crop (Poehlman and Sleper, 1995). Its importance derives from the properties of wheat gluten, a cohesive network of endosperm proteins that stretch with the expansion of fermenting dough, yet hold together when heated to produce a "risen" loaf of bread. Only wheat (*Triticum aestivum* L.), and to a lesser extent rye and triticale, has this property. Its diversity of uses, nutritive content, and storage qualities has made wheat a staple food for more than one third of the world's population.

South Africa is a net importer of wheat. During 2004 it was indicated that domestic consumption of wheat is about 2.7 million ton, while the annual production over the same period averaged around 1.7 million ton (SAGL, 2004). The wheat production for the 2005 season (1.89 million ton) was 11% higher than in the previous season (SAGL, 2005), but 7.9% lower than the 5-year average of 2.04 million ton (2000/2001 to 2004/2005 seasons). Local consumption in South Africa is about 2.6 million ton per annum and the local production varies between 2 - 2.2 million ton per annum, therefore in a normal year 400 000 – 600 000 ton of wheat is being imported (Lochner, 2003). Almost all domestic production of wheat in South Africa is utilized to bake bread. Commercial mills can process over 30 ton of wheat per hour and commercial bakeries develop about six ton of dough per hour in order to produce 8000 loaves of bread per hour (Van Lill *et al*., 1995). It is thus important that locally grown cultivars are consistently of a high grade and therefore stability is an important breeding goal.

The Wheat Board (established in 1938) introduced the purchase and sale of wheat on a quality basis (Fowler and Priestley, 1991) and remained the sole purchaser of all wheat produced in South Africa until the deregulation of this single channel wheat marketing system in 1997. Since then, the decontrolled free trade environment was established and the wheat industry as a whole (wheat breeders and the processing industries, in collaboration with the agricultural sector) is now responsible for control and maintenance of quality standards of the grain for the different market demands.

Wheat marketing systems are consistently in a state of change and the trend is towards identity-preservation and the so-called niche-market or closed-looped marketing systems in which special quality wheat is contracted at a premium price. Quality is therefore becoming more and more important to the wheat farmer, breeder and industry in South Africa. Local breeders mainly develop hard red bread wheat which have to fulfill certain requirements in 19 quality characteristics (milling and baking), as set by the industry to comply over a three year data period. The millers are interested in the highest flour yield and ease of milling, while bakers are interested in receiving a constant grade of grain, whereas farmers cultivate wheat to comply with standards in three (test weight, protein content and falling number) of these characteristics when delivering their harvests at silos (personal communication, J.D. Cilliers, SENSAKO).

South Africa is a country with diverse wheat producing regions (the winter rainfall region, the irrigation regions and the summer rainfall region under dryland conditions), with extreme variation in climatic conditions such as rainfall, daily temperatures, wind and nutritional status of different soil types. This study focused on quality of wheat grown in the Free State province. This area can further be divided into three sub-regions which also vary in climatic conditions, soil types and planting dates (Eastern-, Central- and Western Free State). This is the only region that is planted under winter and facultative wheat types during the autumn and winter months (April to July) on residual soil moisture conserved during the summer rainfall period (October to March).

Around the world, researchers found that environmental conditions influence the milling and baking quality of pure line wheat (Baenziger *et al*., 1985; Van Deventer, 1986; Gaines, 1991; Van Lill, 1992; Purchase, 1997; Crossa *et al.*, 1998; Koekemoer, 2003). Positive and negative heterosis was reported in hybrid quality characteristics, but most hybrids tended to be intermediate between the parents (Borghi *et al.*, 1988; Borghi and Perenzin, 1994; Oury *et al.*, 1995; Cukadar *et al.*, 2001). The low seeding rates recommended in the summer rainfall, winter wheat production agro-ecosystems of the Free State, favor the use of F1 hybrid bread wheat due to yield and performance stability advantage. Hybrids in general have proven to be more consistent in yield performance over seasons and localities than commercial standards and pure line cultivars (Jordaan *et al*., 1999). A generally large gap in the knowledge on hybrid

wheat quality and the restricted number of hybrid wheat programs in the world motivated this study.

The aims of this study were:

To research quality characteristics of hybrid wheat in South Africa

To determine to what extent the quality of hybrid wheat is influenced by the parental male and female genotypes from which the hybrid was compiled

To assess heterosis in South African hybrid bread for wheat quality

To determine the stability performance of hybrids and their parental lines for wheat quality, and its relation to conventional cultivars

To assess sprouting tolerance in hybrid wheat.

CHAPTER 2

LITERATURE REVIEW

"And unto Adam he said: Because thou hast hearkened unto the voice of thy wife, and hast eaten of the tree, of which I commanded thee, saying: Thou shalt not eat of it; cursed is the ground for thy sake; in sorrow shalt thou eat of it all the days of thy life. Thorns also and thistles shall it bring forth to thee; and thou shalt eat the herb of the field. In the sweat of thy face shalt thou eat **bread**…Therefore the LORD God sent him forth from the garden of Eden, to till the ground…" (Genesis, 3, 17-23). This verse describes the expulsion of Adam and Eve from the garden of Eden, may reflect the, so called, Neolithic Revolution, during which man assumed control over his own food production. During this period, the pre-agricultural hunter-gatherer became gradually acquainted with nature's periodicity and with the life cycle of the dominant plants in his environment, and succeeded to domesticate many of them (Feldman *et al*., 1995).

2.1 THE ORIGIN OF WHEAT

The geographic centre of origin of wheat is the south western region of Asia, where it has been grown for more than 10 000 years. The genetic origin of wheat lies in the combination of closely related species to form a polyploid series (Poehlman and Sleper,1995). Wheat falls under the genus *Triticum*, and the species of *Triticum* are grouped into three ploidy classes: diploid (2n = 2x = 14), tetraploid (2n = 4x = 28) and hexaploid (2n = 6x = 42). Of these species only two are of commercial importance: the hexaploid species, *T. aestivum,* also known as bread wheat; and the tetraploid species, *T. turgidum*, the durum wheat used in pasta making.

Tetraploid wheat, or *T. turgidum* (AABB) constitutes of the diploid species, *T. monococcum* (AA), and an unknown parent containing the BB genomes. *T. aestivum* (with the AABBDD genomes), or bread wheat, is an allopolyploid that evolved from combining the AABB genomes of *T. turgidum* with the DD genomes of the diploid species of *Triticum tauschii* (*Aegilops squarrosa*). The D genome introduced genes that control the intrinsic baking qualities of *T. aestivum* that are not found in other *Triticum* species. The 42 chromosomes over the three genomes (AABBDD) are

divided into seven homoeologous groups. Each homoeologous group contains three partially homologous chromosome pairs, one chromosome pair from each of the AA, BB, and DD genomes. The group number and genome originates from the chromosome and therefore identify each chromosome. The three chromosomes within the ABD homoeologous group often contain common loci for a particular character (Poehlman and Sleper, 1995).

Kimber and Sears (1987) also concluded that the way in which the wheat group evolved is clear, and is characterized by a group of diploid species. The diploids diverged from a common ancestor bearing seven chromosomes (gametic number), and tetraploid species resulted from the hybridization between diploids and the consequent doubling of chromosomes. Further hybrid forming between the tetraploids and other diploids evolved, after chromosome doubling, into the hexaploid species.

2.2 THE IMPORTANCE OF WHEAT FOR GLOBAL FOOD SECURITY AND RESEARCH

Wheat is a major staple food for more than half of the world's population, and is expected to remain so or increase in the medium to long term. Unlike maize, more than 90% of wheat is directly consumed by humans, with little used for livestock feed or other purposes. Most people eat a wheat product at least once a week, with some consuming wheat three times a day, providing half, or more, of all calories consumed. About 90% of the wheat produced is common wheat or 'bread' wheat (*Triticum aestivum*), used for diverse leavened breads and flat breads. Alternate uses, the growing population and the new much publicized bio-fuels are expected to increase demand. Factors that will increasingly put pressure on wheat production and quality demands are, for instance, new market demands which are increasing, crops competing for hectares with new end uses and profitability of the different crops, and the occurrence of global warming which changes the effect of the environment. Thus, while demand is rising, production and improvement of wheat cultivars cannot keep up. According to Briggle and Curtis (1987), wheat is the top ranking cereal food grain consumed directly by humans, and its production leads all other crops, including rice, maize and potatoes. It is therefore also true that more land is devoted worldwide to the production of wheat than to any other commercial crop.

In South Africa, the market for bread is currently benefiting from the growth of the economy and bread sales are growing at a rate of almost 5% per annum. This is a clear indication of not just a growth in volumes, but also in the per capita consumption of bread. The Chamber of Baking noted the performance of other carbohydrates competing with bread in the market and found rice consumption has grown at 4.7% per annum in the past two years and the per capita consumption of maize meal is declining (personal communication, Isobel van Schalkwyk (isobel@sacb.co.za), SA Chamber of Baking, 2007).

2.3 HYBRID BREAD WHEAT

2.3.1 BACKGROUND AND HISTORY OF HYBRID WHEAT

In 1962 Wilson and Ross made the necessary breakthrough for hybrid wheat breeding when they transferred fertility-restoring (Rf) genes from *Triticum timopheevii* to common wheat by substitution backcrossing. Two major systems have been utilized in producing commercial hybrid wheat, namely cytoplasmic-genetic systems (CMS) and chemical hybridizing agents (CHAs). The first commercial hybrid wheat was marketed in the United States by DeKalb in 1974 and by Pioneer Hi-Bred International in 1975, both using the CMS system (Edwards, 2001).

The list of countries producing hybrid wheat on a commercial basis in 2000 included the United States, France, Australia and South Africa; those with hybrid wheat at launch phase include the United Kingdom (UK), Denmark, Belgium and Germany; while other countries such as China and India have active research and development programs. Hybrid wheat was formerly marketed in Argentina by Cargill using the CMS system but, as with a number of other major companies, Cargill withdrew from hybrid wheat development. In 1998 the two leading hybrid wheat producing countries were the United States (300 000 ha of hybrids out of a total of 30 million ha of wheat produced, or 1%) and France (80 000 ha of hybrids out of 4.8 million ha of wheat produced, or 1.7%) (Edwards, 2001).

Currently active hybrid breeding programs are operative in Australia, India and China. Only Saaten-Union still has an active breeding program on hybrid wheat in Europe in France and in Germany using a chemical hybridizing agent (CHA) acquired from

Dupont. It is the only CHA with a valid marketing authorization in an EU country (France). Hybrid wheat is grown on 140 000 ha, mostly in France (100 000 ha) and Germany (25 000 ha) (personal communication, Guillaume de Castelbajac, Saaten-Union, 2007).

Research on hybrid wheat which was carried out in the UK reported low levels of heterosis in wheat and found it to be fixable in an inbred line (Angus, 1997). They used CHAs (chemical hybridizing agents) which allowed large scale production but with disappointing yields, only 2-3% above the highest yielding inbred varieties, which did not justify the cost of production. In addition, the first hybrids were developed from conventional inbred lines which consequently produced low seed sets in commercial production. Cockpit, a winter wheat variety from Monsanto Hybritech, was evaluated and produced very high yield of bread making quality grain. This was the result of a combination of parents (Hyb93-25 x Piko) which produced very high seed sets during seed production, but failed to be recommended due to its very high susceptibility to yellow rust (Angus, 1997).

Hybrid wheat in France occupied around 130 000 ha for the season 1999/2000, a little less than 3% of the total area of wheat, due to the difficulty of hybrid seed production and insufficient heterosis compared to the continued genetic progress with conventional lines since the 1980's. A chemical hybridization process was used, but in the long term a genetic system would have been more efficient. Yield gain from the best hybrids reached 10% compared to the best parents, but arrived on the market when the parents were released six to eight years earlier and genetic progress was on average 1% per year. This erodes a large part of the heterosis value for the farmer. The creation of lines specifically bred to make hybrids is only in its infancy and today the heterosis is exploited between lines not created uniquely for this purpose. However, it is possible to quickly combine several types of resistance and that is why hybrids may offer a better yield stability than pure lines. Hybrid varieties of high quality could be developed for the agro-food industries as well as for traditional markets (Bonjean *et al*., 2001).

Only one hybrid wheat features on the German list, Hybnos 1, which was listed as a C quality feed wheat due mainly to low protein content. It yielded 6% above the next best

inbred, but at seed rates economical for hybrids (150-180 seeds/m^2) there was a yield reduction of between 3-4%. Many factors influence the future of hybrids in Germany, as in the rest in Europe. One is the acceptance by the public and end users of hybrids produced by CHAs and with no CMS hybrids in sight, future hybrids will be CHA produced. Unfortunately, the public and end users have been over sensitized by genetically modified (GMO) products and CHA hybrids are perceived to be a facet of this technology. In addition, the present yield advantage of hybrids is not convincing economically. Breeding for general combining ability (GCA) is still at an early stage and there is almost certainly good progress to be made over the next years. A specific German problem will be the protein dilution effect correlated with the higher yield and due to quality minimum standards it will be difficult to produce hybrids that reach the protein levels required for classification as B or A quality. Seed prices remain a problem due to high cost of CHAs, as no registration for the available CHAs is envisaged for Germany, which restricts production in France. One positive aspect for the development of hybrid wheat within Germany is that there appears to be a higher proportion of suitable pollen donors in the German gene pool (Porsche and Taylor, 2001).

Hybrid wheat research was started in Hungary, as elsewhere, after the discovery of CMS. Wide-ranging experiments were carried out in order to develop satisfactory economic seed production systems. Barabás (1973) developed the purple gene hybrid seed production system, in which the restorer parent has purple grain color, while the male sterile (ms) female has normal white or brown colour. The seed of the cytoplasmic male sterile (cms) and restoring fertility (Rf) parents were sown mixed, thus improving the chances of pollination. The purple colored grain produced on lines with the Rf marker were separated from the white hybrid seeds in the mixed harvest using a color selector. After 20 years of research the CMS program was terminated.

In the 1980's the appearance of the CHAs, gave new hope for hybrid wheat production and the application of CHA was initiated in 1983/84. Experience proved the good sterilizing effect of the CHA and ensured efficient, safe seed production, largely independently of climatic and weather conditions. One of the major problems of the CMS system, the imperfect restoration which heavily influenced the performance of the hybrids, could also be overcome by using the CHA. It was soon realized that in order

to achieve adequate seed set, careful selection of the parents had to be carried out. In the case of the pollinators, open flowering, pollen quantity and heading time should be taken into consideration, while the females with good seed set was only possible by experimentation. Even after careful selection of the parents, a considerable number of test crosses produced inadequate amounts of seed. According to the estimates at least 50% seed set is needed to produce an economically competitive hybrid. The low seed set of some combinations reduced the number of possible hybrids, but this did not significantly impoverish the genetic stock (Lang *et al*., 1989). While seed set is largely determined by the parents, the year x seed set interaction seemed to be much less pronounced.

Hungarian researchers did heterosis studies for one year at one location and about 10% of the tested hybrids proved to be highly competitive with the registered varieties. The best hybrids, re-tested at three locations in the second year, out-yielded the average of the four best varieties by 6-22%, 12 of them by more than 15%. The heterosis on midparent values was 4-16%. Trials in Hungary in the autumn of 1987 found that under favorable growing conditions (7-8 t/ha yield level) the hybrids were unable to take advantage of their superior adaptability, stress tolerance and disease resistance. Averaged over a larger number of locations, the hybrids showed less advantage than previously. The F1 performance was 3-10% better than the average of the released varieties and up to 5% better than the average of the four best inbreds. In addition to yield, 8-10% heterosis was measured in plant height, with considerable heterosis in vigor, adaptability, disease resistance and quality. Hybrid research was continued between 1989 and 1996, using a CHA in a broader genetic background. Breeding better parents led to a reduction in the height of the hybrids, but an F1 consistently more productive than the best varieties could not be achieved (Bedo *et al.*, 2001).

In Italy, at the wheat station of Sant' Angelo Lodegiano, studies on hybrid wheat were started in the 1960s (Rusmini, 1967; Boggini, 1975). The first attempts to use a CHA did not lead to usable results (Borghi *et al*., 1973), but a new class of CHA developed in the 1980's made it possible to produce hybrid combinations from a large number of parental lines. Since then, several hundreds of hybrids involving Italian germplasm have been produced and tested in replicated trials sown at normal seed density (Borghi

et al., 1988; 1989; Borghi and Perenzin, 1990; Perenzin *et al*., 1992; Borghi and Perenzin, 1994; Perenzin *et al*., 1997).

A positive trend was observed in the yield potential of the hybrids produced during the last 15 years. None of the first set of 141 hybrids, produced by random crossing of the available varieties, produced 10% more than the checks. In the following top cross, 50% of the hybrids surpassed the checks by 5%, and 19% by more than 10%. Of the 21 hybrids derived from the diallel cross, including the varieties with the highest GCA values, 71% surpassed the control by 5%, and 5% by more than 10%. Finally in the last top crosses of selected varieties, several hybrids out-yielded the best varieties by more than 15%. The approach based on the selection of already existing varieties increases the frequency of hybrids able to compete with the best varieties produced by conventional breeding, but does not increase the level of standard heterosis. A specific breeding program based on reciprocal recurrent selection exploiting and accumulating specific combining ability effects, aimed at increasing the advantage of the hybrids over the varieties beyond the level so far achieved, was established. In wheat, heterotic groups such as those recognized in maize have not yet been identified. An attempt to relate heterotic effects to genetic distances as determined by molecular markers (RFLP, RAPDS and AFLP) or pedigree relationships, showed hybrid performance to be weakly correlated with parental diversity (Perenzin *et al*., 1997). As far as quality is concerned, the hybrids reveal, on average, a lower quality, at least in terms of alveograph W value, than the best traditional varieties, but it appears possible to produce a wide array of hybrids, some of them combining satisfactory quality with a high level of productivity (Perenzin *et al*., 1992).

At no time during the last 25 years have hybrids occupied more than 2% of the wheat area in the HRW (hard red winter) region in the US. The main problems limiting the adoption of hybrids have been the low levels of heterosis relative to the high cost of seed. In regional performance trials hybrid genotypes often occupied a disproportionately high number of positions in the yield ranks. Bruns and Peterson (1998) were able to predict an average heterosis level of 11 to 14% for grain yield using essentially equal germplasm pools for hybrid and pure line genotypes developed by Agripro Seeds Inc. They also found significant yield advantage of hybrids over pure line genotypes tested in the SRPN from 1990 to 1995. Sufficient heterosis does exist

in the hard winter wheat gene pool to justify further development and improvement of hybrid cultivars, but equating agronomic and economic benefit has not yet materialized (Carver *et al.*, 2001).

When strategies for increasing wheat yields are discussed in Mexico, hybrid wheat is often mentioned as an alternative. However, Picket (1993) and Picket and Galwey (1997), evaluating 40 years of wheat hybrid development, concluded that hybrid wheat production is not economically feasible because of limited heterotic advantage, lack of advantage in terms of agronomic, quality or disease resistance, higher seed costs and hybrids would have no advantage over inbred lines.

Mean grain yield of hybrids tested in the Southern Regional Performance Nursery (SRPN), across locations in the southern Great Plains, were significantly higher than for the inbred lines (Peterson *et al.*, 1997). Bruns and Peterson (1998) calculated mean yield advantage of hybrid wheat at 10-13%, and attributed this advantage to better temporal and spatial stability and improved tolerance to heat. In contrast, recent reports of hybrid performance in Europe indicate lower levels of heterosis (5-12%) (Eavis *et al*.,1996). Gallais (1989) stated that, provided over dominance is of little importance in wheat, in the long term inbred line development will be more effective than F1 hybrids. If biotechnological methods can identify increased expression of heterosis by more effective selection of favorable alleles, this impact will likely have equal advantage to inbred and hybrid development. Whether hybrids have a higher absolute yield potential than inbred lines also has to be seen in the light of inbred bread wheat cultivars that already reached grain yields of 17 t/ha (Rajaram and van Ginkel, 2001).

The Australian hybrid wheat breeding program utilizes a CMS system for the production of its hybrids and also uses similar low seeding rates for its hybrids as in South Africa. The hybrid wheat breeding program (SunPrime Research and Development LTD) targets prime hard quality wheat and achieves levels of heterosis that make the hybrids the highest yielding entries in collaborative yield trials conducted across the region. Minimum protein levels of 13% are required for inclusion into Australian wheat grades. But prevailing temperatures and the amount, and timing, of rainfall during grain filling have a major influence on the final grain protein content.

Failure of grain to meet quality requirements is usually due to stresses encountered during grain filling. Breeding programs therefore aim to complement the selection of quality characteristics with resistance to biotic and abiotic stress. A major breeding effort is directed towards sprouting tolerance and Australian varieties are available with some degree of tolerance (O'Brien *et al.*, 2001).

China spends enormous efforts in researching breeding systems for hybrid wheat. The system employed are the CMS system, CHA and the two-line system including photoperiod-sensitive, temperature sensitive and genetic male sterility. Hybrid wheat has a promising future in China after more than 40 years of research. Special yield tests have been established and hybrids entered into regional tests. EY17, EY18, EY19 showed yield advantages from 5.4% to 20% in regional yield trials. The seed production and seed increasing technique was also improved and the seed yield reached 3000 kg/ha (Baoqi *et al.*, 2001).

Significant efforts to breed F1 hybrids have been made in the Japanese universities (Yamada, 1994). Breeding for high-yielding wheat varieties using F1 hybrids has not been performed because the F1 hybrids could not be used commercially due to low quality and lack of scab resistance.

During the late 1960s and 1970's, when hybrid wheat research was at its peak in North America and other developed countries, the Indian wheat program was experiencing the impact of semi-dwarf wheat. Hence not much attention was given to the utilization of heterosis by way of hybrid production. Some reports are available on the development of CMS lines in Indian wheat varieties based on Timopheevii cytoplasm. Partial restorers to this cytoplasm were also identified in some Indian varieties (Miri *et al*., 1970; Prakasa Rao and Jain, 1977). Wheat production in productive areas like Punjab has stabilized and conventional breeding programs were able to provide at best 1% yield gain per year. This prompted a revival of hybrid wheat research as alternative strategy to attain another jump in wheat productivity. Hybrid wheat experiments based on the CMS system was launched with yield increases of 26-40% which was noted in farmers' field demonstrations (Ratnalikar and Singh, 1998).

Hybrid wheat in South Africa

Low seeding rates recommended in the summer rainfall, winter wheat production agro-ecosystems of the Free State favor the use of F1 hybrid bread wheat due to yield performance and stability advantage resulting in reduced relative input cost for seed. Hybrids in general have proven to be more consistent in performance over seasons and localities than commercial standard, pure-line cultivars (Jordaan *et al.*, 1999). Heterosis is maximized in hybrids which are photoperiod sensitive, with little or no vernalization requirement. Since 1980, 14 F1 hybrid winter or facultative bread wheat cultivars have been released for production in South Africa. The use of hybrid crops is usually targeted to higher yield potential environments. Results from South Africa reported that hybrids out-yield inbred lines by 15% at a 2 t/ha mean production potential when narrow row spacing and low seeding rates (< 25 kg/ha) are used. In South Africa 800 000 -1200 000 ha of wheat is planted annually of which +/- 7372 ha consist of hybrid wheat, in total not even 1% of the total of wheat produced (personal communication, Patrick Graham, Director Sensako Wheat Programme). In SA, hybrid wheat is planted at very low densities ranging from as low as 12 kg/ha. Understanding quality in hybrid breeding is critical as seed companies are looking at investing in hybrid wheat again and inheritance and expression of wheat quality of hybrids is thus critical.

2.3.2 QUALITY OF HYBRID WHEAT

Hybrids mostly offer the opportunity to increase yield levels of wheat through exploitation of heterosis to meet the increasing food demand. In addition, a high yielding hybrid needs to meet quality demands as set by the industry. The basic definition of quality in wheat will vary with the market class. The development of high yielding, high quality hybrids would be advantageous to the grower in terms of increased payments as this would help offset some of the additional cost of seed. Wilson and Driscoll (1983) found that breeders have not had any difficulty in producing hybrids of satisfactory milling and baking quality, although the overall quality of the hybrid is highly cross specific (Edwards, 1987).

Where baking characteristics have been reported, the individual traits were shown to be intermediate between the two parents, although a number of specific crosses have shown high-parent heterosis for quality traits (Shebeski, 1966; Wilson, 1968; Boland and Walcott, 1985; Edwards, 1987; Edwards and Dorlencourt, 1994; Cisar and Cooper, 1999).

In an extensive study of hard red winter wheat hybrids grown in regional trials at 10 locations in Oklahoma and Texas, Bequette and Fisher (1980) reported that test weight, flour yield, flour ash and flour color of hybrids were generally superior to the mid-parent value. Test weight and flour yield of several hybrids exceeded the high parent, and it was suggested that heterosis for test weight may occur, although partial dominance for earliness may be the major reason for hybrid superiority under moisture stress conditions. Absorption, mixing time and loaf properties were generally close to the mid-parent value when the parents differed significantly for these properties. It was concluded that prediction of quality in adapted hybrids should be fairly accurate providing that the parental lines have been accurately characterized. Other studies in different environments have pointed to hybrid quality being highly cross specific (Edwards, 1987; Edwards and Dorlencourt, 1994) and not always easy to predict when contrasting parents are used.

The development of inbred lines with good quality characteristics and good combining ability is necessary because, in order to benefit from the combination of dominant alleles in a hybrid, the desirable traits should be dominant or at least partially dominant. Although this is not always the case (Picket, 1993), a number of authors have concluded that high quality hybrids can be achieved.

CIMMYT reported positive and negative heterosis for all quality parameters studied, but found that the bread-making quality of hybrids tended to be intermediate between those of the parents (Cukadar *et al.,* 2001). Most research indicates that bread making-quality of wheat hybrids are intermediate between parental lines when produced from European winter wheat germplasm (Borghi *et al*., 1988; Borghi and Perenzin, 1994; Oury *et al*., 1995; Pickett and Galwey 1997). Grain protein of hybrids ranged between 12.05 and 13.60% and the differences amongst hybrids were significant. Although 45% of the hybrids had lower protein content than both parental

lines, the difference between the parental lines and hybrids was significant only for two hybrids (less than 1% of hybrids). Results were similar for the other parameters with the exception of bread loaf volume. About 56% of hybrids had higher bread loaf volumes than those of both parents, 29% of which were significantly higher. The high loaf volume of hybrids could be explained by better extensibility (smaller alveograph-P/L ratios) of hybrids.

The alveograph-P/L ratios of hybrids were lower when compared to the mid-parent values. The relationship between loaf volume and alveograph-P/L ratio was highly significant. The correlation coefficient was found to be negative and insignificant between hybrid yield and grain protein and flour protein content. Except for SDS sedimentation, all other bread making quality parameters showed negative and also insignificant correlation with yield (positive in the case of alveograph-P/L ratio). Although bread loaf volume was negatively correlated with hybrid yield, it was found possible to breed hybrids with high yield and acceptable end-use quality.

Cukadar *et al.* (2001) found heterosis in extensibility and loaf volume due to the combination of high molecular weight (HMW)- and low molecular weight (LMW)-glutenins that contribute positively to improved gluten and bread-making properties. Certain LMW-glutenins could favor good gluten and bread-making properties. Certain LMW-glutenins are known to favor gluten extensibility (Gupta *et al.*, 1990). Two of the four male lines in this study are known to possess quality-desirable LMW-glutenins (Roberto J. Pena, personal communication). One of these lines was the male parent of the highest yielding hybrids. Also, co-dominance of genes for HMW-glutenin subunits may explain the improved bread loaf volumes of hybrids. These results from CIMMYT indicated that despite a slightly negative association between grain protein content and yield, it is still possible to develop high yielding hybrids with acceptable bread-making quality. Crossing parental lines with strong or medium gluten with a strong but extensible gluten (tenacious) or weak gluten, could produce a hybrid with strong to medium strong and extensible gluten. These data indicate that it is important to select at least one parent with a strong gluten type and quality-desirable HMW and LMW glutenins in order to obtain a hybrid with good bread-making quality.

Borghi and Perenzin (1994) reported that the end-use quality appears to be a function of additive gene action. Cukadar *et al.* (2001) concluded that grain and bread-making quality properties were not adversely affected in a hybrid background. The level of heterosis and bread-making quality in the hybrids depends on the specific parental line combinations used to produce them.

2.4 QUALITY RESEARCH OF PURE LINE BREAD WHEAT

2.4.1 MILLING CHARACTERISTICS

Milling and flour quality is related to grain morphology. Desirable aspects would be large uniform kernel size, plumpness and spherical shape, high density and well filled kernels (Fowler and Priestly, 1991). Short grain with a narrow crease, rounder rather than longer and consistency of shape as well as plumpness are good kernel characteristics. Kernels should exhibit a uniform, smooth surface with the absence of depressions or corrugations.

2.4.1.1 Test weight (HLM)

Weight per unit volume of grain (test weight or hectoliter mass) is an important wheat grading factor of the physical quality in grain (Halverson and Zeleny, 1988). 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 the grain is grown. Test weight is useful in indicating the relative condition of the wheat (Donelson *et al*., 2002). Kernel shriveling could be due to environmental stresses and results in decreased test weight (usually expressed in kilogram per hectolitre). This characteristic is influenced by genotype x environment interaction. However, test weight fluctuations are much smaller than for yield, which indicates that test weight can be tested on single plots rather than replicated plots. Furthermore, yield components are exposed to environmental influences for the entire plant life cycle, where test weight is exposed only for a limited period during the ripening phase (Jalaluddin and Harrison, 1989). Hectolitre mass is of economic value, because it may predict flour yield (Finney *et al*., 1987; Nel *et al*., 1998). Relatively higher test weight and thousand kernel weight values resulted in higher total flour yield

and good milling attributes, where the growing location significantly affected these parameters (Park *et al.*, 1997). Higher test weight is an indication of grain plumpness (McDonald, 1994) visible in a growth season with favorable conditions during grain filling (Evans *et al*., 1975). Growth conditions during grain filling, which affects test weight negatively, are moisture stress, high temperature, nitrogen supply shortages and occurrence of diseases.

According to Van Deventer (1986) the contribution made by South African winter wheat cultivars to the variation in hectolitre mass (38.2%) was significant. In South Africa a test weight of 76 kg hl^{-1} is preferable and a minimum of 74 kg hl^{-1} is required for breadmaking purposes (Nel *et al*.,1998; Barnard and Burger, 2002). According to Charles *et al*. (1996) higher test weight is an indication of higher protein content. Van Lill and Smith (1997) reported that grains containing higher protein were inclined to be harder, which in return increased flour yield.

2.4.1.2 Kernel size (diameter)

Flour is derived from wheat endosperm and thus size, density and shape of the grain determines flour yield potential (Eggitt and Harley, 1975). Marshall *et al*. (1986) found that grain size measured by grain weight or volume was correlated with flour yield.

Steve *et al.* (1995) found a positive and negative relation respectively to flour yield for kernel width and thousand kernel weight. Kernel width was also significantly correlated with kernel volume. However the model explained only a small part of the total variability in flour yield (r^2 = 0.22). Therefore they concluded that higher test weight should not always be regarded as an indication of higher flour yield. Apparently endosperm content (revealed by kernel plumpness), favored by high photosynthetic rates and/or long grain filling periods, is strongly influenced by environmental conditions (Planchon, 1969; Jenner, 1991). Hot and dry growing conditions increase the degree and amount of kernel shriveling and decrease flour yield due to a reduced ratio of endosperm to bran (Pinthus, 1973; Yamazaki, 1976; Pumphrey and Rubenthaler, 1983; Simmonds, 1989). Millar *et al.* (1997) reported a positive correlation between grain size and water absorption for Canadian cultivars, irrespective

of protein class. Additionally, the correlation coefficient for this relationship was even higher than that observed between starch damage and water absorption. Thus larger grains exhibit larger water absorption levels than smaller grains. A phenomenon where larger kernels tend to show lower falling numbers was also reported by Millar *et al.* (1997).

2.4.1.3 Kernel hardness

Hardness is highly heritable and wheat cultivars are specified as either hard or soft. It was found that variation in hardness of winter wheat grown under widely different environmental conditions was affected mainly by genotype (Pomeranz and Mattern, 1988) and to a small extent by environmental and growth conditions (Fowler and De la Roche, 1975; Pomeranz *et al.*, 1985). The strength of the starch and protein interactions, embedded within the endosperm, influence kernel hardness (Barlow *et al.*, 1973).

Van Lill and Smith (1997) reported that grains containing higher protein content were inclined to be harder, which in turn increased flour yield. Extraction is a function of hardness, and endosperm of hard firm wheat grains tends to separate more easily from the bran during the milling process. More starch granules are being damaged when hard wheat is milled, thereby increasing the water absorption levels.

Flour extraction provides a useful measure of milling efficiency (Bass, 1988; Gibson *et al.,* 1998). Gaines (1991) proved that drier climates should favor the production of larger, better filled and harder kernels that tend to produce superior milling characteristics. More moist environments should produce softer kernels that generally produce less damaged starch during milling and lower water absorption values. Correlation analysis showed no relationship of kernel hardness with kernel weight, width or test weight (Hazen and Ward, 1997).

2.4.1.4 Moisture content

Wheat grain is harvested at a moisture percentage of below 15% and dried to at least 12.5% moisture content to reduce the risk of the development of moldiness when in storage. When the moisture content is too high, heat damage could occur as a consequence of a rise in temperature while in storage (Posner and Hibbs, 1997).

2.4.1.5 Conditioning

Conditioning, or tempering, is the controlled addition of moisture to a wheat sample prior to milling to improve millability (Bass, 1988). The primary aim of conditioning is to change the mechanical characteristics of the different tissues of the kernel and thereby improve the separation of the endosperm and the bran to limit bran contamination during flour extraction. The addition of water also triggers a number of biochemical events in the kernel, which modify characteristics of the kernel (Gobin *et al*., 1996). This is to toughen the bran to ensure that it will resist powdering during the milling process (powdered bran cannot be separated from the flour at any stage of the milling action) and to facilitate the physical separation of endosperm from the bran. It also aids in mellowing the endosperm in order that it may be easily reduced to flour and to ensure that flour leaving the grinding rolls are in optimum condition for sifting. Another aim of conditioning is to ensure that the grind produces the optimum level of starch damage consistent with the wheat kernel hardness and flour end-uses (Bass, 1988). Gobin *et al*. (1996) found that conditioning not only influenced milling quality, but also the technological and biochemical quality of the final flour product due to the possible reduction of disulfide groups of protein that remain reduced even after lengthy storage.

Williams (1998) found that kernel hardness and the moisture content of the grain when received, is part of the fundamental knowledge a miller should possess before tempering is conducted. Kernel hardness is indicative of the rate and quantity of water uptake during tempering. Although it is generally accepted that hard wheat endosperm diffuses water at a slower rate than soft wheat endosperm, the exact nature of the interaction is not well understood, but it appears to be affected by vitreousness and the agglomeration of starch and protein in the endosperm (Pomeranz and Williams, 1990).

Delwiche (2000) found that moisture affects wheat texture and that soft and hard wheat exhibit the same trend with moisture content, however, they do it at different response rates.

Water moves more rapidly through small and soft wheat grains than through hard wheat grain. Glenn and Johnston (1994) reported that water diffusion in mealy (soft) endosperm was 1.8 to 4.6 times faster than in hard vitreous endosperm. Consequently the amount of water added and the optimum time of equilibration are different for hard and soft wheat (Osborne, 1991). Usually water is added to obtain a moisture content of approximately 16.0 to 16.5 % for hard wheat and 14.5 to 15.0 % for soft wheat (Williams, 1998). Tempering can be modified by increasing the temperature, moisture component and tempering period. The optimal amount of water and tempering time differs according to the grain characteristics. Hard wheat needs the addition of more water and longer conditioning periods than soft wheat. The optimum conditioning according to kernel hardness is of utmost importance to prevent problems during the milling process. For example, when soft wheat is conditioned for a relatively long period, the endosperm literally sucks the water out of the bran, resulting in brittle bran and “sticky” endosperm. The brittle bran may cause flour color and flour ash problems and the “sticky” endosperm will result in sifting and flow problems in the mill (Wylie, 2002).

Moisture content affects the endosperm compressive strength of hard wheat more than soft wheat (Delwiche, 2000), therefore moisture content has a positive correlation with the energy required to mill the wheat (Fang *et al.,* 1998). Dobraszczyk (1994) found that the fracture toughness decreases as the moisture content increases, irrespective of the degree of vitreousness. He also mentioned that an increase in moisture content increases the energy to fracture the endosperm.

2.4.1.6 Break flour yield

The objective of the break system with the first set of rollers, is to open the wheat kernel and remove the endosperm from the bran coat with the least amount of bran contamination and the small amount of endosperm is reduced to flour. This flour,

called break flour, is sieved out in the grading system (Bass, 1988). The breaking system in a mill is very sensitive to variations from the optimum wheat tempering level. Break flour from low-moisture wheat has higher ash values than flours from well-tempered wheat (Posner and Hibbs, 1997). Break flour yield is primarily a function of wheat kernel hardness (Gaines *et al*., 1996). During milling, hard wheat produces less break flour yield than soft wheat (Stenvert, 1972). This has been confirmed by the research of Gaines (1991), Rogers *et al*. (1993) and Labuschagne *et al.* (1997) who obtained higher break flour yield from softer textured wheat, usually resulting from lower protein soft wheat. Therefore, break flour yields correlated negatively with kernel hardness parameters (Ohm *et al*., 1998). In a study by Morris *et al.* (1999) the traditional measure of grain kernel hardness (break flour) was poorly correlated with other hardness measurements, this could be explained by the tempering of the grain. Tempering improves the correlation between break flour yield and particle size index (Yamazaki and Donelson, 1983).

Break flour yield was positively correlated with larger kernel size (Kosmolak and Dyck, 1981). Across environments, flour yield was highly correlated with hardness, protein percentage and cookie diameter (Basset *et al*.,1989). A negative and significant correlation between break flour yield and protein content for red wheat cultivars was reported by Gaines (1991).

2.4.1.7 Flour yield/ extraction

Higher flour yield from a certain amount of wheat means more profit for the miller and is therefore regarded as very important. Flour yield is also referred to as extraction and is expressed as the percentage of flour obtained from a given amount of wheat (Bass, 1988). Flour extraction is a complex trait, a combination of many minor effects. Kernel hardness, cell wall thickness and endosperm adherence to the bran affect the ease of separation of the endosperm from the non-endosperm components (Marshall *et al*., 1986). The expertise of the miller is also an important factor achieving optimum and good quality flour (Posner and Hibbs, 1997), because factors such as feed rate, roll gap, roll speed, roll differential and tempering procedure also play a significant role (Kilborn *et al*., 1982).

2.4.1.8 Ash

Ash is the residual inorganic material left after incineration and is expressed as a percentage of the original sample. The gradient of ash content increases from the centre to the outer layers of the kernel, so that the highest concentration is located in the seed coat or bran (Fowler and Priestley, 1991). This variability of mineral content can be due to environmental and genetic factors and their interaction. Millers use wheat ash as a quality factor to evaluate the product and are looking for wheat that will produce low ash flours. The ash itself does not affect flour properties and thus, it can be argued, that ash content should not be regarded as a flour quality parameter in bakers' specifications. However, ash values of wheat can be an important tool for the adjustment and control of mills (Posner and Hibbs, 1997). Fowler and De la Roche (1975) considered the use of flour ash useful as a measure of milling efficiency rather than of wheat quality. The ash content of flour is correlated with flour color brightness and provides a means of monitoring the milling process through the assessment of the grade value of flour streams (Oliver *et al*., 1993).

A greater proportion of the ash was removed by the debranning of durum and hard red spring wheat cultivars than in soft wheat cultivars. Although a high positive correlation was observed between flour color and protein content, the ash content appears not to be related to protein content (Preston *et al*., 1995).

2.4.1.9 Consistograph water absorption

Performing the consistograph test provides new data, which broadens the field of application of the alveograph. The initial test carried out at constant hydration will permit the recording of water absorption rate of the flour. The following test is aimed at using the previously determined absorption value, to resume the test at adapted hydration. This allows measuring how stronger doughs behave during mixing and whether more water should be added to determine whether the elasticity could improve. When analyzing very strong gluten types (those with poor elasticity), the adapted hydration test provides the breeder with additional information to determine if

the genotype could be hydrated further and to what extent. This is only possible for dough that allows further hydration, depending on the water absorption capacity.

Water absorption gives an indication of the potential of the protein molecules to absorb moisture. In general it can be said that higher protein content flour results in higher water absorption (Finney and Shogren, 1972; Van Lill and Smith, 1997). For South African wheat flour the ideal absorption level is 62-64% (personal communication: J.D. Cilliers, Quality Laboratory SENSAKO Bethlehem).

2.4.2 BAKING CHARACTERISTICS

2.4.2.1 Flour protein content (FPC) and quality

Protein content in bread wheat quality is an important factor in human nutrition and therefore needs special attention when breeders compile selection strategies (Mihaljev and Kovacev-Djolai, 1978). Wheat grain protein content was shown to be genetically controlled, although significant genotypic or varietal differences were noticed. These are known to be strongly influenced by environmental and agricultural practices (Mihaljev and Kovacev-Djolai, 1978). Genotype x environment interaction was highly significant for grain protein percentage, which is positively associated with large grains (Levy and Feldman, 1989).

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

Along with wheat kernel hardness, protein content is one of the most important factors in determining the end use quality of wheat (Fowler and De la Roche, 1975; Delwiche, 1995) and is important in the classification of wheat. Trade premiums are often offered on high protein wheat.

All the morphological parts of the wheat kernel contain protein, with the germ of embryo containing the highest concentration, but due to the small size, contributes very little to total protein. The major proportion of the total protein is contributed by the gliadin and glutenin components of the storage protein (Hoseney, 1994).

The milling process does not have a significant effect on protein content. It may not be necessary to measure both grain and flour protein (Bhatt and Derera, 1975). Flour protein content is usually around 1% less than the grain protein content (Hoseney, 1994). The protein content of pearled wheat was 1-3 % lower than that of the original grain (Obuchowski and Bushuk, 1980). A comparison of protein content between the whole wheat and the flour, indicates a smaller protein loss with large kernels (Posner and Hibbs, 1997).

Differences in bread baking quality have usually been attributed to differences in protein quality. Protein quality and content (quantity) are very important and are both considered primary characteristics in measuring the potential of flour in relation to its end use properties (Mailhot and Patton, 1988). The direct relationship between protein content in wheat and the baking quality of flour is widely known. The quality and quantity of gluten largely determine the physical dough properties and hence the quality of the final product (Naeem *et al*., 2002). Products made from hard wheat typically require cultivars possessing relatively high protein content due to its correlation with the dough strength of panned bread. Protein content has a large influence on rheological characteristics of the dough and is therefore used as an estimate of baking quality. When considering dough properties, it is known that protein composition controls the special dough properties that make bread wheat flour suitable for leavened products (MacRitchie, 1999). Branlard and Dardevet (1985) carried out their research on the relationships between protein content and quality characteristics of 70 wheat cultivars by analyzing the high molecular weight (HMW) glutenin. Their research indicated that there are relationships between different glutenin subunits and rheological characteristics (strength, tenacity, swelling and extensibility) of the dough that are independent and not influenced by protein content. Andrews and Skerritt (1996) also found protein content and total gluten content to be generally highly correlated with dough extensibility. Fowler and De la Roche (1975) indicated that protein content was the most effective predictor of loaf volume.

Labuschagne *et al.* (1997) reported that the protein content was significantly influenced by the presence of the softness genes. Some contradictory information about the influence of protein content on kernel hardness exists in the literature. A highly significant negative correlation was obtained between protein content and particle size

and a positive correlation between protein content and flour yield (Obuchowski and Bushuk, 1980).

Grain yield and grain protein content are negatively associated in wheat (Halloran, 1981; Löffler and Bush, 1982; Koekemoer, 1996) and no selection has proved to improve both traits simultaneously (Löffler and Bush, 1982; Stoddard and Marshall, 1990). When the grain yield increases and grain protein concentration decreases, the milling and baking quality of bread flour could be affected. Costa and Kronstad (1994) revealed a negative association between grain protein concentration and grain yield and also between grain protein concentration and harvest index. Cox *et al*. (1985) detected significant variability in nitrogen assimilation after anthesis. Nitrogen assimilation after anthesis strongly influenced grain protein, explaining 27 to 39 % of the variation, but no relationship was found with grain protein concentration. Thus, genetic variation in nitrogen assimilation has a role in determining grain yield and protein concentration in wheat. Huebner and Gaines (1992) reported a similar effect and indicated that protein composition varied among kernels from spikes that flowered at different dates. Although there is a general negative correlation between yield and protein content, it has been possible in many breeding programs to increase yield while maintaining a constant protein level (Edwards, 1987).

Genetic improvement of protein content may involve the use of exotic and unadapted wheat as parents (Löffler and Bush, 1982). High grain protein percentages were reported for wild tetraploid wheat *Triticum turgidum* var. *dicoccoides,* the immediate progenitor of most of the cultivated wheat. Their grain protein content ranged between 14.1 and 35.1%. This far exceeds protein values of cultivated wheat ranging between 7 and 21%.

Flour protein concentration is most sensitive to environmental fluctuations, while the percentage protein present as glutenin (independent of flour protein content) was found to be nearly totally genotype dependant (Graybosh *et al.*, 1996). Differences resulting from the environment were the primary source of variation in protein content as found by Bergman *et al*. (1998). Grain protein content in Australian wheat (Stoddard and Marshall, 1990) varied widely. The bulk of this variation was attributed to environmental factors. Grain exposed to warm dry climates during the filling period

tends to be harder in texture and has higher protein content (Bergman *et al.*, 1998). Du Plessis and Agenbag (1994) reported that increasing levels of nitrogen resulted in a higher protein content of two spring wheat cultivars produced in the Swartland. Wheat producers need to pay attention to grain protein content and need to use nitrogen fertilizers to help maintain consistent quality in hard red winter wheat production (Lyon and Shelton, 1999). Miller *et al*. (1984) indicated that the protein content of wheat from localities was highly variable and mainly reflected the amount of fertilizer used and the time of fertilizer application. The level of substrate and available soil nitrogen is controlled by environmental factors such as moisture, temperature and nitrogen fertilizers. Therefore, the significant effect that environment has on protein level should not be unexpected.

2.4.2.2 Hagberg Falling Number (HFN) and pre-harvest sprouting

Sprouting occurs when rainfall during or just prior to harvesting can cause moisture content to increase to a level at which wheat grain germinate while still on the spike and α-amylase activity increases. As its name indicates, pre-harvest sprouting begins before the grain is harvested, while it's still on the spike. Rainfall sets the process in motion, during which the seed imbibes water. Germination starts and starch reserves in the grain endosperm are hydrolyzed through the action of germination enzymes called amylases. The embryo swells and grows as it consumes the hydrolyzed carbohydrate reserve (Trethowan *et al*., 1993).

Pre-harvest sprouting is usually determined by means of a rain simulator (Barnard *et al*., 1997). Visual estimation of the percentage of sprouted kernels (with emergence of the radicle) is used by a number of agencies, but several studies have shown that visual estimation of sprouting can be unreliable (Mares, 1989), in part because much of the commercially relevant damage occurs before germination of the grain is visible (Jensen *et al.*, 1984). The standard method for quantification of sprouting is the falling number (FN) test, a viscosity test in which the time required for a plunger to fall through a heated slurry of whole meal and water in a large glass test tube, is measured (Hagberg, 1960).

Barnard *et al.* (2005) did a study on South African wheat cultivars and the results indicated that a significant correlation exists between FN and most other methods used and that FN was the most reliable respectively for the determination of pre-harvest sprouting and subsequent α-amylase activity. Plant breeders, on the other hand, find the determination of pre-harvest sprouting on a visual scale preferable, since this method is a direct indication of the inherent capability of a genotype to maintain tolerance. This is especially applicable in certain years where no rainfall occurs. Low FN can be experienced in parts where no rain occurred prior to or during harvest. Although a reliable method, variation in FN was reported and the method does not entirely reflect levels of α-amylose activity as other factors such as the gelatinization properties of the starch and fibre can have significant influences (Kruger and Tipples, 1982). Olered (1967), however, indicated that the HFN test is subject to deviation. He indicated that it is possible to obtain different HFNs for the same level of α -amylase activity that are primarily attributed to differences in the amount of starch damage. Later Olered and Jönsson (1970) indicated that the HFN method in its actual form is not the same over the entire range of variation of amylase activity.

This phenomenon, called preharvest sprouting (PHS), has negative effects and reduces yield, lowers test weight, and adversely affects the milling and baking quality of harvested grain. Farmers receive lower prices for sprouted grain and, in most severe cases, their harvests may be downgraded to animal feed.

2.4.2.3 Wet gluten content

Gluten, an insoluble protein in wheat flour is recognized as a basic quality factor of wheat and it forms the cell walls of the crumb and gives the bread its desired texture (Canada – Alberta farm business management initiative, 1999). The amount of gluten in flour is an index of protein content, and the physical properties of the washed-out gluten provide an index of flour strength (Kulkarni *et al*., 1987). A gluten test gives in a few minutes a measurement of protein quantity and an indication of quality, allowing a rapid decision on how to use the wheat. The simplicity of a gluten determination provides important information and is a practical test for wheat and wheat flour

classification at all handling and processing points (silo/elevator, mill and baker). For a plant breeder, to develop wheat with high protein content and protein quality have always been a major goal. Therefore, gluten tests are valuable in screening different cultivars for protein quality and quantity (Mamuya, 2000).

The glutomatic is an automatic apparatus, which develops the gluten from wheat flour. Dough mixing and subsequent separation of starch and other solubles from the dough take place in the same test chamber under controlled standardized conditions. The gluten ball is centrifuged to remove excess water and weighed as wet gluten. This can be examined for elasticity as a protein quality factor. To obtain the dry gluten (protein) amount, the gluten is dried between two Teflon coated hotplates. The higher the percentage of gluten content the higher the expected loaf volume will be (Mamuya, 2000).

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

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

In their study, Robert *et al.* (1996) found that gluten protein fractions were positively correlated with quality parameters, whereas non-gluten fractions were negatively associated with quality. Glutenin was mostly highly positively correlated with loaf grain and texture and was independent of flour protein content. They also noted that flour protein concentration and the percentage of protein present as gliadin and non-gluten

proteins were most sensitive to environmental fluctuations. The glutenin part was found to be almost totally genotype dependant.

2.4.2.4 Mixograph

Mixograph measures and records dough development behavior and its resistance to mixing. The mixing curve (mixogram) indicates optimum development time (point of minimum mobility); tolerance to over-mixing, descending graph width, other dough characteristics (such as being weak or strong) and estimates water absorption. The mixograph has been used to study dough rheology, blending, quality control and for evaluation of hard, soft and durum wheats (Mamuya, 2000).

During dough mixing, the resistance of the system to extension increases progressively until the point of minimum mobility is reached. This is referred to as the dough development time and is considered as the point where dough is optimally mixed (Finney *et al*., 1987). The mixing time of the mixograph (in minutes) indicates the rate at which the flour and water are blended together into a quasi-homogeneous mixture in order to develop a gluten matrix and to incorporate air (Spies, 1990). This method proved to be a valuable criterion for the selection of wheat cultivars with superior quality (Van Lill and Purchase, 1995). A mixograph consists 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. 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 and Hazelton, 1996).

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

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

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

2.4.2.5 Alveograph

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

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

However, as it is for the other rheological characteristics, protein quality (especially certain glutenins) has more influence on alveograph parameters, and this signifies genetic control for this character. Hou *et al.* (1996) studied the relationship of quality of glutenin subunits of selected US soft wheat fours to rheological and baking properties. They noted that the high molecular weight glutenin subunits (HMW-GS); 1 was correlated positively with alveograph extensibility (L), subunit 2* with pressure inside the bubble (P) and P/L values and subunit pair 5+10 with P and strength (W) values.

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

The alveograph stability (ASTAB) value is related to the dough's tenacity and elastic resistance and is a predictor of the dough's ability to retain gas. Alveograph distensibility (AD) is related to the dough's extensibility and predicts the handling characteristics of the dough. Alveograph strength (AS) is the amount of work required for the deformation of the dough and is related to the baking strength of the flour. The P/L ratio (curve configuration ratio) also serves as an index of protein quantity and quality. For example a high ASTAB and short AD would denote a "bucky" or very elastic dough. Weak flours result in low ASTAB and AS values, generally with longer AS values. Likewise, higher ASTAB and AS values with short to medium AD values suggests strong flours (Walker and Hazelton, 1996).

CHAPTER 3

THE EVALUATION OF QUALITY TRAITS IN SOUTH AFRICAN HYBRID BREAD WHEAT

3.1 INTRODUCTION

Since 1980, 14 F1 hybrid winter or facultative bread wheat cultivars have been released for production in South Africa. The use of hybrid crops is usually targeted to higher yield potential environments. Results from South Africa showed that hybrids out-yield inbred lines by 15% at a 2 t/ha mean production potential when narrow row spacing and low seeding rates (< 25 kg/ha) were used (Payne *et al*., 1996).

Hybrids mostly offer the opportunity to increase yield levels of wheat through exploitation of heterosis to meet the increasing food demand. In addition, a high yielding hybrid needs to meet quality demands as set by the industry. The basic definition of quality in wheat will vary with the market class. The development of high yielding, high quality hybrids would be advantageous to the grower in terms of increased income as this would help offset some of the additional cost of seed. Wilson and Driscoll (1983) found that breeders produced hybrids of satisfactory milling and baking quality, although the overall quality of the hybrid is highly cross specific (Edwards, 1987).

Where baking characteristics have been studied, the individual traits were shown to be intermediate between the two parents, although a number of specific crosses have shown high-parent heterosis for quality traits (Shebeski, 1966; Wilson, 1968; Boland and Walcott, 1985; Edwards, 1987; Edwards and Dorlencourt, 1994; Cisar and Cooper, 1999).

In an extensive study of hard red winter wheat hybrids grown in regional trials at 10 locations in Oklahoma and Texas, Bequette and Fisher (1980) reported that test weight, flour yield, flour ash and flour color of hybrids were generally superior to the mid-parent value. Test weight and flour yield of several hybrids exceeded the high parent, and it was suggested that heterosis for test weight may occur, although partial dominance for earliness may be the major reason for hybrid superiority under moisture

stress conditions. Absorption, mixing time and loaf properties were generally close to the mid-parent value when the parents differed significantly for these properties. It was concluded that prediction of quality in adapted hybrids should be fairly accurate, providing that the parental lines have been accurately characterized. Other studies in different environments have pointed to hybrid quality being highly cross specific (Edwards, 1987; Edwards and Dorlencourt, 1994) and not always easy to predict when contrasting parents are used.

The development of inbred lines with good quality characteristics and good combining ability is necessary because, in order to benefit from the combination of dominant alleles in a hybrid, the desirable traits should be dominant or at least partially dominant. Although this is not always the case (Picket, 1993), a number of authors have concluded that high quality hybrids can be achieved.

CIMMYT reported positive and negative heterosis for all quality parameters studied, but found that the bread-making quality of hybrids tended to be intermediate between those of the parents (Cukadar *et al.,* 2001). Most research indicates that bread making-quality of wheat hybrids are intermediate between parental lines when produced from European winter wheat germplasm (Borghi *et al*., 1988; Borghi and Perenzin, 1994; Oury *et al*., 1995; Pickett and Galwey, 1997).

Cukadar *et al.* (2001) found heterosis in extensibility and loaf volume due to the combination of high molecular weight (HMW) and low molecular weight (LMW) glutenin subunits (GS) that contribute positively to improved gluten and bread-making properties. Certain LMW-GS are known to favor gluten extensibility (Gupta *et al.*, 1990). Two of the four male lines in this study are known to possess quality-desirable LMW-GS (Roberto J. Pena, personal communication). One of these lines was the male parent of the highest yielding hybrids. Also, co-dominance of genes for HMW-GS may explain the improved bread loaf volume of hybrids. These results from CIMMYT indicated that despite a slightly negative association between grain protein content and yield, it is still possible to develop high yielding hybrids with acceptable bread-making quality. Crossing parental lines with strong or medium gluten with a strong but extensible gluten (tenacious) or weak gluten, could produce a hybrid with strong to medium strong and extensible gluten. These data indicate that it is important to select

at least one parent with a strong gluten type and quality-desirable HMW-GS and LMW-GS in order to obtain a hybrid with good bread-making quality.

Borghi and Perenzin (1994) reported that end-use quality appears to be a function of additive gene action. Cukadar *et al.* (2001) concluded that grain and bread-making quality properties were not adversely affected in a hybrid background. The level of heterosis and bread-making quality in the hybrids depends on the specific parental line combinations used to produce them.

Wheat cultivation under dryland conditions in the summer rainfall region of South Africa accounts for approximately 50% of the total annual bread wheat production. This is obtained by growing mainly winter and facultative cultivars in the Free Sate (Barnard *et al*., 1999). The identification of the basic components determining and influencing quality is important to breeders as desired by the milling and baking industries while developing cultivars profitable to the producer. Therefore, in order to breed high yielding hybrids which comply with quality requirements, not only should hybrids be analyzed but also their parental female B-lines (CMS) and male Rf-lines (Restoring fertility).

3.2 MATERIALS AND METHODS

3.2.1 Genotypes

The genotypes, growth habit and year of release are given in Tables 3.1 and 3.2. South African hard red winter and facultative bread wheat cultivars and hybrid lines, including their parental lines, were obtained from the 2004 and 2005 winter and facultative hybrid performance trials (IHBPT) of SENSAKO. The commercial check Elands, was released by the Small Grains Institute. A total of 12 genotypes consisting of mostly facultative genotypes were included in the IHBPT trial and 12 genotypes consisting of mostly winter genotypes were included in the WHBPT trial (Winter Hybrid Performance Trial). The genotypes were split in two separate trials to ensure enough space to test enough intermediate and facultative hybrid combinations. Due to lack of space and parenting very old hybrids (before quality testing released) the males R41 and R44 were not included.

Table 3.1: IHBPT wheat genotypes evaluated during 2004 and 2005

Entry	ID/Type	Name/Genotype	Growth habit	Release date
1	Conventional cultivar	Elands	Facultative	1998
2	Hybrid cultivar	SST966 (A966/R41)#	Winter	1996
3	Female B-Line	B966	Winter	
4	Female B-Line	B972	Facultative	
5	Male R-Line	R2	Winter	
6	Male R-Line	R5	Winter	
7	Male R-Line	R6	Winter	
8	Hybrid line	A972/R2*	Facultative	
9	Hybrid line	A972/R5*	Facultative	
10	Hybrid line	A972/R6*	Facultative	
11	Hybrid cultivar	SST972 (A972/R41)#	Facultative	1997
12	Hybrid cultivar	SST983 (A972/R44)#	Facultative	1998

New generation hybrids = *, newly developed hybrids

Old generation hybrids = #, hybrids developed before the year 2000

Cultivar = A genotype that has been released commercially

Line = A genotype that has not been released yet

Female B line = Fertile female, maintainer of the cytoplasmic male sterile A line

Male R line = Restoring fertility male

Table 3.2: WHBPT wheat genotypes evaluated during 2004 and 2005

Entry	ID/Type	Name/Genotype	Growth habit	Release date
1	Conventional cultivar	Elands	Facultative	1998
2	Hybrid cultivar	SST966 (A966/R41)#	Winter	1996
3	Conventional cultivar	SST399	Winter	1999
4	Female B-Line	B966	Winter	
5	Female B-Line	B972	Facultative	
6	Male R-Line	R2	Winter	
7	Male R-Line	R5	Winter	
8	Male R-Line	R6	Winter	
9	Hybrid cultivar	SST935 (A966/R2)*	Winter	2003
10	Hybrid line	A966/R5*	Winter	
11	Hybrid cultivar	SST946 (A966/R6)*	Winter	2004
12	Hybrid cultivar	SST972 (A972/R41)#	Facultative	1997

New generation hybrids = *, newly developed hybrids

Old generation hybrids = #, hybrids developed before the year 2000

Cultivar = A genotype that has been released commercially

Line = A genotype that has not been released yet

Female B line = Fertile female, maintainer of the cytoplasmic male sterile A line

Male R line = Restoring fertility male

3.2.2 Field trials

Trials were conducted in the dryland, summer rainfall region of South Africa. Field trials were planted at six localities throughout the Free State, representing two localities per region (Western Free State, Central Free State and Eastern Free State). The planting dates for localities in the Western Free State was the last week in April, Central Free State localities were planted during the third week in May and the planting in the Eastern Free State took place during the third week of June.

Table 3.3: WHBPT and IHBPT localities for cropping cycles 2004 and 2005.

Region	Locality	Co-ordinates	Dominant soil	Number of trials	
				2004	2005
Western	Bultfontein	28 18'S 26 27 E	Clovelly	2 x WHBPT	2 x WHBPT
Free State				2 x IHBPT	2 x IHBPT
	Kroonstad			2 x WHBPT	2 x WHBPT
				2 x IHBPT	2 x IHBPT
Central	Bainsvlei	29 0'S 25 58'E	Bainsvlei	2 x WHBPT	2 x WHBPT
Free State				2 x IHBPT	2 x IHBPT
	Clocolan	29 13'S 27 19'E	Avalon	2 x WHBPT	2 x WHBPT
				2 x IHBPT	2 x IHBPT
Eastern	Bethlehem	28 12'S 28 18'E	Avalon	2 x WHBPT	2 x WHBPT
Free State				2 x IHBPT	2 x IHBPT
	Reitz	27 45'S 28 33'E	Avalon	2 x WHBPT	2 x WHBPT
				2 x IHBPT	2 x IHBPT

Experimental plots consisting of five rows (5 m in length, with a 40 cm inter row spacing) were planted, using a randomized complete block design with three replicates. A total of 200 kg ha^{-1}, 6:2:1 (31), at a rate of 41 kg ha^{-1} nitrogen, 20 kg ha^{-1} phosphate and 10 kg ha^{-1} potassium fertilizer was applied with planting.

Trials were harvested, air dried and cleaned prior to quality testing.

3.2.3 Laboratory methods

All genotypes were evaluated for quality traits. Test weight was determined using a Franklin chondrometer. Grain samples of 2 kg were milled with a CD-1 mill. First break (break flour yield) and flour yield was then determined.

Grain samples of 7 g were milled with a CYCLOTEC 1093 sample mill (0.5 mm sieve) after which Hagberg Falling Numbers (FLN, s) were determined (AACC, 1983).

Single kernel characteristics were determined using the SKCS 4100 (Perten Instruments, Springfield, IL). This instrument was used to measure kernel diameter

(average diameter of 300 kernels), harvest index (the index as percentage of the pressure of two rollers to crush 300 kernels) and kernel weight (the average weight of 300 kernels in mg).

Protein-, ash- and wet gluten content were analyzed with the Infratec 1241 grain analyzer, NIT (Near Infrared Transmission) FOSS 1241.

Water absorption was measured with the Chopin Consistograph (4604) because of reports that the consistograph water absorption was correlated more accurately with what was found in the industry and it is a quicker method to use (personal communication, Jan Cilliers, SENSAKO Bethlehem).

Mixograph development time (MDT, min) was determined with a 10 g National Mixograph (National Mfg., Lincoln, Nebraska) (AACC, 1983).

Other rheological analyses performed according to the approved methods (AACC, 1983) included the Chopin alveograph determinants: dough strength (AS, cm^2), alveograph stability (ASTAB, mm), alveograph distensibility (AD, mm) and the ratio of stability to distensibility (P/L).

3.2.4 Environmental conditions

The Free State is divided into three regions on the basis of climatic differences. The Eastern Free State has a higher rainfall, lower temperatures and lower evaporation than the other regions. Yellow soils of average effective depth predominate in this area. The Central Free State receives moderate rainfall and temperatures, resulting in lower evaporation. This area has shallow duplex soils. Low rainfall, high temperatures and high evaporation mark the Western Free State. Deep red and yellow sandy loam soils are characteristic of this region. In the northern parts of the Western Free Sate, a soil water table is often present.

3.2.4.1 Year 2004

Trails in the Eastern Free State were the worst in years. Conditions during planting were acceptable, emergence was good but drought during the growing season put pressure on the plants. Rain occurred which interrupted harvesting at some localities (Table 3.4).

3.2.4.2 Year 2005

Conditions during planting were good (Table 3.4). Good emergence and plant densities were observed which ensured a good harvest. A much heavier infection of Russian wheat aphid was noted this year, especially in the Eastern and Central Free State.

Table 3.4: Annual rainfall for the Free State localities (January-December).

Trial Site	Height	Long term annual average rainfall (mm)	Annual rainfall (January-December) 2004	2005
1. Bainsvlei	1372 m	525.6	475.6	353.7
2. Bultfontein	1158 m	381.6	476.5	466.0
3. Bethlehem	1611 m	657.5	534.1	755.3
4. Clocolan	1600 m	699.3	566.5	839.7
5. Kroonstad	1434 m	570.9	565.9	352.8
6. Reitz	1615 m	655.7	563.0	677.0

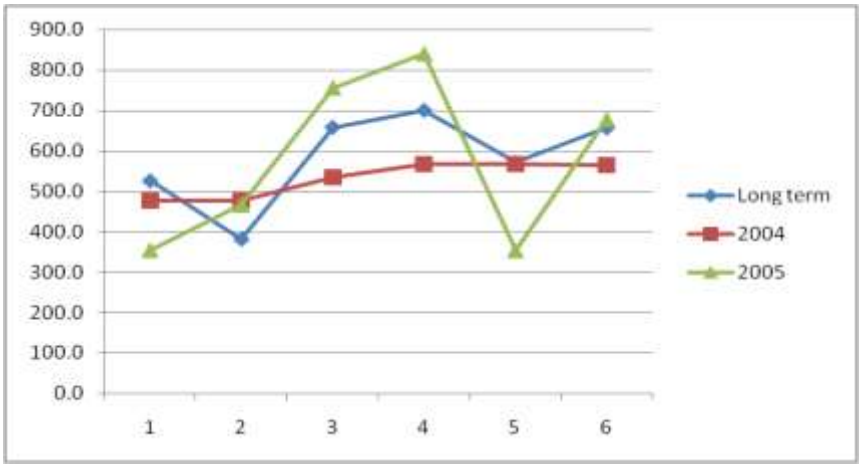

Figure 3.1: Long term and annual rainfall for the six localities (SA Weather).

3.2.5 Statistical analysis

3.2.5.1 Analysis of variance (ANOVA)

Combined analysis of variance for the quality characteristics was performed on both the WHBPT and IHBPT trials. Analyses were done for 2004 and 2005 over a total of six localities per trial per year. The analysis on quality data was done in triplicate (for each replicate) for each entry of each trial. The cultivar means for all the characteristics was used to compare the performance of the genotypes. AGROBASE 20 (Agrobase, 1999) was utilized for the analyses of variance.

3.2.5.2 Calculation of mid-parent and high-parent heterosis

Heterosis was calculated on the 2004 and 2005 combined data for all quality characteristics with no significant differences between replicates.

Percentage of heterosis was calculated as follows:

H_{MP} (mid parent heterosis) = F1- (P1+P2)/2 x 100 where P1 is the value of the one parent (female) and P2 the value of the other parent (male) and F1 the average value of the F1 – hybrid.

High parent heterosis (H_{HP}) was calculated as F1- HP/2 x 100 where HP is the value of the parent with the highest value, either male or female.

In this study another method was introduced where heterosis was determined by comparing the performance of the hybrid to the performance of the best parent used for the characteristic measured. This was the result of the situation caused by highly competitive and successful research in the public sector achieving genetic improvement of wheat at a constant rate by using conventional techniques and procedures. It was found that conventional varieties easily caught up and even outperformed hybrids in various characteristics evaluated.

3.3 RESULTS AND DISCUSSION

3.3.1 Combined analysis of variance

Intermediate Hybrid Performance Trial (IHBPT)

IHBPT 2004

All characteristics revealed highly significant differences for genotype, environment and the interaction between genotype and environment excluding flour yield which differed significantly for environment (Table 3.5). Traits revealing significant differences between replicates were moisture, flour protein content, ash, alveograph distensibility, alveograph strength, and alveograph P/L ratio, falling number and alveograph stability.

IHBPT 2005

All characteristics revealed highly significant differences for genotype, environment and the interaction between genotype and environment excluding ash and consistograph water absorption. Moisture revealed significant differences, and break flour yield and flour protein content revealed highly significant differences between replicates (Table 3.5).

IHBPT 2004 and 2005 combined

The characteristics revealed highly significant differences for genotype, environment and the interactions between genotype by environment, genotype by year, environment by year and genotype by environment by year excluding flour yield and ash. Characteristics that revealed highly significant differences between replicates were moisture, flour protein content, alveograph distensibility and alveograph P/L ratio. Significant differences were recorded for wet gluten content (WGC) and alveograph stability. The year 2004 showed the most variation of the two years (Table 3.5).

Winter Hybrid Performance Trial (WHBPT)

WHBPT 2004

All characteristics revealed highly significant differences for genotype, environment and the interaction between genotype and environment excluding ash and wet gluten content which did not differ significantly for genotype and genotype by environment interaction. Moisture, hardness, break flour yield, flour yield, flour protein content,

alveograph distensibility, P/L ratio and-stability and consistograph water absorption revealed highly significant differences between replicates (Table 3.6).

WHBPT 2005

All characteristics revealed highly significant differences for genotype, environment and the interaction between genotype and environment. Flour protein content and mixograph mixing time revealed highly significant differences between replicates (Table 3.6).

WHBPT 2004 and 2005 combined

The characteristics revealed highly significant differences for genotype, environment and the interactions between genotype by environment, genotype by year, environment by year and genotype by environment by year except for test weight and falling number (Table 3.6).

Characteristics that revealed highly significant differences between replicates were moisture, hardness, break flour yield, flour yield, flour protein content, alveograph distensibility, alveograph P/L and- stability and consistograph water absorption (Table 3.6).

Table 3.5 : The Anova for quality measurements during 2004, 2005 and 2004+2005 combined for the BHBPT trial

17 QUALITY CHARACTERISTICS FOR SIX ENVIRONMENTS DURING YEAR 2004																		
SOURCE	df	HLM	MOIST	SKCSDIAM	SKCSG	SKCS_HI	BFLY	FLY	FPC	HFN	ASH	WGC	ADIST	ASTR	ASTAB	APL	CABS	MMT
Total	215																	
Replicates	2	0.489	2.730**	0.0160	3.431	0.383	2.545	10.368	2.310**	962.722*	0.006**	11.505	4420.667**	111.421**	888.514*	2.781**	1.063	0.112
Genotype	11	22.557**	1.298**	0.271**	84.012**	274.708**	33.385**	44.043**	6.262**	10338.596**	0.002**	69.512**	4513.515**	467.338**	910.567**	3.156**	11.214**	1.247**
Environments	5	74.214**	1.888**	0.260**	130.102**	371.900**	47.652**	13.532*	9.244**	18088.711**	0.006**	89.800**	2508.322**	389.389**	4554.942**	5.739**	3.708**	1.536**
Genotype by Environment	55	2.771**	0.138	0.020**	8.369**	31.618**	2.623**	10.600**	1.001**	837.210**	0.001*	14.712**	464.443*	43.755**	436.455**	0.771**	1.257**	0.263**
Residual	142	0.381	0.132	0.007	3.246	12.125	1.122	5.771	0.411	313.868	0.001	7.951	291.958	16.576	218.542	0.412	0.667	0.135
Grand Mean		75.713	10.897	2.425	34.225	67.367	17.135	55.521	11.461	389.722	0.550	32.941	92.667	33.126	72.153	1.501	58.495	3.048
C.V.		0.82%	3.34%	3.52%	5.26%	5.17%	6.18%	4.33%	5.59%	4.79%	5.54%	8.56%	18.44%	12.29%	20.49%	42.74%	1.40%	12.07%
LSD for entry		0.3408	0.2008	0.0472	0.9944	1.9217	0.5846	1.3258	0.3538	9.7774	0.0168	1.5552	9.4299	2.2469	8.1586	0.3540	0.4509	0.2031
17 QUALITY CHARACTERISTICS FOR SIX ENVIRONMENTS DURING YEAR 2005																		
SOURCE	df	HLM	MOIST	SKCSDIAM	SKCSG	SKCS_HI	BFLY	FLY	FPC	HFN	ASH	WGC	ADIST	ASTR	ASTAB	APL	CABS	MMT
Total	215																	
Replicates	2	3.701	0.064*	0.001	0.347	12.846	2.206**	2.520	2.191**	684.949	0.015	17.104	58.875	0.144	720.681	0.030	0.279	0.049
Genotype	11	17.026**	0.116**	0.194**	75.867**	612.451**	35.228**	34.106**	11.452**	5918.530**	0.009	158.172**	566.931**	713.884**	5446.586**	0.219**	1.594*	1.347**
Environments	5	76.606**	4.587**	0.798**	391.808**	619.935**	18.848**	121.774**	17.877**	21883.882**	0.029**	252.826**	1860.175**	868.084**	11380.322**	0.486**	22.485**	1.422**
Genotype by Environment	55	6.419**	0.052**	0.013**	7.793**	34.720**	4.989**	31.044**	2.520**	1386.907**	0.011**	38.931**	255.421**	77.100**	2744.702**	0.155**	2.412**	0.198**
Residual	142	2.052	0.016	0.006	2.403	6.517	0.454	3.563	0.379	245.724	0.005	10.269	29.110	21.268	316.127	0.047	0.688	0.058
Grand Mean		77.167	10.959	2.466	35.863	70.951	20.099	56.932	13.094	391.468	0.566	37.272	78.292	44.179	138.833	0.633	59.117	2.288
C.V.		1.86%	1.14%	3.08%	4.32%	3.60%	3.35%	3.37%	4.70%	4.00%	12.80%	8.60%	6.89%	10.44%	12.81%	34.04%	1.40%	10.49%
LSD for entry		0.7906	0.0691	0.0419	0.8555	1.4088	0.3719	1.0417	0.3399	8.6511	0.0400	1.7686	2.9776	2.5451	9.8125	0.1190	0.4577	0.1325
17 QUALITY CHARACTERISTICS FOR SIX ENVIRONMENTS DURING BOTH YEARS 2004 AND 2005 COMBINED																		
SOURCE	df	HLM	MOIST	SKCSDIAM	SKCSG	SKCS_HI	BFLY	FLY	FPC	HFN	ASH	WGC	ADIST	ASTR	ASTAB	APL	CABS	MMT
Total	431																	
Replicates	2	3.440	1.797**	0.006	2.404	5.230	0.204	5.954	3.986**	314.447	0.004	28.264*	2077.521**	54.238	891.021*	1.559**	1.051	0.154
Genotype	11	34.990**	0.774**	0.447**	148.104**	761.840**	58.703**	44.073**	14.885**	14763.922**	0.009**	158.998**	2480.698**	998.090**	3602.172**	1.566**	8.094**	2.151**
Environments	5	139.346**	2.750**	0.292**	172.696**	434.436**	39.876**	76.929**	19.772**	13.937.497**	0.011**	291.044**	2365.960**	974.793**	9179.704**	3.122**	20.016**	1.951**
Year	1	228.391**	0.422*	0.182**	289.756**	1387.754**	949.363**	18.204*	288.120**	51069.002**	0.030**	2026.180**	22317.188**	13194.806**	480200.021**	61.285**	41.689**	62.350**
Genotype by Environment	55	4.860**	0.092	0.011**	5.540**	30.909**	4.442**	20.229**	1.690**	1052.636**	0.006**	26.230**	323.603**	54.257**	1318.595**	0.423**	1.823**	0.182**
Genotype by Year	11	4.593**	0.640**	0.018**	11.775**	125.319**	9.910**	34.077**	2.829**	1493.204**	0.002	68.686**	2599.748**	203.132**	2754.980**	1.811**	4.715**	0.442**
Environments by Year	5	11.475**	3.725**	0.767**	349.214**	557.399**	26.624**	58.376**	7.349**	26035.097**	0.025**	51.581**	2002.538**	282.680**	6755.560**	3.103**	6.177**	1.007**
Genotype by Environment by Year	55	4.330**	0.098	0.022**	10.622**	35.429**	3.170**	21.416**	1.831**	1171.481**	0.006**	27.413**	396.262**	66.598**	1862.562**	0.504**	1.846**	0.279**
Residual	286	1.214	0.081	0.007	2.814	9.312	0.814	4.683	0.396	287.162	0.003	9.049	176.208	19.190	270.487	0.236	0.675	0.096
Grand Mean		76.440	10.928	2.446	35.044	69.159	18.617	55.726	12.278	390.595	0.558	35.107	85.479	38.653	105.493	1.067	58.806	2.668
C.V.		1.44%	2.60%	3.31%	4.79%	4.41%	4.85%	3.88%	5.13%	4.45%	10.12%	8.57%	15.53%	11.33%	15.59%	45.54%	1.40%	11.61%
LSD for entry		0.4285	0.1104	0.0315	0.6525	1.1869	0.3510	0.8417	0.2447	6.5912	0.0220	1.1700	5.1631	1.7039	6.3970	0.1890	0.3195	0.1205

df = Degrees of Freedom
MS = MEAN SQUARE
** Significant at P < 0.01.
* Significant at P < 0.05.

Table 3.6 : The Anova for quality measurements during 2004, 2005 and 2004+2005 combined for the WHBPT trial

17 QUALITY CHARACTERISTICS FOR SIX ENVIRONMENTS DURING YEAR 2004																		
SOURCE	df	HLM	MOIST	SKCSDIAM	SKCSG	SKCS_HI	BFLY	FLY	FPC	HFN	ASH	WGC	ADIST	ASTR	ASTAB	APL	CABS	MMT
Total	215																	
Replicates	2	0.214	6.355**	0.002	3.324	222.090**	70.830**	22.587**	1.766*	1694.264	0.003	18.426	20051.616**	3.476	8092.977**	36.561**	5.397**	0.006
Genotype	11	23.001**	0.799**	0.156**	50.942**	219.266**	27.685**	26.284**	5.156**	6916.561**	0.003	73.793**	4638.197**	217.771**	2236.984**	5.566**	10.753**	1.864**
Environments	5	52.340**	0.732**	0.255**	99.532**	486.845**	40.730**	32.343**	15.849**	23032.767**	0.006**	338.575**	2098.682**	693.379**	4503.616**	5.732**	4.469**	1.137**
Genotype by Environment	55	1.474**	0.264**	0.016**	7.824**	49.398**	2.126*	4.093*	0.838**	1702.312**	0.001	20.948	418.470*	38.448**	304.375	0.532	1.493**	0.243**
Residual	142	0.349	0.105	0.006	2.720	12.970	1.343	2.780	0.453	555.804	0.002	17.321	272.353	20.231	290.198	0.618	0.514	0.105
Grand Mean		75.371	11.171	2.351	32.643	71.526	17.323	54.447	11.308	381.139	0.551	32.756	97.968	33.013	68.356	1.794	58.669	3.083
C.V.		0.78%	2.90%	3.32%	5.05%	5.04%	6.69%	3.06%	5.95%	6.19%	7.74%	12.71%	16.85%	13.62%	24.92%	43.81%	1.22%	10.51%
LSD for entry		0.3261	0.1767	0.0431	0.9103	1.9875	0.6397	0.9201	0.3716	13.0110	0.0235	2.2969	9.1078	2.4823	9.4015	0.4337	0.3958	0.1788
17 QUALITY CHARACTERISTICS FOR SIX ENVIRONMENTS DURING YEAR 2005																		
SOURCE	df	HLM	MOIST	SKCSDIAM	SKCSG	SKCS_HI	BFLY	FLY	FPC	HFN	ASH	WGC	ADIST	ASTR	ASTAB	APL	CABS	MMT
Total	215																	
Replicates	2	2.272	0.024	0.006	3.989	0.393	1.444	8.089	2.353**	62.296	0.002	17.111	100.685	39.386	288.227	0.020	0.004	0.165*
Genotype	11	21.527**	0.263**	0.093**	57.473**	506.993**	32.498**	15.196**	14.636**	10837.584**	0.026**	116.539**	903.963**	400.404**	3612.130**	0.416**	1.537**	1.336**
Environments	5	53.396**	4.528**	0.663**	375.399**	538.207**	42.408**	11.455**	12.863**	12585.841**	0.022**	163.709**	2294.885**	186.065**	5329.274**	0.991**	17.247**	0.691**
Genotype by Environment	55	6.340**	0.058**	0.011**	5.625**	34.005**	4.748**	26.215**	2.575**	2276.053**	0.007**	37.234**	208.471**	75.693**	910.504**	0.130**	1.944**	0.226**
Residual	142	2.480	0.014	0.006	2.984	11.094	0.514	2.761	0.410	1074.308	0.002	13.476	37.056	19.533	227.678	0.027	0.547	0.045
Grand Mean		77.597	10.888	2.414	34.729	75.296	19.522	63.630	12.871	404.454	0.617	36.681	89.148	44.562	115.287	0.840	60.109	2.288
C.V.		2.03%	1.08%	3.23%	4.97%	4.42%	3.67%	2.61%	4.98%	3.65%	7.66%	10.01%	6.83%	9.92%	13.09%	19.55%	1.23%	9.26%
LSD for entry		0.8691	0.0648	0.0430	0.9534	1.8382	0.3957	0.9171	0.3534	8.1468	0.0261	2.0259	3.3595	2.4391	8.3274	0.0906	0.4081	0.1172
17 QUALITY CHARACTERISTICS FOR SIX ENVIRONMENTS DURING BOTH YEARS 2004 AND 2005 COMBINED																		
SOURCE	df	HLM	MOIST	SKCSDIAM	SKCSG	SKCS_HI	BFLY	FLY	FPC	HFN	ASH	WGC	ADIST	ASTR	ASTAB	APL	CABS	MMT
Total	431																	
Replicates	2	1.324	3.542**	0.000	0.509	107.351**	27.310**	28.647**	3.988**	570.558	0.004	35.178	9561.627**	18.190	2919.843**	17.829**	2.783**	0.054
Genotype	11	42.082**	0.396**	0.227**	90.921**	673.841**	44.599**	25.448**	17.346**	14978.446**	0.018**	147.705**	3484.679**	510.100**	4283.280**	3.600**	6.162**	2.617**
Environments	5	84.575**	3.511**	0.187**	154.617**	667.269**	54.656**	16.400**	16.516**	8012.237*	0.019**	318.883**	1347.519**	684.209**	5641.241**	3.200**	15.025**	0.658**
Year	1	535.380**	8.642**	0.417**	469.980**	1535.370**	522.280**	9108.030**	263.906**	58706.704**	0.467**	1663.376**	8400.521**	14405.160**	237867.521**	98.298**	223.891**	68.275**
Genotype by Environments	11	3.611**	0.159**	0.013**	5.997**	32.508**	3.756**	15.679**	1.645**	1893.006**	0.004**	27.512**	264.933	56.561**	581.694**	0.323	1.428**	0.197**
Genotype by Year	55	2.446	0.665**	0.023**	17.494**	52.416**	15.584**	16.032**	2.446**	2775.699**	0.012**	42.626**	2057.480*	108.075**	1565.834**	2.381**	6.128**	0.383**
Environments by Year	5	21.161**	1.750**	0.731**	320.114**	357.783**	28.482**	27.398**	12.195**	27606.370**	0.009**	183.401**	3046.049**	195.255**	4191.649**	3.523**	6.691**	1.171**
Genotype by Environment by Year	55	4.203**	0.163**	0.014**	7.652**	50.895**	3.117**	14.629**	1.769**	2087.359**	0.005**	30.670**	362.008**	57.580**	633.186**	0.339	2.009**	0.272**
Residual	288	1.413	0.079	0.006	2.880	12.753	1.237	2.765	0.430	392.446	0.002	15.294	227.683	19.915	295.318	0.451	0.545	0.075
Grand Mean		76.484	11.029	2.383	33.686	73.411	18.423	59.038	12.089	392.796	0.584	34.719	93.558	38.787	91.822	1.317	59.389	2.686
C.V.		1.55%	2.54%	3.28%	5.04%	4.86%	6.04%	2.82%	5.42%	5.04%	7.69%	11.26%	16.13%	11.51%	18.72%	51.01%	1.24%	10.22%
LSD for entry		0.4623	0.1091	0.0304	0.6601	1.3890	0.4325	0.6468	0.2549	7.7053	0.0175	1.5211	5.8690	1.7358	6.6841	0.2612	0.2872	0.1068

df = Degrees of Freedom
MS = MEAN SQUARE
** Significant at P < 0.01.
* Significant at P < 0.05.

Table 3.7 : Genotype means of combined localities planted during 2004-2005 of the IHBPT trial

	TEST WEIGHT						SKCS-DIAMETER						SKCS-GRAM					
GENOTYPE	TW04	R	TW05	R	TW04+5	R	SD04	R	SD05	R	SD04+5	R	SG04	R	SG05	R	SG04+5	R
ELANDS	77.00	1	78.27	2	77.63	1	2.47	6	2.50	7	2.48	6	34.78	6	36.81	6	35.79	6
SST966	76.47	3	77.84	4	77.16	3	2.42	8	2.51	6	2.46	8	33.68	9	36.63	7	35.15	7
B966	76.94	2	76.85	9	76.90	5	2.38	9	2.36	10	2.37	9	33.72	8	32.99	12	33.36	9
B972	75.44	9	76.96	8	76.20	8	2.50	5	2.47	8	2.48	7	34.24	7	34.14	9	34.19	8
R2	72.93	12	75.29	12	74.11	12	2.29	10	2.39	9	2.34	10	31.58	10	34.44	8	33.01	10
R5	74.60	11	76.22	10	75.41	11	2.21	12	2.31	11	2.26	11	30.93	11	33.57	10	32.25	11
R6	75.58	8	75.96	11	75.77	10	2.23	11	2.29	12	2.26	12	30.87	12	33.11	11	31.99	12
A972/R2	76.11	5	78.13	3	77.12	4	2.55	1	2.55	4	2.55	1	36.52	3	37.86	2	37.19	3
A972/R5	76.10	6	77.59	5	76.85	6	2.53	3	2.56	2	2.55	2	36.72	2	38.56	1	37.64	1
A972/R6	76.19	4	78.42	1	77.31	2	2.54	2	2.56	3	2.55	3	36.89	1	37.78	3	37.34	2
SST972	75.15	10	77.09	7	76.12	9	2.53	4	2.57	1	2.55	4	35.52	4	37.06	5	36.29	5
SST983	76.05	7	77.37	6	76.71	7	2.46	7	2.54	5	2.50	5	35.24	5	37.43	4	36.34	4
ENVIRONM. MEAN	75.713		77.167		76.440		2.425		2.466		2.446		34.225		35.863		35.044	
CV (%)	0.62%		1.86%		1.44%		3.52%		3.08%		3.31%		5.26%		4.32%		4.79%	
LSD	0.3408		0.7906		0.4285		0.0472		0.0419		0.0315		0.9944		0.8555		0.6525	

	SKCS-HARDNESS INDEX						BREAK FLOUR YIELD						FLOUR YIELD					
GENOTYPE	HI04	R	HI05	R	HI04+5	R	BFL04	R	BFL05	R	BFL04+5	R	FLY04	R	FLY05	R	FLY04+5	R
ELANDS	68.95	5	71.12	7	70.03	6	19.81	1	21.94	2	20.88	1	58.83	1	56.23	5	57.53	1
SST966	63.38	11	75.85	4	69.62	7	19.15	2	20.48	4	19.81	3	56.95	3	55.19	10	56.07	5
B966	69.09	4	72.23	6	70.66	5	18.23	3	23.33	1	20.78	2	56.30	4	57.10	2	56.70	3
B972	72.13	3	76.61	3	74.37	3	15.66	12	18.20	12	16.93	12	57.54	2	56.66	4	57.10	2
R2	68.16	6	75.30	5	71.73	4	17.53	5	19.47	8	18.50	5	54.91	7	53.41	12	54.16	11
R5	72.97	1	78.77	1	75.87	1	16.11	10	19.20	10	17.65	11	53.89	12	53.96	11	53.93	12
R6	72.56	2	77.18	2	74.87	2	16.52	7	19.92	5	18.22	6	54.26	10	58.59	1	56.42	4
A972/R2	66.04	7	66.83	8	66.44	8	16.15	9	19.22	9	17.69	10	54.13	11	56.04	6	55.09	9
A972/R5	64.70	9	64.65	10	64.68	11	16.94	6	18.99	11	17.96	7	55.56	5	55.74	8	55.65	7
A972/R6	63.95	10	66.43	9	65.19	9	16.18	8	19.71	7	17.94	8	54.50	8	56.85	3	55.68	6
SST972	60.97	12	62.42	12	61.70	12	17.63	4	20.82	3	19.23	4	55.08	6	55.77	7	55.43	8
SST983	65.51	8	64.03	11	64.77	10	15.71	11	19.92	6	17.81	9	54.31	9	55.64	9	54.97	10
ENVIRONM. MEAN	67.367		70.951		69.159		17.135		20.099		18.617		55.521		55.932		55.726	
CV (%)	5.17%		3.60%		4.41%		0.062		0.034		0.049		4.33%		3.37%		3.88%	
LSD	1.9217		1.4088		1.1869		0.585		0.372		0.351		1.3258		1.0417		0.8417	

	HAGBERG FALLING NUMBER						ASH						ALVEO STRENGTH					
GENOTYPE	HFN04	R	HFN05	R	HFN04+5	R	A04	R	A05	R	A04+5	R	AST04	R	AST05	R	AST04+5	R
ELANDS	380.33	2	383.89	10	382.11	6	0.56	3	0.59	2	0.57	2	45.43	1	58.16	1	51.79	1
SST966	359.67	8	402.50	2	381.08	7	0.53	12	0.56	7	0.54	10	30.76	8	44.33	7	37.54	8
B966	431.11	1	433.83	1	432.47	1	0.57	1	0.63	1	0.60	1	37.30	3	47.77	3	42.53	2
B972	380.06	3	394.78	5	387.42	4	0.55	6	0.57	3	0.56	3	30.33	9	46.89	4	38.61	5
R2	346.33	11	388.72	7	367.53	10	0.55	8	0.56	9	0.55	8	30.12	10	49.72	2	39.92	4
R5	375.50	6	400.00	4	387.75	3	0.54	9	0.56	10	0.55	9	26.62	12	37.68	9	32.15	12
R6	376.39	4	401.00	3	388.69	2	0.55	5	0.56	5	0.56	6	27.66	11	37.41	11	32.54	11
A972/R2	351.44	9	384.28	7	367.86	9	0.55	4	0.56	8	0.56	7	33.26	5	43.82	8	38.54	6
A972/R5	375.72	5	391.61	6	383.67	5	0.56	2	0.56	6	0.56	4	32.67	6	37.54	10	35.11	10
A972/R6	370.17	7	386.72	8	378.44	8	0.54	11	0.54	12	0.54	12	34.14	4	36.71	12	35.43	9
SST972	342.89	12	365.33	11	353.92	12	0.54	10	0.55	11	0.54	11	30.83	7	44.64	6	37.73	7
SST983	347.06	10	364.94	12	356.19	11	0.55	7	0.57	4	0.56	5	38.39	2	45.49	5	41.94	3
ENVIRONM. MEAN	369.722		391.468		380.595		0.550		0.566		0.558		33.126		44.179		38.653	
CV (%)	4.79%		4.00%		4.45%		5.54%		12.80%		10.12%		12.29%		10.44%		11.33%	
LSD	9.7774		8.6511		6.5912		0.0168		0.4000		0.0220		2.2469		2.5451		1.7039	

	CONSISTO WATERABSORPTION						MIXOGRAPH MIXING TIME					
GENOTYPE	CWA04	R	CWA05	R	CWA04+5	R	MT04	R	MT05	R	MT04+5	R
ELANDS	59.39	2	59.46	1	59.43	2	3.25	5	2.85	1	3.05	1
SST966	57.42	12	59.34	4	58.38	10	3.31	3	2.3	7	2.8	5
B966	60.08	1	59.17	7	59.63	1	2.92	7	1.98	11	2.45	10
B972	59.26	3	59.45	2	59.36	3	2.74	11	2.35	5	2.54	7
R2	57.54	11	58.82	11	58.18	12	3.06	6	2.36	4	2.71	6
R5	58.47	7	58.87	10	58.67	7	2.71	12	1.87	12	2.29	12
R6	58.08	9	58.93	9	58.51	9	2.77	10	2.25	8	2.51	9
A972/R2	57.79	10	59.23	5	58.51	8	3.36	2	2.36	3	2.86	3
A972/R5	58.77	4	59.42	3	59.09	4	2.89	8	2.01	10	2.45	11
A972/R6	58.52	6	59.01	8	58.76	6	2.87	9	2.16	9	2.52	8
SST972	58.09	8	58.50	12	58.30	11	3.42	1	2.65	2	3.03	2
SST983	58.53	5	59.20	6	58.86	5	3.28	4	2.32	6	2.8	4
ENVIRONM. MEAN	58.495		59.117		58.806		3.048		2.288		2.668	
CV (%)	1.40%		1.40%		1.40%		12.07%		10.49%		11.61%	
LSD	0.4509		0.4577		0.3195		0.2031		0.1325		0.1205	

Table 3.8 : Genotype means of combined localities planted during 2004-2005 of the WHBPT trial

	TEST WEIGHT						SKCS-DIAMETER						SKCS-GRAM					
GENOTYPE	TW04	R	TW05	R	TW04+5	R	SD04	R	SD05	R	SD04+5	R	SG04	R	SG05	R	SG04+5	R
ELANDS	76.28	3	78.41	4	77.35	5	2.42	3	2.45	3	2.43	3	33.93	2	36.16	3	35.05	2
SST966	76.72	2	79.12	1	77.92	1	2.39	4	2.47	2	2.43	4	32.56	8	36.49	2	34.52	4
SST399	74.54	9	76.61	10	75.57	10	2.32	9	2.44	4	2.38	7	29.88	12	31.59	12	30.74	12
B966	76.84	1	77.93	6	77.38	4	2.33	8	2.34	10	2.33	10	33.15	7	32.70	11	32.93	9
B972	74.82	8	76.47	11	75.64	8	2.47	2	2.44	5	2.45	2	33.77	3	33.40	9	33.58	7
R2	73.39	12	76.01	12	74.70	12	2.29	10	2.41	9	2.35	9	31.23	9	35.34	7	33.29	8
R5	74.02	11	76.66	9	75.34	11	2.22	11	2.27	12	2.25	12	30.73	10	33.03	10	31.88	11
R6	74.41	10	76.75	8	75.58	9	2.20	12	2.33	11	2.27	11	30.62	11	33.73	8	32.17	10
SST935 (A966/R2)	75.84	6	78.98	2	77.41	2	2.37	5	2.42	7	2.39	5	33.46	5	35.47	5	34.46	5
A966/R5	76.17	5	78.66	3	77.41	3	2.34	6	2.43	6	2.38	6	33.64	4	35.91	4	34.78	3
SST946 (A966/R6)	76.22	4	78.33	5	77.27	6	2.33	7	2.41	8	2.37	8	33.17	6	35.47	6	34.32	6
SST972	75.20	7	77.26	7	76.23	7	2.53	1	2.55	1	2.54	1	35.58	1	37.46	1	36.52	1
ENVIRONM. MEAN	75.371		77.597		76.484		2.351		2.414		2.383		32.643		34.729		33.686	
CV (%)	0.78%		2.03%		1.55%		3.32%		3.23%		3.28%		5.05%		4.97%		5.04%	
LSD	0.3261		0.8691		0.4623		0.0431		0.0430		0.0304		0.9103		0.9534		0.6601	

	HAGBERG FALLING NUMBER						ASH						ALVEO STRENGTH					
GENOTYPE	HFN04	R	HFN05	R	HFN04+5	R	A04	R	A05	R	A04+5	R	AST04	R	AST05	R	AST04+5	R
ELANDS	377.33	7	368.78	10	373.06	11	0.56	4	0.7	1	0.63	1	41.39	1	51.69	1	46.54	1
SST966	388.78	4	362.89	11	375.83	10	0.54	11	0.64	3	0.59	3	32.37	7	50.12	2	41.24	3
SST399	376.78	8	408.94	6	392.86	6	0.53	12	0.61	4	0.57	10	33.76	5	47.62	4	40.69	4
B966	423.00	1	437.78	1	430.39	1	0.58	1	0.68	2	0.63	2	36.16	2	47.26	5	41.71	2
B972	376.72	9	405.61	8	391.17	7	0.55	6	0.58	11	0.57	11	32.31	8	44.26	7	38.29	7
R2	360.39	11	403.50	9	381.94	9	0.56	2	0.59	10	0.58	7	31.23	9	48.01	3	39.62	6
R5	377.61	6	414.61	4	396.11	4	0.55	7	0.6	9	0.58	8	28.82	12	37.81	12	33.32	12
R6	364.83	10	413.17	5	389.00	8	0.56	5	0.61	7	0.58	5	29.02	11	38.15	11	33.58	11
SST935 (A966/R2)	377.78	5	408.56	7	393.17	5	0.56	3	0.61	6	0.58	4	34.48	3	46.89	6	40.69	5
A966/R5	398.22	3	416.11	3	407.17	3	0.54	10	0.6	8	0.57	9	34.27	4	40.91	9	37.59	8
SST946 (A966/R6)	401.61	2	419.06	2	410.33	2	0.55	8	0.61	5	0.58	6	32.64	6	39.66	10	36.15	9
SST972	350.61	12	344.44	12	347.53	12	0.54	9	0.57	12	0.56	12	29.71	10	42.36	8	36.04	10
ENVIRONM. MEAN	381.139		404.454		392.796		0.551		0.617		0.584		33.013		44.562		38.787	
CV (%)	6.19%		3.65%		5.04%		7.74%		7.66%		7.69%		13.62%		9.92%		11.51%	
LSD	13.0110		8.1468		7.7053		0.0235		0.0261		0.0175		2.4823		2.4391		1.7358	

	WET GLUTEN CONTENT						MIXOGRAPH MIXING TIME					
GENOTYPE	WGC04	R	WGC05	R	WGC04+5	R	MT04	R	MT05	R	MT04+5	R
ELANDS	34.43	3	37.22	5	35.82	4	3.45	2	2.87	1	3.16	1
SST966	29.63	12	35.27	8	32.45	12	3.51	1	2.32	7	2.91	3
SST399	32.90	6	33.56	12	33.23	9	3.42	3	2.48	2	2.95	2
B966	32.21	8	39.21	2	35.71	5	2.74	11	2.06	10	2.40	11
B972	35.31	2	42.65	1	38.98	1	2.75	10	2.35	6	2.55	9
R2	36.12	1	36.46	6	36.29	2	3.14	5	2.26	8	2.70	7
R5	33.92	4	38.59	3	36.25	3	2.58	12	1.80	12	2.19	12
R6	33.75	5	37.41	4	35.58	6	2.88	9	2.03	11	2.46	10
SST935 (A966/R2)	30.23	11	35.20	10	32.71	10	3.09	6	2.38	4	2.74	5
A966/R5	31.37	9	35.31	7	33.34	8	3.08	7	2.10	9	2.59	8
SST946 (A966/R6)	30.89	10	34.08	11	32.49	11	3.03	8	2.37	5	2.70	6
SST972	32.31	7	35.22	9	33.76	7	3.34	4	2.46	3	2.90	4
ENVIRONM. MEAN	32.756		36.681		34.719		3.083		2.288		2.686	
CV (%)	12.71%		10.01%		11.26%		10.51%		9.28%		10.22%	
LSD	2.2969		2.0259		1.5211		0.1788		0.1172		0.1068	

Table 3.9a: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Intermediate Hybrid Performance Trial (IHBPT) for test weight (HLM).

TEST WEIGHT (HLM)									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
IHBPT	Bainsvlei	A972/R2	78.79	78.99	75.31	77.15	164.00	78.99	-20.00
		A972/R5	77.74	78.99	76.62	77.81	-6.50	78.99	-125.00
		A972/R6	79.53	78.99	75.02	77.01	252.50	78.99	54.00
	Bethlehem	A972/R2	76.49	74.98	72.66	73.82	267.00	74.98	151.00
		A972/R5	76.08	74.98	73.53	74.26	182.50	74.98	110.00
		A972/R6	76.09	74.98	74.74	74.86	123.00	74.98	111.00
	Bultfontein	A972/R2	77.80	75.46	73.09	74.28	352.50	75.46	234.00
		A972/R5	76.93	75.46	73.66	74.56	237.00	75.46	147.00
		A972/R6	78.38	75.46	74.16	74.81	357.00	75.46	292.00
	Clocolan	A972/R2	77.49	77.94	76.10	77.02	47.00	77.94	-45.00
		A972/R5	77.63	77.94	78.04	77.99	-36.00	78.04	-41.00
		A972/R6	77.48	77.94	78.21	78.08	-59.50	78.21	-73.00
	Kroonstad	A972/R2	77.57	77.01	75.72	76.37	120.50	77.01	56.00
		A972/R5	77.82	77.01	76.23	76.62	120.00	77.01	81.00
		A972/R6	77.69	77.01	78.31	77.66	3.00	78.31	-62.00
	Reitz	A972/R2	74.57	72.82	71.78	72.30	227.00	72.82	175.00
		A972/R5	74.89	72.82	74.41	73.62	127.50	74.41	48.00
		A972/R6	74.67	72.82	74.20	73.51	116.00	74.20	47.00
	Combined localities	A972/R2	77.12	76.20	74.11	75.15	196.35	76.20	91.80
		A972/R5	76.85	76.20	75.41	75.81	104.15	76.20	64.70
		A972/R6	77.31	76.20	75.77	75.99	131.95	76.20	110.60
		Average	77.09	76.20	75.10	75.65	144.15	76.20	89.03

Table 3.9b: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Intermediate Hybrid Performance Trial (IHBPT) for kernel diameter (SKCS-DIAM).

SKCS DIAMETER (KERNEL SIZE)									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
IHBPT	Bainsvlei	A972/R2	2.54	2.48	2.25	2.37	17.50	2.48	6.00
		A972/R5	2.55	2.48	2.18	2.33	22.00	2.48	7.00
		A972/R6	2.58	2.48	2.19	2.34	24.50	2.48	10.00
	Bethlehem	A972/R2	2.53	2.51	2.39	2.45	8.00	2.51	2.00
		A972/R5	2.54	2.51	2.34	2.43	11.50	2.51	3.00
		A972/R6	2.54	2.51	2.32	2.42	12.50	2.51	3.00
	Bultfontein	A972/R2	2.43	2.43	2.24	2.34	9.50	2.43	0.00
		A972/R5	2.48	2.43	2.16	2.30	18.50	2.43	5.00
		A972/R6	2.46	2.43	2.12	2.28	18.50	2.43	3.00
	Clocolan	A972/R2	2.67	2.51	2.53	2.52	15.00	2.53	14.00
		A972/R5	2.67	2.51	2.36	2.44	23.50	2.51	16.00
		A972/R6	2.64	2.51	2.41	2.46	18.00	2.51	13.00
	Kroonstad	A972/R2	2.58	2.54	2.36	2.45	13.00	2.54	4.00
		A972/R5	2.59	2.54	2.26	2.40	19.00	2.54	5.00
		A972/R6	2.62	2.54	2.31	2.43	19.50	2.54	8.00
	Reitz	A972/R2	2.56	2.42	2.28	2.35	21.00	2.42	14.00
		A972/R5	2.48	2.42	2.24	2.33	15.00	2.42	6.00
		A972/R6	2.45	2.42	2.19	2.31	14.50	2.42	3.00
	Combined localities	A972/R2	2.55	2.48	2.34	2.41	14.05	2.48	7.10
		A972/R5	2.55	2.48	2.26	2.37	17.90	2.48	6.80
		A972/R6	2.55	2.48	2.26	2.37	17.95	2.48	6.80
		Average	2.55	2.48	2.28	2.38	16.63	2.48	6.90

Table 3.9c: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Intermediate Hybrid Performance Trial (IHBPT) for kernel gram (SKCS-G).

SKCS GRAM (KERNEL SIZE)									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
IHBPT	Bainsvlei	A972/R2	36.27	33.43	30.48	31.96	431.50	33.43	284.00
		A972/R5	37.02	33.43	30.47	31.95	507.00	33.43	359.00
		A972/R6	37.58	33.43	30.38	31.91	567.50	33.43	415.00
	Bethlehem	A972/R2	36.92	35.78	34.35	35.07	185.50	35.78	114.00
		A972/R5	37.42	35.78	34.43	35.11	231.50	35.78	164.00
		A972/R6	37.63	35.78	32.95	34.37	326.50	35.78	185.00
	Bultfontein	A972/R2	34.62	32.00	30.87	31.44	318.50	32.00	262.00
		A972/R5	35.92	32.00	29.92	30.96	496.00	32.00	392.00
		A972/R6	35.20	32.00	29.07	30.54	466.50	32.00	320.00
	Clocolan	A972/R2	40.13	34.63	36.77	35.70	443.00	36.77	336.00
		A972/R5	40.67	34.63	33.92	34.28	639.50	34.63	604.00
		A972/R6	39.93	34.63	35.37	35.00	493.00	35.37	456.00
	Kroonstad	A972/R2	38.63	36.32	33.85	35.09	354.50	36.32	231.00
		A972/R5	38.58	36.32	32.93	34.63	395.50	36.32	226.00
		A972/R6	39.37	36.32	32.83	34.58	479.50	36.32	305.00
	Reitz	A972/R2	36.57	32.97	31.75	32.36	421.00	32.97	360.00
		A972/R5	36.23	32.97	31.83	32.40	383.00	32.97	326.00
		A972/R6	34.30	32.97	31.32	32.15	215.50	32.97	133.00
	Combined localities	A972/R2	37.19	34.19	33.01	33.60	358.90	34.19	299.90
		A972/R5	37.64	34.19	32.25	33.22	441.95	34.19	344.90
		A972/R6	37.34	34.19	31.99	33.09	424.85	34.19	314.60
		Average	37.39	34.19	32.42	33.30	408.57	34.19	319.80

Table 3.9d: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Intermediate Hybrid Performance Trial (IHBPT) for hardness index (SKCS-HI).

SKCS HARDNESS INDEX									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
IHBPT	Bainsvlei	A972/R2	65.66	73.74	76.97	75.36	-969.50	76.97	-1131.00
		A972/R5	63.46	73.74	79.16	76.45	-1299.00	79.16	-1570.00
		A972/R6	64.41	73.74	78.17	75.96	-1154.50	78.17	-1376.00
	Bethlehem	A972/R2	64.92	71.27	71.03	71.15	-623.00	71.27	-635.00
		A972/R5	65.43	71.27	74.92	73.10	-766.50	74.92	-949.00
		A972/R6	65.52	71.27	74.61	72.94	-742.00	74.61	-909.00
	Bultfontein	A972/R2	69.67	76.87	73.48	75.18	-550.50	76.87	-720.00
		A972/R5	66.57	76.87	75.78	76.33	-975.50	76.87	-1030.00
		A972/R6	67.27	76.87	75.10	75.99	-871.50	76.87	-960.00
	Clocolan	A972/R2	61.43	77.36	66.11	71.74	-1030.50	77.36	-1593.00
		A972/R5	60.68	77.36	75.23	76.30	-1561.50	77.36	-1668.00
		A972/R6	61.50	77.36	74.42	75.89	-1439.00	77.36	-1586.00
	Kroonstad	A972/R2	70.41	74.92	74.83	74.88	-446.50	74.83	-442.00
		A972/R5	70.12	74.92	77.10	76.01	-589.00	77.10	-698.00
		A972/R6	66.13	74.92	75.27	75.10	-896.50	75.27	-914.00
	Reitz	A972/R2	66.52	72.05	67.94	70.00	-347.50	72.05	-553.00
		A972/R5	61.82	72.05	73.02	72.54	-1071.50	73.02	-1120.00
		A972/R6	66.33	72.05	71.64	71.85	-551.50	72.05	-572.00
	Combined localities	A972/R2	66.44	74.37	71.73	73.05	-661.35	74.37	-793.50
		A972/R5	64.68	74.37	75.87	75.12	-1044.20	75.87	-1119.40
		A972/R6	65.19	74.37	74.87	74.62	-942.90	74.87	-967.90
		Average	65.43	74.37	74.15	74.26	-882.82	75.04	-960.27

Table 3.9e: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Intermediate Hybrid Performance Trial (IHBPT) for break flour yield (BFLY).

BREAK FLOUR YIELD (BFLY)									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
IHBPT	Bainsvlei	A972/R2	17.84	16.30	17.24	16.77	107.00	17.24	60.00
		A972/R5	18.54	16.30	17.29	16.80	174.50	17.29	125.00
		A972/R6	18.03	16.30	17.08	16.69	134.00	17.08	95.00
	Bethlehem	A972/R2	19.61	18.11	19.58	18.85	76.50	19.58	3.00
		A972/R5	20.27	18.11	18.94	18.53	174.50	18.94	133.00
		A972/R6	19.01	18.11	19.25	18.68	33.00	19.25	-24.00
	Bultfontein	A972/R2	16.99	16.30	17.63	16.97	2.50	17.63	-64.00
		A972/R5	16.85	16.30	18.02	17.16	-31.00	18.02	-117.00
		A972/R6	17.26	16.30	18.16	17.23	3.00	18.16	-90.00
	Clocolan	A972/R2	17.66	16.84	18.52	17.68	-2.00	18.52	-86.00
		A972/R5	18.05	16.84	16.05	16.45	160.50	16.84	121.00
		A972/R6	18.42	16.84	17.45	17.15	127.50	17.45	97.00
	Kroonstad	A972/R2	16.74	16.56	17.59	17.08	-33.50	17.59	-85.00
		A972/R5	16.91	16.56	17.74	17.15	-24.00	17.74	-83.00
		A972/R6	17.80	16.56	18.19	17.38	42.50	18.19	-39.00
	Reitz	A972/R2	17.28	17.46	20.44	18.95	-167.00	20.44	-316.00
		A972/R5	17.16	17.46	17.89	17.68	-51.50	17.89	-73.00
		A972/R6	17.15	17.46	19.19	18.33	-117.50	19.19	-204.00
	Combined localities	A972/R2	17.69	16.93	18.50	17.71	-2.85	18.50	-81.40
		A972/R5	17.96	16.93	17.65	17.29	66.90	17.65	31.10
		A972/R6	17.94	16.93	18.22	17.57	36.85	18.22	-27.70
		Average	17.86	16.93	18.12	17.53	33.63	18.12	-26.00

Table 3.9f: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Intermediate Hybrid Performance Trial (IHBPT) for flour yield (FLY).

FLOUR YIELD (FLY)									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
IHBPT	Bainsvlei	A972/R2	52.89	54.76	53.97	54.37	-147.50	54.76	-187.00
		A972/R5	54.79	54.76	55.08	54.92	-13.00	55.08	-29.00
		A972/R6	53.57	54.76	55.19	54.98	-140.50	55.19	-162.00
	Bethlehem	A972/R2	55.30	56.37	55.03	55.70	-40.00	56.37	-107.00
		A972/R5	56.72	56.37	56.05	56.21	51.00	56.37	35.00
		A972/R6	55.61	56.37	55.37	55.87	-26.00	56.37	-76.00
	Bultfontein	A972/R2	55.51	62.26	54.07	58.17	-265.50	62.26	-675.00
		A972/R5	54.17	62.26	54.60	58.43	-426.00	62.26	-809.00
		A972/R6	54.19	62.26	60.76	61.51	-732.00	62.26	-807.00
	Clocolan	A972/R2	54.35	55.59	54.56	55.08	-72.50	55.59	-124.00
		A972/R5	55.27	55.59	52.55	54.07	120.00	55.59	-32.00
		A972/R6	56.67	55.59	54.29	54.94	173.00	55.59	108.00
	Kroonstad	A972/R2	53.90	53.88	52.23	53.06	84.50	53.88	2.00
		A972/R5	54.77	53.88	53.28	53.58	119.00	53.88	89.00
		A972/R6	55.60	53.88	53.83	53.86	174.50	53.88	172.00
	Reitz	A972/R2	58.57	59.75	55.10	57.43	114.50	59.75	-118.00
		A972/R5	58.18	59.75	52.00	55.88	230.50	59.75	-157.00
		A972/R6	58.41	59.75	59.11	59.43	-102.00	59.75	-134.00
	Combined localities	A972/R2	55.09	57.10	54.16	55.63	-54.35	57.10	-201.50
		A972/R5	55.65	57.10	53.93	55.51	13.65	57.10	-145.10
		A972/R6	55.68	57.10	56.42	56.76	-108.65	57.10	-142.50
		Average	55.47	57.10	54.84	55.97	-49.78	57.10	-163.03

Table 3.9g: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Intermediate Hybrid Performance Trial (IHBPT) for falling number (HFN).

HAGBERG FALLING NUMBER (HFN)									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
IHBPT	Bainsvlei	A972/R2	361.00	397.50	390.50	394.00	-3300.00	397.50	-3650.00
		A972/R5	379.67	397.50	391.33	394.42	-1474.50	397.50	-1783.00
		A972/R6	384.17	397.50	388.17	392.84	-866.50	397.50	-1333.00
	Bethlehem	A972/R2	367.17	396.83	378.67	387.75	-2058.00	396.83	-2966.00
		A972/R5	396.67	396.83	410.67	403.75	-708.00	410.67	-1400.00
		A972/R6	375.83	396.83	393.67	395.25	-1942.00	396.83	-2100.00
	Bultfontein	A972/R2	345.67	367.67	356.67	362.17	-1650.00	367.67	-2200.00
		A972/R5	358.50	367.67	365.17	366.42	-792.00	367.67	-917.00
		A972/R6	348.00	367.67	372.50	370.09	-2208.50	372.50	-2450.00
	Clocolan	A972/R2	350.17	394.67	331.00	362.84	-1266.50	394.67	-4450.00
		A972/R5	377.33	394.67	349.50	372.09	524.50	394.67	-1734.00
		A972/R6	374.83	394.67	375.17	384.92	-1009.00	394.67	-1984.00
	Kroonstad	A972/R2	375.00	373.00	372.67	372.84	216.50	373.00	200.00
		A972/R5	372.67	373.00	387.50	380.25	-758.00	387.50	-1483.00
		A972/R6	381.50	373.00	385.00	379.00	250.00	385.00	-350.00
	Reitz	A972/R2	408.17	394.83	375.67	385.25	2292.00	394.83	1334.00
		A972/R5	417.17	394.83	422.33	408.58	859.00	422.33	-516.00
		A972/R6	406.33	394.83	417.67	406.25	8.00	417.67	-1134.00
	Combined localities	A972/R2	367.86	387.42	367.53	377.47	-961.15	387.42	-1955.90
		A972/R5	383.67	387.42	387.75	387.58	-391.65	387.75	-408.30
		A972/R6	378.44	387.42	388.69	388.06	-961.15	388.69	-1024.60
		Average	376.66	387.42	381.32	384.37	-771.32	387.95	-1129.60

Table 3.9h: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Intermediate Hybrid Performance Trial (IHBPT) for ash.

ASH									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
IHBPT	Bainsvlei	A972/R2	0.54	0.53	0.56	0.55	-0.50	0.56	-2.00
		A972/R5	0.52	0.53	0.55	0.54	-2.00	0.55	-3.00
		A972/R6	0.51	0.53	0.55	0.54	-3.00	0.55	-4.00
	Bethlehem	A972/R2	0.55	0.57	0.56	0.57	-1.50	0.57	-2.00
		A972/R5	0.57	0.57	0.56	0.57	0.50	0.57	0.00
		A972/R6	0.54	0.57	0.56	0.57	-2.50	0.57	-3.00
	Bultfontein	A972/R2	0.52	0.56	0.54	0.55	-3.00	0.56	-4.00
		A972/R5	0.53	0.56	0.54	0.55	-2.00	0.56	-3.00
		A972/R6	0.49	0.56	0.56	0.56	-7.00	0.56	-7.00
	Clocolan	A972/R2	0.57	0.59	0.57	0.58	-1.00	0.59	-2.00
		A972/R5	0.56	0.59	0.56	0.58	-1.50	0.59	-3.00
		A972/R6	0.56	0.59	0.56	0.58	-1.50	0.59	-3.00
	Kroonstad	A972/R2	0.56	0.58	0.55	0.57	-0.50	0.58	-2.00
		A972/R5	0.55	0.58	0.56	0.57	-2.00	0.58	-3.00
		A972/R6	0.55	0.58	0.57	0.58	-2.50	0.58	-3.00
	Reitz	A972/R2	0.62	0.55	0.53	0.54	8.00	0.55	7.00
		A972/R5	0.63	0.55	0.53	0.54	9.00	0.55	8.00
		A972/R6	0.57	0.55	0.57	0.56	1.00	0.57	0.00
	Combined localities	A972/R2	0.56	0.56	0.55	0.56	-0.15	0.56	-0.40
		A972/R5	0.56	0.56	0.55	0.56	0.55	0.56	0.10
		A972/R6	0.54	0.56	0.56	0.56	-2.30	0.56	-2.30
		Average	0.55	0.56	0.55	0.56	-0.63	0.56	-0.87

Table 3.9i: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Intermediate Hybrid Performance Trial (IHBPT) for alveograph strength (ASTR-W).

ALVEO STRENGTH (ASTR-W)									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
IHBPT	Bainsvlei	A972/R2	34.63	35.72	37.72	36.72	-209.00	37.72	-309.00
		A972/R5	33.78	35.72	25.47	30.60	318.50	35.72	-194.00
		A972/R6	33.85	35.72	30.27	33.00	85.50	35.72	-187.00
	Bethlehem	A972/R2	33.98	36.23	37.48	36.86	-287.50	37.48	-350.00
		A972/R5	33.37	36.23	34.25	35.24	-187.00	36.23	-286.00
		A972/R6	35.30	36.23	31.80	34.02	128.50	36.23	-93.00
	Bultfontein	A972/R2	43.22	35.08	47.18	41.13	209.00	47.18	-396.00
		A972/R5	38.07	35.08	32.60	33.84	423.00	35.08	299.00
		A972/R6	36.68	35.08	35.05	35.07	161.50	35.08	160.00
	Clocolan	A972/R2	37.18	42.23	33.25	37.74	-56.00	42.23	-505.00
		A972/R5	31.18	42.23	31.82	37.03	-584.50	42.23	-1105.00
		A972/R6	31.68	42.23	27.82	35.03	-334.50	42.23	-1055.00
	Kroonstad	A972/R2	39.22	38.98	40.22	39.60	-38.00	40.22	-100.00
		A972/R5	34.03	38.98	31.58	35.28	-125.00	38.98	-495.00
		A972/R6	30.90	38.98	31.77	35.38	-447.50	38.98	-808.00
	Reitz	A972/R2	43.00	43.43	43.65	43.54	-54.00	43.65	-65.00
		A972/R5	40.20	43.43	37.18	40.31	-10.50	43.43	-323.00
		A972/R6	44.13	43.43	38.52	40.98	315.50	43.43	70.00
	Combined localities	A972/R2	38.54	38.61	39.92	39.27	-72.65	39.92	-138.10
		A972/R5	35.11	38.61	32.15	35.38	-27.60	38.61	-350.40
		A972/R6	35.43	38.61	32.54	35.58	-15.00	38.61	-318.50
		Average	36.36	38.61	34.87	36.74	-38.42	39.05	-269.00

Table 3.9j: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Intermediate Hybrid Performance Trial (IHBPT) for consistograph waterabsorption (CABS).

CONSISTOGRAPH WATERABSORPTION (CABS)									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
IHBPT	Bainsvlei	A972/R2	57.23	58.60	57.23	57.92	-68.50	58.60	-137.00
		A972/R5	28.23	58.60	57.47	58.04	-2980.50	58.60	-3037.00
		A972/R6	58.33	58.60	58.47	58.54	-20.50	58.60	-27.00
	Bethlehem	A972/R2	58.45	59.57	57.87	58.72	-27.00	59.57	-112.00
		A972/R5	59.45	59.57	58.83	59.20	25.00	59.57	-12.00
		A972/R6	58.83	59.57	57.63	58.60	23.00	59.57	-74.00
	Bultfontein	A972/R2	58.42	58.70	58.57	58.64	-21.50	58.70	-28.00
		A972/R5	58.67	58.70	58.22	58.46	21.00	58.70	-3.00
		A972/R6	58.13	58.70	58.67	58.69	-55.50	58.70	-57.00
	Clocolan	A972/R2	58.78	60.48	58.87	59.68	-89.50	60.48	-170.00
		A972/R5	60.00	60.48	60.22	60.35	-35.00	60.48	-48.00
		A972/R6	58.93	60.48	59.25	59.87	-93.50	60.48	-155.00
	Kroonstad	A972/R2	58.57	60.12	58.52	59.32	-75.00	60.12	-155.00
		A972/R5	58.67	60.12	58.87	59.50	-82.50	60.12	-145.00
		A972/R6	58.55	60.12	58.45	59.29	-73.50	60.12	-157.00
	Reitz	A972/R2	59.63	58.67	58.02	58.35	128.50	58.67	96.00
		A972/R5	59.55	58.67	58.42	58.55	100.50	58.67	88.00
		A972/R6	59.80	58.67	58.57	58.62	118.00	58.67	113.00
	Combined localities	A972/R2	58.51	59.36	58.18	58.77	-25.30	59.36	-84.60
		A972/R5	59.09	59.36	58.67	59.01	8.15	59.36	-26.60
		A972/R6	58.76	59.36	58.51	58.93	-16.70	59.36	-59.60
		Average	58.79	59.36	58.45	58.90	-11.28	59.36	-56.93

Table 3.9k: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Intermediate Hybrid Performance Trial (IHBPT) for mixograph mixing time (MMT).

MIXOGRAPH MIXING TIME (MMT)									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
IHBPT	Bainsvlei	A972/R2	3.12	2.56	2.85	2.71	41.50	2.85	27.00
		A972/R5	2.69	2.56	2.75	2.66	3.50	2.75	-6.00
		A972/R6	2.58	2.56	2.57	2.57	1.50	2.57	1.00
	Bethlehem	A972/R2	3.03	2.51	3.01	2.76	27.00	3.01	2.00
		A972/R5	2.38	2.51	2.58	2.55	-16.50	2.58	-20.00
		A972/R6	2.64	2.51	2.93	2.72	-8.00	2.93	-29.00
	Bultfontein	A972/R2	3.00	2.71	2.73	2.72	28.00	2.73	27.00
		A972/R5	2.65	2.71	2.20	2.46	19.50	2.71	-6.00
		A972/R6	2.50	2.71	2.63	2.67	-17.00	2.71	-21.00
	Clocolan	A972/R2	2.59	2.21	2.38	2.30	29.50	2.38	21.00
		A972/R5	2.20	2.21	1.93	2.07	13.00	2.21	-1.00
		A972/R6	2.44	2.21	2.16	2.19	25.50	2.21	23.00
	Kroonstad	A972/R2	2.61	2.67	2.44	2.56	5.50	2.67	-6.00
		A972/R5	2.31	2.67	1.94	2.31	0.50	2.67	-36.00
		A972/R6	2.32	2.67	2.17	2.42	-10.00	2.67	-35.00
	Reitz	A972/R2	2.83	2.60	2.85	2.73	10.50	2.85	-2.00
		A972/R5	2.47	2.60	2.34	2.47	0.00	2.60	-13.00
		A972/R6	2.63	2.60	2.59	2.60	3.50	2.60	3.00
	Combined localities	A972/R2	2.86	2.54	2.71	2.63	23.75	2.71	15.30
		A972/R5	2.45	2.54	2.29	2.42	3.30	2.54	-9.10
		A972/R6	2.52	2.54	2.51	2.53	-0.80	2.54	-2.30
		Average	2.61	2.54	2.50	2.52	8.75	2.60	1.30

Table 3.10a: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Winter Performance Trial (WHBPT) for test weight (HLM).

TEST WEIGHT (HLM)									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
WHBPT	Bainsvlei	A966/R2=SST935	78.23	76.82	74.73	75.78	245.50	76.82	141.00
		A966/R5	76.78	76.82	76.26	76.54	24.00	76.82	-4.00
		A966/R6=SST946	77.71	76.82	75.34	76.08	163.00	76.82	89.00
	Bethlehem	A966/R2=SST935	76.32	76.05	74.53	75.29	103.00	76.05	27.00
		A966/R5	76.76	76.05	74.05	75.05	171.00	76.05	71.00
		A966/R6=SST946	74.58	76.05	74.64	75.35	-76.50	76.05	-147.00
	Bultfontein	A966/R2=SST935	75.74	75.57	72.71	74.14	160.00	75.57	17.00
		A966/R5	75.89	75.57	74.41	74.99	90.00	75.57	32.00
		A966/R6=SST946	76.23	75.57	73.82	74.70	153.50	75.57	66.00
	Clocolan	A966/R2=SST935	78.76	78.83	77.01	77.92	84.00	78.83	-7.00
		A966/R5	79.18	78.83	76.45	77.64	154.00	78.83	35.00
		A966/R6=SST946	78.73	78.83	77.30	78.07	66.50	78.83	-10.00
	Kroonstad	A966/R2=SST935	78.52	79.18	75.95	77.57	95.50	79.18	-66.00
		A966/R5	79.03	79.18	76.48	77.83	120.00	79.18	-15.00
		A966/R6=SST946	78.85	79.18	76.80	77.99	86.00	79.18	-33.00
	Reitz	A966/R2=SST935	76.91	77.85	73.27	75.56	135.00	77.85	-94.00
		A966/R5	76.83	77.85	74.28	76.07	76.50	77.85	-102.00
		A966/R6=SST946	77.54	77.85	75.59	76.72	82.00	77.85	-31.00
	Combined localities	A966/R2=SST935	77.41	77.38	74.70	76.04	137.20	77.41	0.30
		A966/R5	77.41	77.38	75.34	76.36	105.10	77.41	0.10
		A966/R6=SST946	77.27	77.38	75.58	76.48	79.15	77.38	-10.70
		Average	77.37	77.38	75.21	76.29	107.15	77.40	-3.43

Table 3.10b: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Winter Hybrid Performance Trial (WHBPT) for kernel diameter (SKCS-DIAM).

SKCS DIAMETER (KERNEL SIZE)									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
WHBPT	Bainsvlei	A966/R2=SST935	2.38	2.35	2.27	2.31	7.00	2.35	3.00
		A966/R5	2.37	2.35	2.19	2.27	10.00	2.35	2.00
		A966/R6=SST946	2.36	2.35	2.20	2.28	8.50	2.35	1.00
	Bethlehem	A966/R2=SST935	2.42	2.33	2.33	2.33	9.00	2.33	9.00
		A966/R5	2.38	2.33	2.25	2.29	9.00	2.33	5.00
		A966/R6=SST946	2.38	2.33	2.31	2.32	6.00	2.33	5.00
	Bultfontein	A966/R2=SST935	2.32	2.29	2.23	2.26	6.00	2.29	3.00
		A966/R5	2.34	2.29	2.16	2.23	11.50	2.29	5.00
		A966/R6=SST946	2.29	2.29	2.20	2.25	4.50	2.29	0.00
	Clocolan	A966/R2=SST935	2.43	2.35	2.46	2.41	2.50	2.46	-3.00
		A966/R5	2.47	2.35	2.36	2.36	11.50	2.36	11.00
		A966/R6=SST946	2.44	2.35	2.35	2.35	9.00	2.35	9.00
	Kroonstad	A966/R2=SST935	2.42	2.40	2.37	2.39	3.50	2.40	2.00
		A966/R5	2.32	2.40	2.26	2.33	-1.00	2.40	-8.00
		A966/R6=SST946	2.38	2.40	2.25	2.33	5.50	2.40	-2.00
	Reitz	A966/R2=SST935	2.40	2.29	2.44	2.37	3.50	2.44	-4.00
		A966/R5	2.44	2.29	2.27	2.28	16.00	2.29	15.00
		A966/R6=SST946	2.41	2.29	2.30	2.30	11.50	2.30	11.00
	Combined localities	A966/R2=SST935	2.39	2.33	2.35	2.34	5.05	2.35	4.30
		A966/R5	2.39	2.33	2.25	2.29	9.40	2.33	5.50
		A966/R6=SST946	2.37	2.33	2.27	2.30	7.25	2.33	4.40
		Average	2.38	2.33	2.29	2.31	7.23	2.34	4.73

Table 3.10c: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Winter Hybrid Performance Trial (WHBPT) for kernel weight (SKCS-G).

SKCS Weight									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
WHBPT	Bainsvlei	A966/R2=SST935	33.67	32.82	31.61	32.22	145.50	32.82	85.00
		A966/R5	34.04	32.82	30.07	31.45	259.50	32.82	122.00
		A966/R6=SST946	33.54	32.82	30.27	31.55	199.50	32.82	72.00
	Bethlehem	A966/R2=SST935	34.93	33.37	32.98	33.18	175.50	33.37	156.00
		A966/R5	35.59	33.37	32.80	33.09	250.50	33.37	222.00
		A966/R6=SST946	35.08	33.37	33.23	33.30	178.00	33.37	171.00
	Bultfontein	A966/R2=SST935	32.40	32.19	30.08	31.14	126.50	32.19	21.00
		A966/R5	32.69	32.19	29.24	30.72	197.50	32.19	50.00
		A966/R6=SST946	31.66	32.19	30.12	31.16	50.50	32.19	-53.00
	Clocolan	A966/R2=SST935	36.04	33.82	36.24	35.03	101.00	36.24	-20.00
		A966/R5	36.69	33.82	34.18	34.00	269.00	34.18	251.00
		A966/R6=SST946	36.62	33.82	34.42	34.12	250.00	34.42	220.00
	Kroonstad	A966/R2=SST935	35.31	34.32	33.85	34.09	122.50	34.32	99.00
		A966/R5	33.85	34.32	32.54	33.43	42.00	34.32	-47.00
		A966/R6=SST946	33.87	34.32	31.61	32.97	90.50	34.32	-45.00
	Reitz	A966/R2=SST935	34.43	31.05	34.96	33.01	142.50	34.96	-53.00
		A966/R5	35.81	31.05	32.45	31.75	406.00	32.45	336.00
		A966/R6=SST946	35.14	31.05	33.39	32.22	292.00	33.39	175.00
	Combined localities	A966/R2=SST935	34.46	32.93	33.29	33.11	135.65	33.29	117.20
		A966/R5	34.78	32.93	31.88	32.40	237.60	32.93	184.80
		A966/R6=SST946	34.32	32.93	32.18	32.55	176.95	32.93	139.00
		Average	34.52	32.93	32.45	32.69	183.40	33.05	147.00

Table 3.10d: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Winter Hybrid Performance Trial (WHBPT) for Hagberg falling number (HFN).

HAGBERG FALLING NUMBER (HFN)									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
WHBPT	Bainsvlei	A966/R2=SST935	399.50	415.33	413.17	414.25	-1475.00	415.33	-1583.00
		A966/R5	410.67	415.33	403.83	409.58	109.00	415.33	-466.00
		A966/R6=SST946	408.17	415.33	401.50	408.42	-24.50	415.33	-716.00
	Bethlehem	A966/R2=SST935	411.83	450.00	384.50	417.25	-542.00	450.00	-3817.00
		A966/R5	408.00	450.00	403.67	426.84	-1883.50	450.00	-4200.00
		A966/R6=SST946	410.83	450.00	404.00	427.00	-1617.00	450.00	-3917.00
	Bultfontein	A966/R2=SST935	369.50	406.50	362.00	384.25	-1475.00	406.50	-3700.00
		A966/R5	386.33	406.50	387.33	396.92	-1058.50	406.50	-2017.00
		A966/R6=SST946	417.67	406.50	363.50	385.00	3267.00	406.50	1117.00
	Clocolan	A966/R2=SST935	379.33	447.67	370.83	409.25	-2992.00	447.67	-6834.00
		A966/R5	390.17	447.67	387.83	417.75	-2758.00	447.67	-5750.00
		A966/R6=SST946	395.33	447.67	381.50	414.59	-1925.50	447.67	-5234.00
	Kroonstad	A966/R2=SST935	389.83	450.00	376.33	413.17	-2333.50	450.00	-6017.00
		A966/R5	433.33	450.00	386.50	418.25	1508.00	450.00	-1667.00
		A966/R6=SST946	426.00	450.00	386.50	418.25	775.00	450.00	-2400.00
	Reitz	A966/R2=SST935	409.00	428.17	384.83	406.50	250.00	428.17	-1917.00
		A966/R5	414.50	428.17	407.50	417.84	-333.50	428.17	-1367.00
		A966/R6=SST946	404.00	428.17	397.00	412.59	-858.50	428.17	-2417.00
	Combined localities	A966/R2=SST935	393.17	432.95	381.94	407.44	-1427.75	432.95	-3977.80
		A966/R5	407.17	432.95	396.11	414.53	-736.10	432.95	-2577.80
		A966/R6=SST946	410.33	432.95	389.00	410.97	-63.95	432.95	-2261.20
		Average	403.56	432.95	389.02	410.98	-742.60	432.95	-2938.93

Table 3.10e: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Winter Hybrid Performance Trial (WHBPT) for ash.

ASH									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
WHBPT	Bainsvlei	A966/R2=SST935	0.58	0.60	0.52	0.56	2.00	0.60	-2.00
		A966/R5	0.56	0.60	0.56	0.58	-2.00	0.60	-4.00
		A966/R6=SST946	0.59	0.60	0.55	0.58	1.50	0.60	-1.00
	Bethlehem	A966/R2=SST935	0.59	0.61	0.61	0.61	-2.00	0.61	-2.00
		A966/R5	0.61	0.61	0.57	0.59	2.00	0.61	0.00
		A966/R6=SST946	0.57	0.61	0.63	0.62	-5.00	0.63	-6.00
	Bultfontein	A966/R2=SST935	0.60	0.67	0.60	0.64	-3.50	0.67	-7.00
		A966/R5	0.58	0.67	0.57	0.62	-4.00	0.67	-9.00
		A966/R6=SST946	0.59	0.67	0.57	0.62	-3.00	0.67	-8.00
	Clocolan	A966/R2=SST935	0.59	0.62	0.58	0.60	-1.00	0.62	-3.00
		A966/R5	0.58	0.62	0.59	0.61	-2.50	0.62	-4.00
		A966/R6=SST946	0.58	0.62	0.58	0.60	-2.00	0.62	-4.00
	Kroonstad	A966/R2=SST935	0.57	0.63	0.58	0.61	-3.50	0.63	-6.00
		A966/R5	0.57	0.63	0.58	0.61	-3.50	0.63	-6.00
		A966/R6=SST946	0.59	0.63	0.58	0.61	-1.50	0.63	-4.00
	Reitz	A966/R2=SST935	0.57	0.64	0.57	0.61	-3.50	0.64	-7.00
		A966/R5	0.53	0.64	0.59	0.62	-8.50	0.64	-11.00
		A966/R6=SST946	0.55	0.64	0.59	0.62	-6.50	0.64	-9.00
	Combined localities	A966/R2=SST935	0.58	0.63	0.58	0.60	-1.85	0.63	-4.70
		A966/R5	0.57	0.63	0.58	0.60	-2.95	0.63	-5.80
		A966/R6=SST946	0.58	0.63	0.58	0.60	-2.55	0.63	-5.10
		Average	0.58	0.63	0.58	0.60	-2.45	0.63	-5.20

Table 3.10f: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Winter Hybrid Performance Trial (WHBPT) for wet gluten content (WGC).

WET GLUTEN CONTENT (WGC)									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
WHBPT	Bainsvlei	A966/R2=SST935	31.37	31.39	32.90	32.15	-77.50	32.90	-153.00
		A966/R5	29.31	31.39	35.11	33.25	-394.00	35.11	-580.00
		A966/R6=SST946	28.30	31.39	33.90	32.65	-434.50	33.90	-560.00
	Bethlehem	A966/R2=SST935	32.28	36.81	40.22	38.52	-623.50	40.22	-794.00
		A966/R5	31.72	36.81	37.26	37.04	-531.50	37.26	-554.00
		A966/R6=SST946	34.78	36.81	34.66	35.74	-95.50	36.81	-203.00
	Bultfontein	A966/R2=SST935	33.09	32.60	34.86	33.73	-64.00	34.86	-177.00
		A966/R5	32.47	32.60	36.43	34.52	-204.20	36.43	-395.70
		A966/R6=SST946	32.90	32.60	36.99	34.80	-189.50	36.99	-409.00
	Clocolan	A966/R2=SST935	31.76	35.95	33.79	34.87	-311.00	35.95	-419.00
		A966/R5	32.21	35.95	37.04	36.50	-428.50	37.04	-483.00
		A966/R6=SST946	30.60	35.95	33.82	34.89	-428.50	35.95	-535.00
	Kroonstad	A966/R2=SST935	33.47	33.68	35.29	34.49	-101.50	35.29	-182.00
		A966/R5	39.13	33.68	36.07	34.88	425.50	36.07	306.00
		A966/R6=SST946	35.35	33.68	37.96	35.82	-47.00	37.96	-261.00
	Reitz	A966/R2=SST935	34.31	43.86	40.70	42.28	-797.00	43.86	-955.00
		A966/R5	35.21	43.86	35.61	39.74	-452.50	43.86	-865.00
		A966/R6=SST946	32.98	43.86	36.15	40.01	-702.50	43.86	-1088.00
	Combined localities	A966/R2=SST935	32.71	35.71	36.29	36.00	-328.95	36.29	-357.70
		A966/R5	33.34	35.71	36.25	35.98	-264.25	36.25	-291.00
		A966/R6=SST946	32.49	35.71	35.58	35.65	-316.05	35.71	-322.50
		Average	32.85	35.71	36.04	35.88	-303.08	36.08	-323.73

Table 3.10g: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Winter Hybrid Performance Trial (WHBPT) for alveograph strength (ASTR-W).

ALVEO STRENGTH (ASTR-W)									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
WHBPT	Bainsvlei	A966/R2=SST935	39.55	39.12	35.47	37.30	225.50	39.12	43.00
		A966/R5	30.55	39.12	27.67	33.40	-284.50	39.12	-857.00
		A966/R6=SST946	34.82	39.12	30.82	34.97	-15.00	39.12	-430.00
	Bethlehem	A966/R2=SST935	41.78	44.85	43.57	44.21	-243.00	44.85	-307.00
		A966/R5	39.97	44.85	39.40	42.13	-215.50	44.85	-488.00
		A966/R6=SST946	37.07	44.85	34.97	39.91	-284.00	44.85	-778.00
	Bultfontein	A966/R2=SST935	42.48	41.02	39.78	40.40	208.00	41.02	146.00
		A966/R5	37.42	41.02	31.17	36.10	132.50	41.02	-360.00
		A966/R6=SST946	37.03	41.02	36.77	38.90	-186.50	41.02	-399.00
	Clocolan	A966/R2=SST935	36.43	39.73	33.97	36.85	-42.00	39.73	-330.00
		A966/R5	32.83	39.73	30.13	34.93	-210.00	39.73	-690.00
		A966/R6=SST946	30.90	39.73	30.22	34.98	-407.50	39.73	-883.00
	Kroonstad	A966/R2=SST935	41.47	34.83	40.78	37.81	366.50	40.78	69.00
		A966/R5	43.78	34.83	33.53	34.18	960.00	34.83	895.00
		A966/R6=SST946	34.78	34.83	31.33	33.08	170.00	34.83	-5.00
	Reitz	A966/R2=SST935	42.40	50.68	44.13	47.41	-500.50	50.68	-828.00
		A966/R5	40.97	50.68	38.00	44.34	-337.00	50.68	-971.00
		A966/R6=SST946	42.30	50.68	37.40	44.04	-174.00	50.68	-838.00
	Combined localities	A966/R2=SST935	40.69	41.71	39.62	40.66	2.45	41.71	-102.40
		A966/R5	37.59	41.71	33.32	37.51	7.45	41.71	-412.40
		A966/R6=SST946	36.15	41.71	33.58	37.64	-149.45	41.71	-556.00
		Average	38.14	41.71	35.51	38.61	-46.52	41.71	-356.93

Table 3.10h: Mid-parent heterosis (H_{MP}) and high-parent heterosis (H_{HP}) of hybrid combinations during 2004 and 2005 combined for the Winter Hybrid Performance Trial (WHBPT) for mixing time (MMT).

MIXOGRAPH MIXING TIME (MMT)									
Trial	Expt.	Genotype	F1	FeP1	MaP2	MPV	% Het.	HPV	% Het.
WHBPT	Bainsvlei	A966/R2=SST935	2.95	2.17	2.86	2.52	43.50	2.86	9.00
		A966/R5	2.68	2.17	2.27	2.22	46.00	2.27	41.00
		A966/R6=SST946	2.79	2.17	2.64	2.41	38.50	2.64	15.00
	Bethlehem	A966/R2=SST935	2.91	2.39	2.95	2.67	24.00	2.95	-4.00
		A966/R5	2.53	2.39	2.06	2.23	30.50	2.39	14.00
		A966/R6=SST946	2.83	2.39	2.30	2.35	48.50	2.39	44.00
	Bultfontein	A966/R2=SST935	2.97	2.58	2.80	2.69	28.00	2.80	17.00
		A966/R5	2.72	2.58	2.19	2.39	33.50	2.58	14.00
		A966/R6=SST946	2.72	2.58	2.52	2.55	17.00	2.58	14.00
	Clocolan	A966/R2=SST935	2.65	2.25	2.48	2.37	28.50	2.48	17.00
		A966/R5	2.54	2.25	2.11	2.18	36.00	2.25	29.00
		A966/R6=SST946	2.51	2.25	2.34	2.30	21.50	2.34	17.00
	Kroonstad	A966/R2=SST935	2.46	2.48	2.66	2.57	-11.00	2.66	-20.00
		A966/R5	2.58	2.48	2.12	2.30	28.00	2.48	10.00
		A966/R6=SST946	2.80	2.48	2.31	2.40	40.50	2.48	32.00
	Reitz	A966/R2=SST935	2.49	2.53	2.42	2.48	1.50	2.53	-4.00
		A966/R5	2.48	2.53	2.39	2.46	2.00	2.53	-5.00
		A966/R6=SST946	2.56	2.53	2.64	2.59	-2.50	2.64	-8.00
	Combined localities	A966/R2=SST935	2.74	2.40	2.70	2.55	19.05	2.70	3.80
		A966/R5	2.59	2.40	2.19	2.29	29.35	2.40	18.80
		A966/R6=SST946	2.70	2.40	2.46	2.43	27.20	2.46	24.10
		Average	2.68	2.40	2.45	2.42	25.20	2.52	15.57

3.3.1.1 Test weight (HLM)

Test weight or hectolitre mass is considered important in the prediction of flour yield and represents the mass of wheat per volume.

Intermediate Hybrid Performance Trial (IHBPT)

IHBPT 2004

Elands (quality check) had the highest test weight during 2004, not differing significantly from the female B966. The hybrids SST966, A972/R6 had significantly higher test weight than A972/R2, A972/R5 and SST983. Above mentioned genotypes were the only ones to have test weights above 76 kg hl^{-1}. The male R2 had significantly lower test weight than the male R5 and R6 with the lowest test weight of all genotypes. With exception of the female B966 and SST972 most hybrids had higher test weight than the male and female they were combined from (Table 3.7).

IHBPT 2005

The hybrid A972/R6 had the highest test weight during 2005 followed by the quality check Elands and the hybrid A972/R2, these genotypes did not differ significantly from each other. All the hybrids A972/R2, SST966, A972/R5, SST983 and SST972 followed Elands with test weights of 77 kg hl^{-1} and above. The hybrids were followed by the females B972 and B966, with test weight above 76 kg hl^{-1}. The males, as was the case in 2004, ranked in the last three positions with only R5 above the minimum of 76 kg hl^{-1}. The male R2 again was the genotype with the lowest test weight of all. Most hybrids had higher test weight than the males and females they were combined from (Table 3.7).

IHBPT 2004 and 2005 combined

The quality check Elands ranked first with the highest test weight and did not differ significantly from the hybrid A972/R6 which ranked second with the highest test weight within the hybrids (Table 3.7). The female with the best test weight was B966 and it had a significantly higher test weight than the other female B972. The female B972 did not perform significantly higher than the hybrid SST972 (A972/R41) and the male R6. The male genotypes were the only entries below a test weight of 76 $kghl^{-1}$ and R5 and R2 being significantly poorer than all the other genotypes resulting in the males with the lowest test weight of all genotypes. Most hybrids had higher test weights than the

males and females they were combined from. The year 2004 had lower average test weight than 2005. The males R2 and R5 had the lowest hectoliter mass and low flour yield. The female B966 had high test weight and high flour yield. In contrast B972 had low test weight and high flour yield which could be explained by the higher break flour yield and is an indication of harder wheat. The hybrid A972/R6 had the highest test weight with the best flour yield and SST983 with the lowest test weight resulted in the lowest extraction (flour yield). Although the hybrid A972/R5 had lower test weight than A972/R6, it did not influence this hybrid's flour yield negatively.

The hybrid A972/R5 had negative mid and high parent heterosis for test weight at Bainsvlei and Clocolan and hybrid A972/R6 at Clocolan (Table 3.9a).

On average both the mid-and high-parent heterosis was positive for test weight. Bequette and Fisher (1980) also reported that the test weight of hybrids was generally superior to the mid-parent value, and that several hybrids exceeded the high-parent and they suggested that positive heterosis for test weight occurs. The female the hybrids consisted of, outperformed the male regarding test weight.

Winter Hybrid Performance Trial (WHBPT)

WHBPT 2004

The female B966 and SST966 had a test weight significantly higher than that of the other genotypes (Table 3.8). The female B966 differed significantly from female B972. The males R2, R5 and R6 differed significantly and R2 had a significantly lower test weight than all other genotypes. The hybrid SST966 had a significantly higher test weight than all hybrids, followed by A966/R6 and A966/R5. The hybrid SST972 had the lowest test weight of all hybrids but did not differ significantly from its female B972.

WHBPT 2005

All genotypes had a test weight of above 76 kg hl^{-1} and all the A966-hybrids did not differ significantly from each other but had significantly higher test weight than the other genotypes (Table 3.8). The females did not differ significantly from each other. The males did not differ significantly but had lower test weights than most genotypes.

WHBPT 2004 and 2005 combined

The A966 genepool grouped together in the top positions together with the quality check Elands. The hybrid SST966 (A966/R41) significantly outperformed the group A966/R2, A966/R5, A966/R6, their female B966 and the quality check Elands. In Table 3.8 B972 had significantly lower test weight than the highest performing B966 and did not differ significantly from the males R5 and R6 as well as the winter cultivar SST399. SST399 is one of the longest growers in the Sensako cultivar package. The male R2 had significantly lower test weight than all other genotypes (Table 3.8).

Positive mid-parent heterosis was found (Table 3.10a) for test weight. High- parent heterosis was low but positive for the hybrids SST935 (A966/R2) and A966/R5. Negative high-parent heterosis was recorded for the hybrid SST946 (A966/R6) due to the female having a slightly higher average test weight. Only at Bultfontein positive mid-and high-parent was seen.

3.3.1.2 Kernel size (SKCS-DIAM)

Intermediate Hybrid Performance Trial (IHBPT)

IHBPT 2004

The hybrids, except SST983, containing the female A972 had the highest values for diameter. They had significantly bigger kernels than SST966 (Table 3.7). They were followed by the female B972, Elands, the hybrid SST966, and then the female B966. It seems that the female determines the diameter as the males had the smallest diameter. The female B972 with significantly higher diameter/bigger kernels than B966, grouped together with the hybrids containing the female A972. This same trend was observed with the hybrid SST966 and its female B966 which grouped together. The males R2, R5 and R6 had significantly smaller kernels than all other genotypes (Table 3.4).

IHBPT 2005

The hybrids containing the female A972 had the highest value for kernel diameter and included SST983 during 2005. With the exception of SST983 all A972-hybrids outperformed SST966. The female A972 had significantly larger kernels than B966

and it seems as if the female caused the higher diameter as the males had the lowest diameter. The female B972 with the higher diameter also ranked the highest of the females. This same trend was observed with the hybrid SST966 and its female B966 which performed poorer than the A972 hybrid group as the female also performed below the female B972. The males R5 and R6 had significantly smaller kernels than all other genotypes (Table 3.7).

IHBPT 2004 and 2005 combined

The hybrids containing the female A972, ranked the highest for diameter. A972/R2, A972/R5, A972/R6, SST972 (A972/R41), SST983 (A972/R44) followed by their female B972 which had the highest diameter within the female genepool. The same trend was observed with the hybrid SST966 and followed by its female B966. The A972-hybrids outperformed Elands for kernel diameter. Within the female genepool, B972 had the highest diameter, which was significantly higher than the other male B966 (Table 3.7). B972 and the hybrid SST966 (A966/R41) did not differ significantly. The males had the lowest diameter of all genotypes. The year 2004 had lower average diameter values than 2005. Although the hybrids had the largest kernels they did not result in the highest flour yield.

On average both the mid-and high-parent heterosis was positive for kernel diameter at all localities. The female the hybrids consisted of, outperformed the male for test weight (Table 3.9b).

Winter Hybrid Performance Trial (WHBPT)

WHBPT 2004

The hybrid SST972 had significantly larger kernels than all genotypes in the winter trial, followed by its female B972 with a significantly smaller kernel. The female B972 had significantly larger kernels than B966. The A966-hybrids had intermediate kernel size while the males had significantly smaller kernels (Table 3.8).

WHBPT 2005

SST972 had significantly larger kernels than all other genotypes during 2005 and in 2004 (Table 3.8). The A966-hybrids ranked intermediate and had significantly smaller kernels than SST972. The female B972 had significantly larger kernels than B966.

The males raked the lowest and R5 had significantly smaller kernels than all other genotypes during 2005.

WHBPT 2004 and 2005 combined

The facultative hybrid SST972 (A972/R41) had the highest diameter of all winter genotypes. Hybrid SST972 significantly outperformed the female it consisted of which ranked second (Table 3.8). With exception of SST946 (A966/R6), all hybrids had significantly higher diameters than the males. The female B972 had a significantly higher diameter than B966 which is known for its smaller kernel. The males differed significantly from each other and ranked the lowest for diameter values.

The winter hybrids improved on average almost 5% in kernel diameter on high-parent calculations and 7% on mid-parent calculations. It would have been interesting to see the effect on flour yield but due to high variation in the data flour yield could not be discussed. In general positive mid-and high- parent heterosis was seen (Table 3.10b).

3.3.1.3 Kernel size (SKCS-G)

Intermediate Hybrid Performance Trial (IHBPT)

IHBPT 2004

The same trend as with SKCS-diameter was found with SKCS-weight. The hybrids, containing the female A972, had the largest kernels. The female A972 determined the higher diameter as the males ranked the lowest. The female B972 with the highest diameter also ranked the highest of the females and had significantly larger kernels than B966. The same trend was observed with the hybrid SST966 and its female B966 which performed significantly poorer than the A972- hybrid group and the female B972 (Table 3.7). The A972-hybrid combinations had higher SKCS values than Elands, thus for kernel size (weight and diameter together) it seems that the A972-hybrid combinations had bigger kernels than Elands and the female mainly contributed to it.

IHBPT 2005

The A972-hybrids again ranked higher than all other genotypes for kernel weight. The female B972 had higher kernel weight than the female B966, the latter having the

lowest kernel weight in the 2005 IHBPT trial. The female with the highest kernel weight produced the hybrids with the highest kernel weight. The female B966 had the lowest kernel weight of the two and its hybrid had the lowest kernel weight of all the hybrids (Table 3.7).

IHBPT 2004 and 2005 combined

The hybrid A972/R5 ranked first with the highest kernel weight followed by the other hybrid combinations containing A972, A972/R6, A972/R2, A972/R44, A972/R41. The first three hybrids A972/R5, A972/R6 and A972/R2 did not differ significantly, but had heavier kernels than the two old hybrids SST972 and SST983 (A972/R41, A972/R44). They were followed by the quality check Elands and the hybrid SST966 (A966/R41). The female B972 had significantly heavier kernels than B966 (Table 3.7). The three males ranked the lowest for kernel weight.

Just as the case with diameter, the females contributed the most to heavier kernels. The hybrids had heavier kernels than the females and males they were combined from. Again the hybrids had the heaviest kernels which resulted in the highest flour yield. The females resulted in higher flour yield without having the heaviest kernels. The males had lighter kernels and extracted low volumes flour yield.

On average both the mid-and high-parent heterosis was positive for kernel weight at all localities (Table 3.9c). The females the hybrids consisted of, outperformed the males. The 2004 season resulted in smaller kernels than the 2005 season.

Winter Hybrid Performance Trial (WHBPT)

WHBPT 2004

The hybrid SST972 had significantly larger kernels than all other genotypes in the winter trial. The female of SST972 and B972 had a significantly smaller kernel size than all other genotypes. The female B972 had significantly larger kernels than B966. The A966-hybrids had intermediate kernel size, the males had significantly smaller kernels than all other genotypes (Table 3.8).

WHBPT 2005

Again SST972 had significantly heavier kernels than all other genotypes (Table 3.8). The female of SST972 and B972 had significantly heavier kernels than B966. The A966-hybrids had intermediate kernel weight. The males had among the lightest kernels. The winter conventional cultivar SST399 had the lightest kernels of all genotypes in the trial.

WHBPT 2004 and 2005 combined

The hybrid SST972 (A972/R41) again had significantly bigger kernels than all other genotypes (Table 3.8). With the exception of SST946 (A966/R6), the hybrids did not differ significantly from the quality check Elands. All hybrids had significantly higher kernel weight than the females and males. The males along with SST399 had the smallest kernels of all genotypes.

Al three hybrids revealed a high percentage of positive mid- and high-parent heterosis for kernel weight (Table 3.10c). On average the females had higher kernel diameter and weight than the males, but the hybrids outperformed the males and females they originated from.

3.3.1.4 Kernel hardness (SKCS-HI)

Intermediate Hybrid Performance Trial (IHBPT)

IHBPT 2004

The male R5 was the hardest genotype followed by the male R6. They were followed by the female B972. The male R2, the female B966 and the quality check had intermediate values for hardness. The hybrid SST966 (A966/R41) was the only hybrid that differed in hardness over the two years, being softer in 2004. The hybrids containing A972 were the softest of all genotypes and were softer than both its parents (Table 3.7).

IHBPT 2005

The same trend was observed as in 2004, except for the hybrid SST966 (A966/R41) which resulted in a harder kernel in 2005. The male R5 was significantly harder than

the other genotypes and had significantly harder kernels than the male R6 (Table 3.7). They were followed by the female B972. Again the male R2, the female B966 and the quality check Elands had intermediate values for hardness. The hybrids containing A972 had the softest kernels and were softer than both the parents it was combined from.

IHBPT 2004 and 2005 combined

The hybrids were the softest of all genotypes. The males and then the females were hardest of all and Elands was intermediate between the hybrids and the parents. The hardest male (R5) combined with the hardest female (B972) resulted in the softest hybrid of the three and the second hardest male (R6) combined with the hardest female (B972) resulted in the second softest hybrid and the same with the third hardest male (R2) in combination with the hardest female. Thus it seems as if the hardness of the male in combination with the same female influenced the hardness of the hybrid in the same order as of the males but resulting in the opposite, a softer hybrid. The hybrid SST972 was significantly softer than all other genotypes (Table 3.7). The hybrids A972/R5, SST983, A972/R6, A972/R2 were significantly harder than SST972, and significantly softer than SST966 and Elands. The year 2004 resulted in average lower hardness values than 2005.

Both mid- and high-parent heterosis was negative for kernel hardness, thus the hybrids had softer kernels than the parents (Table 3.9d). In some cases hardness of the genotype is reflected in the break flour yield. For example R5 and R6 were the hardest entries of all and this was reflected in the low break flour yield value of R5 and not in the high break flour yield of R6. These two males differed in their ability to extract flour and R5 had lower flour yield than R6. The hybrid SST966 was the hardest hybrid and had the highest break flour yield.

3.3.1.5 Break flour yield (BFLY)

Intermediate Hybrid Performance Trial (IHBPT)

IHBPT 2004

Elands had significantly higher break flour yield than all other genotypes. The hybrid ranking second, SST966, and the female B966 which ranked third, differed significantly from each other. B972 had the lowest break flour yield of the females. R2 had the highest break flour yield of all males and differed significantly from R6 and R5. R5 had the lowest break flour yield of all males. The new generation hybrids had lower break flour yield than the older cultivars SST966 and SST972. The two closely related hybrids SST972 (A972/R41) and SST983 (A972/R44) differed significantly in terms of break flour yield, the only difference between the two being the male (Table 3.7). The new generation hybrid A972/R5 outperformed the male and female parental lines.

IHBPT 2005

The female B966 had significantly higher break flour yield than all other genotypes (Table 3.7). Elands yielded significantly lower than B966 followed by the hybrids SST972 and SST966. The female B972 had, as in 2004, the lowest break flour yield of the females and all genotypes in the trial. The male R6 had the best break flour yield of all males with R5 having a significantly lower value. The new generation hybrids had lower break flour yield than the older cultivars. The two closely related hybrids SST972 (A972/R41) and SST983 (A972/R44) differed less in 2005 in terms of break flour yield. The three new generation hybrids A972/R2, A972/R5, A972/R6 did not outperform the males they were combined from, but the hybrids performed poorer than the males they were compiled from. All hybrids with B972 as parental line still outperformed the female B972 it was compiled from.

IHBPT 2004 and 2005 combined

Elands had the best break flour yield of all genotypes. The female B972 had the lowest break flour yield of all genotypes. The male R2 had the best break flour yield of all males. The new generation hybrids had lower break flour yields than most of the older hybrids (A966/R41, A972/R41).

The two closely related hybrids SST972 (A972/R41) and SST983 (A972/R44) differed significantly in terms of break flour yield, the only difference between the two being the male (Table 3.7). The two new generation hybrids A972/R5 and A972/R6 had significantly higher break flour yields than A972/R2.

The new generation hybrid A972/R5 was the only new hybrid which outperformed both the male and female parents. The other two new hybrids A972/R6 and A972/R2 had lower break flour yields than their males. Reitz showed negative mid and high parent heterosis (Table 3.9e). This could be due to the lowest average test weight for Reitz. Hybrid A972/R2 revealed negative mid and high parent heterosis due to the high break flour yield of the male and the low value of the female. In contrast the hybrid A972/R5 had positive heterosis for break flour yield with the hybrid outperforming its parents. The year 2005 had significantly higher break flour yields than 2004 .

3.3.1.6 Flour yield (FLY)

Intermediate Hybrid Performance Trial (IHBPT)

IHBPT 2004

Elands did not differ significantly from B972 and had the highest flour yield of all genotypes (Table 3.7). In most cases poor break flour yield predicts poor flour yield, but the female B972 which had poor break flour yield resulted in the second best genotype for flour yield. The older hybrid SST966 (A966/R41) and its female B966 followed B972 and did not differ significantly from each other. The male R5 had the lowest extraction value and differed significantly from R2. The hybrid A972/R2 extracted the lowest flour yield of all hybrids and differed significantly from the other hybrids.

IHBPT 2005

A different scenario was observed in 2005 when the male R6 ranked top for flour yield and the males R2 and R5 had the lowest flour yield of all genotypes. The males R2 and R5 did not differ for flour yield but extracted significantly lower flour than R6. The females did not differ significantly for flour yield during 2005. The hybrid A972/R6 was the only genotype with flour yield significantly higher than Elands (Table 3.7).

IHBPT 2004 and 2005 combined

Elands had the highest flour yield followed with both the females B972 and B966 (Table 3.4). The male which extracted the highest flour yield was R6. The other two males, R2 and R5, extracted the lowest flour yield of all genotypes. These males did

not differ significantly from the hybrid SST983 (A972/R44). All the hybrids ranked intermediate between the best male R6 and the other two males R2 and R5 which is an indication of additive inheritance. The hybrid SST966 did not differ significantly from A972/R6, and A972/R5 did not differ significantly from SST972 (Table 3.7).

Kroonstad was the only location which revealed positive mid-and high-parent heterosis for flour yield for all three the new generation hybrids A972/R2, A972/R5, A972/R6 (Table 3.9f). The hybrid A972/R5 showed positive mid- and high-parent heterosis at Bethlehem and A972/R6 revealed the same at Clocolan. But in general the hybrids indicated negative heterosis for flour yield over all the locations (Table 3.9f). Bequette and Fisher (1980) reported the opposite as they found flour yield of hybrids to be superior to the mid-parent and that several hybrids exceeded the high-parent. There was not much difference between the average flour yield of 2004 and 2005, although the rankings differed, which is an indication of gxe-interaction.

3.3.1.7 Hagberg falling number (HFN)

Intermediate Hybrid Performance Trial (IHBPT)

IHBPT 2005

The average falling number of 2005 reflected very high falling numbers and was not near the cut off for selection. The males R6 and R5 had significantly higher falling numbers than R2. The female B972 had significantly higher falling number than B966 which had significantly lower test weight than all genotypes included in the trial. The hybrid SST966 had significantly higher falling number than SST972 and SST983 (Table 3.7).

IHBPT 2004 and 2005 combined

The female B966 had significantly higher falling number than all other genotypes (Table 3.7). The female B972 had a significantly lower falling number than B966. The males R6 and R5 had significantly lower falling number than B966, and R2 had the lowest falling number of all the males. The hybrid A972/R5 had the highest falling number of all hybrids and outperformed A972/R2, SST972 and SST983 significantly.

SST972 and the closely related SST983 had significantly lower falling numbers than all other genotypes.

Negative mid-and high-parent heterosis was reported (Table 3.9g). The two males R5 and R6 had higher falling numbers than the male R2, the females and hybrids. The hybrid underperformed against the mid-parent value and against the parent with the highest falling number. A male like R2 with inherently poor falling number must therefore be selected against in the male program.

Winter Hybrid Performance Trial (WHBPT)

WHBPT 2004

The female B966 had significantly higher falling number than all other genotypes (Table 3.8). The male R2 had the lowest falling number and did not differ significantly from R6. The hybrid SST972 had the lowest test weight of all genotypes in the trial and differed significantly from all entries except R2.

WHBPT 2005

Falling number was higher than the selection cut off. The only genotype scoring falling number below the selection level was B966 although it performed the best during 2004. This could be due to variability in rainfall for the two years. The males did not differ significantly from each other but R2 had the lowest value. SST972 had a significantly lower falling number than all hybrids (Table 3.8).

WHBPT 2004 and 2005 combined

Just as in the intermediate trial the female B966 had significantly higher falling number than all other genotypes (Table 3.8). The female B972 ranked eighth and had significantly lower falling number than B966. The males had significantly lower falling number than B966, and R5 outperformed the other males significantly. The male R2 had the lowest falling number of all males. The hybrid A966/R6 and A966/R5 had significantly higher falling number than all hybrids included in the trial and outperformed the intermediate hybrid SST972. The hybrid SST972 ranked just below Elands and had significantly lower falling numbers than the other genotypes.

Both mid-and high-parent heterosis was negative for Hagberg falling number (Table 3.10d). In this case the opposite than in the intermediate trail was found, where the females had high falling numbers mainly due to the contribution of the female B966 most hybrids consisted of. Again, R2 was responsible for the low falling number in the hybrid SST935 (A966/R2) and the other two hybrids outperformed SST935 due to the males having higher falling numbers. This is also reflected in the higher negative heterosis values of SST935 (Table 3.10d).

3.3.1.8 Ash content

Millers use wheat ash as a quality criterion and prefer wheat that will produce low ash flours. The ash itself does not affect flour properties and it can be argued, that ash content should not be regarded as a flour quality parameter in baker's specifications. However, ash values of wheat can be an important tool for the adjustment of mills (Posner and Hibbs, 1997). Fowler and De la Roche (1975) considered the use of flour ash useful as a measure of milling efficiency rather than of wheat quality. The ash content of flour is correlated with flour color brightness and provides a means of monitoring the milling process through the assessment of the grade value of flour streams (Oliver *et al*., 1993). The lower the ash value, the better the flour quality.

Intermediate Hybrid Performance Trial (IHBPT)

IHBPT 2004

The female B966, the hybrid A972/R5 and the conventional variety Elands underperformed with milling efficiency and flour color brightness below the rest of the genotypes (Table 3.7).

IHBPT 2005

In 2005 the average ash was higher than for 2004, with the female B966 and Elands having significantly higher, less preferable, milling efficiency and flour color brightness than all other genotypes (Table 3.7).

IHBPT 2004 and 2005 combined

The hybrid combination A972/R6 had the lowest ash value and it means that the lower the value the less impurity in the flour. The female line B966 had the highest ash value

over both years. Among the hybrids A972/R6, SST972 (A972/R41), SST966 (A966/R41) had the lowest ash value over both years. These three hybrids did not differ significantly from each other and from the male R5 (Table 3.7). All hybrid combinations and male lines had the lowest ash values and the females (B966, B972) and the conventional variety Elands had the highest ash values. Thus hybrids and male lines milled more efficient with more acceptable flour color brightness. The ash values of 2005 were slightly higher than 2004 although there was no genotype by year interaction, thus genotypes did not differ significantly over the years. Environment by year and environment with genotypes interactions was highly significant for this characteristic.

In the case of ash values negative heterosis would be preferable if the hybrid could have lower ash values than the parents. In general negative heterosis was the case (Table 3.9h) except for the hybrid A972/R5 of which the high value at Reitz resulted in positive heterosis in general. Bequette and Fisher (1980) reported that they found ash of the hybrids superior to the mid-parent and in the case of South African germplasm the opposite was found. But in most cases the hybrids revealed negative heterosis at most localities except Reitz.

Winter Hybrid Performance Trial (WHBPT)

WHBPT 2004

SST399 had superior low ash value compared to all other genotypes. The female B966 had the highest ash of all genotypes (Table 3.8).

WHBPT 2005

Elands and the female B966 had the worst ash value (high) of all genotypes. The hybrid SST972 had superior milling efficiency and flour color brightness compared to the rest of the genotypes. The males did not differ significantly (Table 3.8).

WHBPT 2004 and 2005 combined

Elands and the female B966 had significantly higher ash values which are undesirable (Table 3.8). The female B972 had significantly lower ash values than the female B972. The males R2, R5 and R6 did not differ significantly from each other and did not differ significantly from SST966 (A966/R41), SST935 (A966/R2), SST946 (A966/R6),

A966/R5, SST399 (conventional cultivar) and B972 (female). The hybrid SST972 had the best ash value and revealed the highest milling efficiency of all genotypes.

In terms of heterosis and ash value the definition of high-parent heterosis (HPH) is not applicable as one would rather use the term low parent heterosis (LPH) in order to get the ash value of the hybrid lower as its parents. Fortunately the heterosis of both mid- and high-parent heterosis were negative which means one could also strive to breed hybrids with negative high-parent heterosis (Table 3.10e).

3.3.1.9 Wet gluten content (WGC)

Winter Hybrid Performance Trial (WHBPT)

WHBPT 2004

The male R2 ranked first with the highest wet gluten content and did not differ significantly from the female B972, the conventional variety Elands and the male R5. The female B972 had significantly higher wet gluten content than the female B966. The A966-hybrids had significantly lower wet gluten content than the males and B972 (Table 3.8).

WHBPT 2005

Again B972 ranked top with significantly higher wet gluten content than other genotypes (Table 3.8). But this time R2 had significantly lower wet gluten than B972. The females B972 and B966, although ranking first and second, differed significantly from each other. The males R5 and R6 had significantly higher wet gluten content than R2. The hybrids A966/R6 and the conventional cultivar SST399 had the lowest wet gluten content.

WHBPT 2004 and 2005 combined

Wet gluten is an indication of the protein level (personal communication J.D. Cilliers) and is highly correlated with protein content. Wet gluten can therefore also predict the level of protein. The female B972 had the highest wet gluten level as well as the highest protein level and the hybrid SST966 had the lowest wet gluten level with the lowest protein level. The female B972 had significantly higher wet gluten level than all other genotypes. The female B966 had significantly lower wet gluten than B972. The

males R2, R5 and R6 did not differ significantly (Table 3.8). The hybrids SST972, A966/R5, A966/R2, A966/R6 and SST966 and the conventional cultivar SST399 had significantly lower wet gluten content than all other genotypes and so was the level of protein of the hybrids and SST399.

The hybrids had much lower wet gluten content than their parents and revealed negative mid and high parent heterosis (Table 3.10f) and therefore higher protein or wet gluten content should be selected for in the parents.

3.3.1.10 Alveograph strenght (ASTR-W)

Alveograph strength is the amount of work required for the deformation of the dough and is related to the baking strength of the flour. Weak flours result in low stability and strength values, generally with longer alveograph strength values. Likewise, higher alveograph stability and alveograph strength values with short to medium alveograph distensibility values suggest strong flours (Walker and Hazelton, 1996). According to Van Lill and Smith (1997) protein content influences alveograph measurements. They also found that for winter wheat in the summer rainfall region in South Africa, measurements were sensitive to environmental effects.

Intermediate Hybrid Performance Trial (IHBPT)

IHBPT 2004

The quality check Elands and hybrid SST983 had significantly stronger dough than the rest of the genotypes. The female B966 had significantly stronger dough than B972. The male R2 had significantly stronger dough than R6 and R5 (Table 3.7).

IHBPT 2005

Again Elands had the strongest dough. The male R2 had significantly stronger dough than R5 and R6. The females did not differ significantly. The hybrids A972/R5 and A972/R6 had significantly weaker dough than all other hybrids (Table 3.7).

IHBPT 2004 and 2005 combined

The quality check Elands had the highest alveograph strength value and produced dough which was significantly stronger than that of all other genotypes (Table 3.7).

The female B966 produced significantly stronger dough than female B972. The two males R6 and R5 produced significantly weaker dough than R2. The only hybrid that produced stronger dough was SST983 (A972/R44), which revealed significantly stronger dough than the rest of the hybrids. The hybrids were influenced by the strength of the male as the hybrid ranked closely to the male.

Negative heterosis for alveograph strength was seen (Table 3.9i). Hybrids therefore tend to produce weaker dough than the parents. The two males with the weaker dough produced hybrids intermediate to the male and female parent where the female consisted of the stronger dough values. The hybrids A972/R5 had positive mid-and high-parent heterosis at Bultfontein and A972/R6 had positive mid-and high-parent heterosis at both Bultfontein and Reitz.

Winter Hybrid Performance Trial (WHBPT)

WHBPT 2004

Elands had significantly stronger dough than all other genotypes. The female B966 had stronger dough than B972 and they differed significantly. The males as well as the hybrid SST972 had weaker dough. The hybrid A966/R2 had significantly stronger dough than all hybrids (Table 3.8).

WHBPT 2005

During the winter trial of 2005 the male R2 had significantly stronger dough than R5 and R6 (Table 3.8). Elands still had the strongest dough and did not differ significantly from SST966. SST966 had significantly stronger dough than all other hybrids. The female B966 had significantly stronger dough than B972.

WHBPT 2004 and 2005 combined

The quality check Elands had the strongest dough and differed significantly from the rest of the genotypes (Table 3.8). Female B966 had significantly stronger dough than the female B972. R5 and R6 had significantly weaker dough than the male R2. The hybrids SST966 and A966/R2 had significantly stronger dough than A966/R5, A966/R6 and SST972.

The hybrid SST946 (A966/R6) revealed negative mid and high parent heterosis regarding alveograph strength (Table 3.10g). Low positive mid-parent heterosis was

revealed for the hybrids SST935 (A966/R2) and A966/R5. The same hybrids revealed negative high-parent values.

3.3.1.11 Consistograph waterabsorption (CABS)

The water absorption gives an indication of the potential of the protein molecules to absorb moisture at constant and adapted hydration (J.D. Cilliers), and high values are desirable.

Intermediate Hybrid Performance Trial (IHBPT)

IHBPT 2004

The female B966 had the highest water absorption and differed significantly from Elands and B972 (Table 3.7). The female B972 had significantly higher absorption than all hybrid genotypes compiled from this female. The new generation hybrids had significantly lower water absorption than the females and the quality check Elands. The male R2 and the hybrid SST966 had the lowest value of all. The two hybrids A972/R5 and A972/R2 did not differ significantly from their male.

IHBPT 2005

During 2005 less variation existed than in 2004. Like in 2004 Elands and B972 ranked in top positions. The males had significantly lower water absorption than the females and most hybrids (Table 3.7). The males R2, R5, R6 did not differ significantly from each other and from the hybrids SST972. The hybrid A972/R6 did not differ significantly from the three males.

IHBPT 2004 and 2005 combined

The female B966 did not differ significantly from Elands and B972. The hybrids tended to be intermediate between the parents with A972/R5 the best hybrid which did not differ significantly from the female B972. The male R2 had significantly lower water absorption than all genotypes but the hybrid SST972 (A972/R41) (Table 3.7).

In general negative heterosis was evident for this characteristic with exception of A972/R5 and the locality Reitz which revealed positive heterosis (Table 3.9j). It is undesirable for hybrids to have low water absorption values Bequette and Fisher

(1980) reported that absorption were generally close to the mid-parent when the parents differed significantly for these properties.

3.3.1.12 Mixograph mixing time (MMT)

Mixograph measures dough development behavior and its resistance to mixing. During dough mixing the resistance of the system to extension increases progressively until the point of minimum mobility is reached. This is referred to as the dough development time and is considered as the point where dough is optimally mixed (Finney *et al*., 1987). The mixing time of the mixograph (in minutes) indicates the rate at which the flour and water are blended together into a quasi-homogeneous mixture in order to develop a gluten matrix and to incorporate air (Spies, 1990). This method proved to be a valuable criterion for the selection of wheat cultivars with superior quality (Van Lill and Purchase, 1995). Mixograph mixing time is dependent on both protein quality and quantity (Khathar *et al*., 1994). Van Lill (1992) noted that mixograph mixing requirement was largely genetically determined. This signifies its importance as selection criteria in early generation wheat lines.

Intermediate Hybrid Performance Trial (IHBPT)

IHBPT 2004

Elands and the hybrids SST983, SST966, A972/R2 and SST972 had significantly higher mixing times than all other genotypes. The male R2 had significantly longer mixing times than R5 and R6. The females did not differ significantly and B972 ranked among the shortest mixing times.

IHBPT 2005

This season resulted in shorter mixing times, with Elands and the hybrid SST972 with significantly longer mixing times than the other genotypes. The males differed significantly, R5 with the shortest mixing time of all genotypes (Table 3.7). The females differed significantly as well, B966 with the shortest mixing time.

IHBPT 2004 and 2005 combined

The quality check Elands and hybrid SST972 did not differ significantly from each other and revealed significantly longer mixograph mixing times than for the other genotypes

(Table 3.7). The females differed significantly from each other, B966 had the shortest mixing time and males R5 had the shortest mixing time. The new generation hybrid with the longest mixing time was A972/R2 and the hybrid A972/R5 with shortest mixing time.

In most cases positive mid-parent heterosis was recorded with exception of A972/R6 (Table 3.9k). This translated into the hybrids having longer mixing time than the average of both the parents which could be undesirable. Mostly negative high-parent heterosis was seen with exception of A972/R2. The hybrid A972/R2 had positive high- and mid-parent heterosis which means the hybrid had longer mixing times than the average of the parents as well as higher mixing time than the parent with the longest mixing time which would also not be desirable. Bequette and Fisher (1980) reported that mixing time was generally close to the mid-parent when the parents differed significantly for these properties and South African germplasm was superior to the mid- and high-parent.

Winter Hybrid Performance Trial (WHBPT)

WHBPT 2004

All genotypes had mixing times above the required value. The females B972 and B966 did not differ significantly. The males differed significantly, R2 having the longest mixing time and R5 the shortest. The hybrids SST966 and SST972 had significantly longer mixing time than other genotypes and A966/R6 the shortest of all hybrids (Table 3.8).

WHBPT 2005

Elands had the best mixing time of all genotypes and differed significantly from the rest of the genotypes (Table 3.8). Most hybrids had mixing times above the required value. The female B966 and the males R6 and R5 had short mixing times. The hybrid A966/R5 had a short mixing time which differed significantly from the most other hybrids.

WHBPT 2004 and 2005 combined

The conventional quality check Elands had the longest mixograph mixing time and differed significantly from the rest of the genotypes (Table 3.8). The conventional

cultivar SST399 ranked second and did not differ significantly from the two older hybrids SST966 (A966/R41) and SST972 (A972/R41). The new generation hybrids A966/R2 and A966/R6 had significantly longer mixing time than A966/R5. Males differed significantly from each other, R2 having the longest mixing time and R5 the shortest mixing time. The female B972 had significantly higher mixograph mixing time than B966.

Positive mid-and high-parent heterosis was seen for mixograph mixing time (Table 3.10h). The hybrids had significantly lower mixing time than the conventional quality check Elands and would be regarded well within the limits for mixograph mixing time. On average the males had the longest mixing time. Bequette and Fisher (1980) reported that mixing time were generally close to the mid-parent when the parents differed significantly for these properties and South African germplasm were superior to the mid and high-parent.

3.4 CONCLUSIONS AND RECOMMENDATION

Major variation was recorded for many characteristics, even more so in the winter hybrid performance trial. As the offspring of the F1 hybrid is F2 grain, it generally could be one of the explanations why so much variation was recorded. The males underwent less quality selection than the females and were in some cases very different from the females and conventional cultivars, which were selected for the same program. The male program functions separately from the females and conventional cultivars to prevent inbreeding. The females therefore complied more with required quality standards than the males. This diversity between the male and female genepool could be contributing to variation. The milling characteristics revealed less variation than the rheological data. The effect of genotype environment interaction needs further investigation.

In general the males had poor quality in comparison with the females and conventional cultivars and should undergo more strict selection procedures for quality characteristics.

In general high-parent heterosis revealed a clear indication of heterosis in a definite direction, depending on the characteristic measured. In most cases the mid-and high-parent heterosis was in the same direction. Test weight revealed positive mid-and high-parent heterosis over the two year period for both the intermediate and winter hybrid performance trial. This was a very positive trend as higher test weight was achieved by the hybrid over its parents and the higher the test weight the more advantageous as well in terms of flour yield. The males should undergo more strict selection for test weight and this could advance the hybrid even more if positive heterosis is a given. Positive heterosis was also calculated on kernel weight and size over the two years for both the intermediate and winter hybrid performance trial. Again the males had smaller and lighter kernels and could benefit from strict selection pressure to advance the hybrids for positive heterosis.

Negative heterosis was reported for the hardness index for the year 2004 and 2005 for the intermediate hybrid performance trial. The males had softer kernels than the rest of the genotypes. As long as the hybrids do not go below the selection level for hardness this should not be a problem, but the hybrids will benefit from a combination of harder males and females.

Flour yield revealed negative heterosis and the hybrid extracted lower flour yield than its parents. This is very negative and therefore the male which had the softer kernel needs to undergo increased selection pressure for flour yield. If both the male and female had increased flour yield this could probably lift the average flour yield of the hybrid. The heterosis calculations of falling number explained the huge problem farmers had in certain years with falling number and negative heterosis was found for both the intermediate and winter hybrid performance trial. This emphasizes the need for breeding for increased falling numbers in the male and female program.

The negative heterosis for ash for both the intermediate and winter hybrid performance trial was positive, as a lower ash value for the hybrids indicated higher milling efficiency and color brightness of the hybrids. Alveograph strength resulted in negative heterosis and thus stronger parent types could be used and the hybrids would tend to have lower strength values.

Water absorption expressed negative heterosis and the hybrids tended to have lower water absorption levels than the parents and this could be negative for hybrid quality performance. Again the males contributed to low absorption levels and should undergo stricter selection. The hybrids had positive heterosis for mixing time over both the intermediate and winter hybrid performance trial. During the characterization of the parents special attention should be given to parents so that genotypes which mix too long can be excluded to reduce hybrid mixing time.

Table 3.11 : Genotype and environment means of individual localities planted during 2004-2005 of the IHBPT trial

TEST WEIGHT (HLM)

	2004										2005										2004 + 2005									
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	74.91	4	75.46	3	76.57	2	77.08	3	78.21	4	77.77	2	77.95	5	76.19	2	78.40	5	79.86	1	79.92	3	77.28	9	76.43	4	75.83	1	78.49	3	78.47	1	79.06	2	77.52	6
SST966	75.15	2	76.40	2	78.15	3	74.89	8	77.75	7	76.49	9	78.10	3	73.29	8	79.19	1	78.87	4	77.69	7	79.93	2	76.62	1	74.84	4	78.67	1	76.88	6	77.72	8	78.21	2
B966	75.86	1	76.44	1	78.77	1	75.11	7	78.38	2	77.09	4	77.09	7	72.69	11	78.26	6	78.05	6	77.75	6	77.27	10	76.48	3	74.56	7	78.51	2	76.58	7	78.06	6	77.18	9
B972	74.00	6	73.23	10	76.68	8	73.37	10	76.99	8	78.34	1	75.96	9	72.40	12	77.34	11	77.55	7	80.99	1	77.54	8	74.98	8	72.82	11	77.01	10	75.46	9	78.09	3	77.94	4
R2	72.06	12	70.53	12	73.45	12	72.25	12	74.85	12	74.46	12	73.27	11	73.03	10	78.00	10	73.92	12	75.77	11	77.75	7	72.66	12	71.78	12	75.72	12	73.09	12	75.31	11	76.10	12
R5	73.81	8	74.05	5	75.29	11	72.65	11	75.81	10	75.98	10	73.24	12	74.77	6	77.16	12	74.66	10	77.43	8	80.09	1	73.53	11	74.41	8	76.23	11	73.66	11	76.62	10	78.04	3
R6	75.05	3	74.87	4	77.56	4	73.88	8	74.89	11	77.24	3	74.43	10	73.54	7	79.05	2	74.43	11	75.15	12	79.16	3	74.74	10	74.20	9	78.31	4	74.16	10	75.02	12	78.21	1
A972/R2	73.73	9	73.53	9	76.29	10	77.32	1	78.76	1	77.03	6	79.26	1	75.61	4	78.85	3	78.28	5	78.61	5	77.95	6	76.49	2	74.57	6	77.57	8	77.80	4	78.79	5	77.49	7
A972/R5	74.08	5	73.97	6	76.85	7	76.50	5	78.12	6	77.09	5	78.08	4	75.80	3	78.79	4	77.35	8	77.36	9	78.17	5	76.08	6	74.89	3	77.82	5	76.93	5	77.74	7	77.63	5
A972/R6	73.86	7	73.75	7	77.37	5	77.19	2	78.28	3	76.69	8	78.33	2	75.59	5	78.01	9	79.57	2	80.77	2	78.27	4	76.09	5	74.67	5	77.69	6	76.38	2	79.53	1	77.48	8
SST972	72.74	11	73.07	11	76.63	9	76.05	6	76.45	9	75.94	11	76.79	8	77.44	1	78.09	8	76.60	9	77.23	10	76.40	11	74.76	9	75.25	2	77.36	9	76.33	8	76.84	9	76.17	11
SST983	73.69	10	73.69	8	77.08	6	76.71	4	78.20	5	76.82	7	77.61	6	73.16	9	78.10	7	78.39	3	79.59	4	76.38	12	75.65	7	73.42	10	77.59	7	78.05	3	78.90	4	76.66	10
ENVIRONMENTAL MEAN	74.077		74.081		76.891		75.250		77.223		76.754		76.674		74.458		78.270		77.378		78.204		78.018		75.375		74.270		77.581		76.314		77.714		77.386	
CV (%)	0.66%		0.74%		0.46%		0.75%		0.43%		1.03%		1.54%		3.68%		0.98%		1.19%		1.43%		1.27%		1.24%		2.65%		0.76%		0.99%		1.05%		1.13%	
LSD	0.8069		0.7669		0.4918		0.7868		0.4633		1.1045		1.6557		3.8445		1.0744		1.2858		1.5679		1.3853		0.9061		1.9078		0.5728		0.7346		0.7872		0.8482	

MOISTURE (MOIST)

	2004										2005										2004 + 2005									
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	10.80	3	10.90	2	11.13	6	11.13	10	10.77	7	11.07	2	11.30	7	10.73	7	10.73	1	11.37	5	11.63	1	10.73	1	11.05	3	10.82	3	10.93	4	11.25	5	11.20	2	10.90	2
SST966	10.50	8	10.57	9	11.03	7	11.27	4	11.10	2	10.67	11	11.77	1	10.73	9	10.57	9	11.43	3	11.30	4	10.63	4	11.13	2	10.65	7	10.80	7	11.35	3	11.20	3	10.65	10
B966	10.53	7	10.70	5	10.80	11	11.20	7	10.57	10	10.80	9	11.37	3	10.80	5	10.37	12	11.60	2	11.30	5	10.57	7	10.95	8	10.75	5	10.58	12	11.35	2	10.93	10	10.68	8
B972	10.30	11	10.60	8	10.83	10	11.20	8	10.53	12	11.03	3	11.03	12	10.47	12	10.40	11	11.17	7	11.17	10	10.50	11	10.67	12	10.53	10	10.62	10	11.18	10	10.85	12	10.77	5
R2	10.03	12	10.40	10	10.97	8	11.17	9	10.90	5	10.63	12	11.40	2	10.77	6	10.57	8	11.37	6	11.13	12	10.57	8	10.72	11	10.58	9	10.77	9	11.27	4	11.02	8	10.60	12
R5	10.43	9	10.17	11	10.77	12	11.03	11	10.97	3	10.67	10	11.30	6	10.73	8	10.43	10	11.43	4	11.20	8	10.60	6	10.87	9	10.46	11	10.60	11	11.23	6	11.08	5	10.63	11
R6	10.30	10	10.03	12	10.90	9	10.77	12	10.87	6	10.97	6	11.33	4	10.83	4	10.63	6	11.50	1	11.13	11	10.50	9	10.82	10	10.43	12	10.77	8	11.13	12	11.00	7	10.73	6
A972/R2	10.73	5	10.80	4	11.20	4	11.20	6	10.70	8	11.03	4	11.30	5	10.50	11	10.63	7	11.10	12	11.27	7	10.63	5	11.02	4	10.66	6	10.92	6	11.15	11	10.98	8	10.83	4
A972/R5	10.77	4	10.80	3	11.30	2	11.23	5	10.60	9	10.90	8	11.13	11	10.90	2	10.67	5	11.13	9	11.20	9	10.47	12	10.95	7	10.85	2	10.98	2	11.18	9	10.90	11	10.68	9
A972/R6	10.83	2	10.70	6	11.23	3	11.33	2	10.53	11	10.90	7	11.13	10	10.57	10	10.67	3	11.10	11	11.33	2	10.50	10	10.98	5	10.63	8	10.96	3	11.22	7	10.93	9	10.70	7
SST972	10.70	6	10.70	7	11.20	5	11.30	3	10.90	4	11.03	5	11.23	8	10.63	3	10.67	4	11.13	8	11.33	3	10.67	3	10.97	6	10.77	4	10.93	5	11.22	8	11.12	4	10.85	3
SST983	11.60	1	12.07	1	12.07	1	11.60	1	11.23	1	11.37	1	11.20	9	10.93	1	10.73	2	11.13	10	11.27	6	10.70	2	11.40	1	11.50	1	11.40	1	11.37	1	11.28	1	11.03	1
ENVIRONMENTAL MEAN	10.628		10.703		11.119		11.203		10.806		10.922		11.292		10.733		10.589		11.281		11.272		10.106		10.960		10.718		10.854		11.242		11.039		10.756	
CV (%)	3.44%		4.04%		2.40%		2.02%		1.55%		4.99%		1.61%		1.00%		0.66%		0.92%		1.11%		0.84%		2.87%		3.24%		1.91%		1.67%		1.34%		3.63%	
LSD	0.5129		0.6062		0.3747		0.3167		0.2346		0.7636		0.2545		0.1509		0.1463		0.1452		0.1759		0.1396		0.3062		0.3369		0.201		0.182		0.1436		0.3786	

SKCS-HI (HI)

	2004										2005										2004 + 2005									
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	74.57	1	67.53	5	73.18	5	66.00	6	67.81	7	64.60	7	66.66	7	66.99	7	72.93	7	82.41	3	72.26	7	65.47	7	70.62	6	67.26	5	73.06	7	74.20	4	70.04	7	66.04	6
SST966	62.03	12	61.13	10	70.88	8	64.43	8	64.85	10	66.95	11	80.95	1	71.34	5	75.76	4	82.68	4	77.46	2	66.94	6	71.49	3	66.24	8	73.31	5	73.55	5	71.16	6	61.95	8
B966	68.87	8	64.23	7	73.13	6	68.73	2	73.29	5	66.27	5	68.91	6	65.76	8	73.29	6	77.31	8	75.54	4	72.67	4	68.89	7	65.00	9	73.21	6	73.02	7	74.41	4	69.42	4
B972	71.91	5	70.90	3	74.73	2	69.08	1	74.43	4	71.75	1	70.63	5	73.20	2	75.11	5	84.67	1	73.06	6	82.67	1	71.27	4	72.05	2	74.92	3	76.87	1	73.74	5	77.36	1
R2	63.93	11	63.09	8	73.37	4	65.02	7	76.52	3	65.06	6	78.14	2	72.79	3	76.29	3	81.93	6	75.42	5	67.22	5	71.03	5	67.94	4	74.83	4	73.48	6	76.97	3	66.11	5
R5	72.58	2	72.82	1	75.62	1	67.83	3	78.68	2	70.29	3	77.25	3	73.21	1	78.58	1	83.73	2	79.66	1	80.17	2	74.92	1	73.02	1	77.10	1	75.78	2	79.16	1	75.23	2
R6	72.30	3	71.61	2	74.13	3	67.37	4	78.98	1	70.75	2	76.93	4	71.47	4	76.41	2	82.83	3	77.36	3	78.09	3	74.61	2	71.64	3	75.27	2	75.10	3	78.17	2	74.42	3
A972/R2	66.09	9	70.50	4	70.76	9	61.13	9	69.05	6	69.72	9	64.76	8	62.54	10	70.05	9	78.20	7	62.27	8	63.14	10	64.92	10	66.52	6	70.41	8	69.67	8	65.66	8	61.43	10
A972/R5	72.21	4	62.27	9	67.39	10	60.71	10	67.33	8	58.30	10	58.65	10	61.36	12	72.84	8	72.42	10	59.59	11	63.06	11	65.43	9	61.82	10	70.12	9	66.57	11	63.46	10	60.68	11
A972/R6	70.12	6	66.64	6	63.33	12	58.18	12	66.60	9	59.84	8	60.93	9	67.01	6	68.92	10	76.36	9	62.21	9	63.10	9	65.52	8	66.33	7	66.13	12	67.27	10	64.41	9	61.50	9
SST972	64.37	10	58.55	11	64.96	11	59.26	11	63.07	12	55.62	12	58.36	11	62.06	11	67.66	11	68.36	12	59.04	12	60.57	12	60.60	12	60.30	11	66.31	11	63.82	12	61.06	12	58.10	12
SST983	68.92	7	55.38	12	71.96	7	66.50	5	63.94	11	66.34	4	58.84	12	63.29	9	67.55	12	71.27	11	60.24	10	63.48	8	63.64	11	59.33	12	69.76	10	68.86	5	62.09	11	64.91	7
ENVIRONMENTAL MEAN	68.907		65.321		71.119		64.521		70.545		63.787		68.249		67.584		72.951		78.514		69.509		68.902		68.578		66.453		72.053		71.519		70.027		66.345	
CV (%)	5.98%		4.86%		4.23%		6.16%		2.97%		6.23%		4.27%		3.13%		3.79%		3.58%		3.50%		3.44%		5.13%		4.07%		3.93%		4.86%		3.22%		4.89%	
LSD	5.7782		4.4528		4.2212		5.586		2.0421		5.5706		4.0874		2.9631		3.8728		3.9425		3.4133		3.326		3.4128		2.6242		2.7463		3.3665		2.1879		3.1424	

SKCS-G (G)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	38.37	10	34.93	5	35.67	6	33.00	6	39.23	5	35.47	6	43.77	2	37.87	1	37.33	7	30.47	11	32.27	7	39.17	7	37.07	3	36.40	2	36.50	6	31.73	9	35.75	5	37.32	6
SST966	31.60	7	32.73	8	33.97	9	32.80	8	36.00	8	34.97	8	40.30	7	37.47	2	36.93	8	32.10	7	31.93	8	41.03	4	35.95	7	35.10	6	35.45	8	32.45	7	33.97	7	38.00	4
B966	32.60	1	32.63	9	34.10	8	32.80	9	35.10	9	35.10	7	35.20	12	31.97	12	33.33	11	32.30	6	32.27	6	32.87	12	33.90	11	32.30	9	33.72	10	32.55	6	33.68	8	33.98	11
B972	31.97	3	33.53	7	34.53	7	32.90	7	36.57	7	35.53	4	39.60	8	32.40	11	38.10	6	31.10	9	30.30	11	33.33	11	35.78	8	32.97	8	36.32	7	32.00	8	33.43	9	34.63	10
R2	31.70	5	30.40	10	32.73	10	31.03	10	30.60	11	33.00	11	37.00	9	33.10	10	34.97	9	30.70	10	30.37	10	40.53	6	34.36	10	31.78	11	33.85	9	30.87	10	30.48	10	36.77	8
R5	32.13	2	29.33	11	32.00	12	28.70	12	31.67	10	31.77	12	36.73	10	34.33	7	33.87	10	31.13	8	29.27	12	36.07	10	34.43	9	31.83	10	32.93	11	29.92	11	30.47	11	33.92	12
R6	30.27	11	28.47	12	32.40	11	29.23	11	30.33	12	34.50	9	35.63	11	34.17	9	33.27	12	28.90	12	30.43	9	36.23	9	32.95	12	31.32	12	32.83	12	29.07	12	30.38	12	35.37	9
A972/R2	31.63	6	36.33	3	37.27	3	35.20	3	39.73	2	38.87	1	42.20	5	36.80	3	40.00	1	33.93	5	32.80	4	41.40	3	36.92	4	36.67	1	38.63	2	34.62	5	36.27	3	40.13	2
A972/R5	30.43	8	36.37	2	38.77	2	36.40	1	39.57	3	38.80	2	44.40	1	36.10	4	38.40	2	35.43	1	34.47	1	42.53	1	37.42	2	36.23	4	38.58	3	35.92	1	37.02	2	40.67	1
A972/R6	31.63	4	34.40	6	40.60	1	35.30	4	41.00	1	38.23	3	43.43	3	34.20	8	38.13	5	35.10	2	34.17	2	41.63	2	37.63	1	34.30	7	39.37	1	35.20	3	37.58	1	39.63	3
SST972	30.40	9	37.97	1	36.77	4	35.13	5	37.23	6	35.63	5	41.97	6	34.80	6	38.33	3	34.40	3	34.10	3	38.73	8	36.18	6	36.38	3	37.55	4	34.77	4	35.67	6	37.18	7
SST983	30.10	12	36.20	4	36.80	5	36.20	2	39.30	4	34.17	10	42.47	4	35.97	5	38.30	4	34.37	4	32.57	5	40.90	5	36.28	5	35.58	5	37.40	5	35.28	2	35.93	4	37.53	5
ENVIRONMENTAL MEAN	31.253		33.525		35.442		33.233		36.361		35.536		40.225		34.931		36.747		32.494		32.078		38.703		35.739		34.228		36.094		32.864		34.219		37.119	
CV (%)	4.85%		6.10%		4.93%		6.83%		3.97%		4.19%		4.79%		4.72%		3.76%		3.10%		4.66%		4.35%		4.90%		5.57%		4.33%		5.36%		4.24%		4.22%	
LSD	2.1268		2.8668		2.4479		3.1627		2.0229		2.0861		2.7017		2.3102		1.9395		1.412		2.0938		2.3593		1.6957		1.8461		1.515		1.7066		1.4047		1.5193	

SKCS-DIAMETER (DIAM)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	2.28	9	2.45	5	2.54	5	2.40	8	2.70	5	2.45	7	2.80	2	2.57	1	2.53	8	2.19	10	2.26	9	2.63	8	2.54	1	2.51	3	2.53	6	2.30	9	2.48	6	2.54	7
SST966	2.30	5	2.37	8	2.43	9	2.42	7	2.55	8	2.47	6	2.72	6	2.51	3	2.53	7	2.27	8	2.28	8	2.72	3	2.51	7	2.44	7	2.48	8	2.35	7	2.42	8	2.59	4
B966	2.30	4	2.37	9	2.43	8	2.36	9	2.39	9	2.44	8	2.41	11	2.37	9	2.36	10	2.28	7	2.32	6	2.41	12	2.36	10	2.37	9	2.40	9	2.32	8	2.36	9	2.43	10
B972	2.36	1	2.45	6	2.47	7	2.54	4	2.65	6	2.50	4	2.65	8	2.39	8	2.61	3	2.32	6	2.31	7	2.52	9	2.51	8	2.42	8	2.54	5	2.43	6	2.48	7	2.51	9
R2	2.29	6	2.23	10	2.34	10	2.29	10	2.24	10	2.36	11	2.48	9	2.33	11	2.38	9	2.19	9	2.25	10	2.69	6	2.39	9	2.28	10	2.36	10	2.24	10	2.25	10	2.53	8
R5	2.25	10	2.13	11	2.24	12	2.13	12	2.22	11	2.27	12	2.43	10	2.35	10	2.29	12	2.19	11	2.15	12	2.44	10	2.34	11	2.24	11	2.26	12	2.16	11	2.18	12	2.36	12
R6	2.23	12	2.10	12	2.28	11	2.16	11	2.19	12	2.40	9	2.41	12	2.28	12	2.34	11	2.08	12	2.19	10	2.42	11	2.32	12	2.19	12	2.31	11	2.12	12	2.19	11	2.41	11
A972/R2	2.33	2	2.55	2	2.54	4	2.54	3	2.72	2	2.63	1	2.72	7	2.56	2	2.61	2	2.33	5	2.37	4	2.71	5	2.53	4	2.56	2	2.58	4	2.43	5	2.54	3	2.67	1
A972/R5	2.26	9	2.48	3	2.60	2	2.55	2	2.70	4	2.59	2	2.81	1	2.47	6	2.57	5	2.41	3	2.39	3	2.74	1	2.54	3	2.48	4	2.59	3	2.48	2	2.55	2	2.67	2
A972/R6	2.31	3	2.46	4	2.66	1	2.48	6	2.76	1	2.56	3	2.76	4	2.44	7	2.58	4	2.44	2	2.41	1	2.72	2	2.54	2	2.45	6	2.62	1	2.46	3	2.58	1	2.64	3
SST972	2.28	7	2.63	1	2.55	3	2.56	1	2.65	7	2.48	5	2.76	5	2.51	4	2.64	1	2.44	1	2.40	2	2.65	7	2.52	5	2.57	1	2.60	2	2.50	1	2.53	4	2.57	5
SST983	2.25	11	2.45	7	2.60	6	2.51	5	2.70	3	2.37	10	2.79	3	2.50	5	2.54	6	2.39	4	2.34	5	2.71	4	2.52	6	2.47	5	2.52	7	2.45	4	2.52	5	2.54	6
ENVIRONMENTAL MEAN	2.288		2.389		2.464		2.411		2.539		2.461		2.645		2.440		2.499		2.294		2.306		2.613		2.466		2.415		2.481		2.352		2.422		2.537	
CV (%)	3.31%		4.15%		3.73%		3.60%		2.41%		3.14%		3.75%		3.19%		2.60%		2.40%		2.87%		2.96%		3.63%		3.78%		3.17%		3.31%		2.60%		3.00%	
LSD	0.1061		0.1389		0.1288		0.1216		0.0858		0.1082		0.1392		0.109		0.0912		0.0771		0.0929		0.1085		0.0867		0.0884		0.0763		0.0755		0.0609		0.0737	

BREAK FLOUR YIELD (BFLY)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04RE/TZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	21.26	1	20.52	1	19.37	1	19.58	1	18.72	2	19.44	2	21.24	3	23.78	2	20.20	4	19.48	3	22.05	3	24.92	1	21.26	2	22.15	2	19.79	2	19.53	1	20.38	1	22.18	1
SST966	20.96	2	19	4	17.77	3	17.27	3	19.39	1	20.49	1	19.4	11	21.53	3	20.48	3	19.84	2	20.56	8	21.04	4	20.18	5	20.27	4	19.13	3	18.55	3	19.96	3	20.77	3
B966	20.51	4	19.66	3	17.66	2	17.01	4	16.11	4	18.26	3	23.05	1	27.03	1	22.22	1	21.60	1	21.23	6	24.84	2	21.78	1	23.35	1	20.04	1	19.30	2	18.67	5	21.65	2
B972	17.32	10	16.2	10	15.08	11	15.29	11	15.22	10	14.85	11	18.9	12	18.73	9	18.02	12	17.32	12	17.38	12	18.83	10	18.11	12	17.46	9	16.56	12	16.30	11	16.30	12	16.84	11
R2	19.75	6	20.28	2	16.53	5	16.83	5	16.77	6	16.02	9	19.41	10	20.59	4	18.65	9	18.42	8	18.71	11	21.02	5	19.58	7	20.44	3	17.59	8	17.63	7	17.24	10	18.52	8
R5	18.41	8	16.82	7	15.74	9	16.57	6	15.43	8	13.65	12	19.46	9	18.95	7	19.74	7	19.47	4	19.14	9	18.46	12	18.94	10	17.89	7	17.74	7	18.02	5	17.29	9	16.05	12
R6	17.87	9	18.29	5	15.4	9	17.31	2	15.24	9	14.99	10	20.63	5	20.08	5	20.97	2	19.01	5	18.92	10	19.91	7	19.25	8	19.19	5	18.19	5	18.16	4	17.08	11	17.45	10
A972/R2	18.77	7	16.4	9	15.17	10	16.36	8	13.73	12	16.47	8	20.45	6	18.16	11	18.31	11	17.62	11	21.95	4	18.85	9	19.61	6	17.28	10	16.74	11	16.99	9	17.84	8	17.66	9
A972/R5	20.79	3	16.19	11	15.44	8	16.02	9	15.79	5	17.4	5	19.75	8	18.12	12	19.38	10	17.67	10	21.28	5	18.71	11	20.27	4	17.16	11	16.91	10	16.85	10	16.54	6	18.05	8
A972/R6	17.22	11	16.13	12	15.53	7	15.74	10	15.46	7	17.02	6	20.78	4	18.17	10	20.08	5	18.77	6	20.60	7	19.82	6	19.01	9	17.15	12	17.90	6	17.26	8	18.03	7	18.42	7
SST972	20.2	5	17.25	6	17.86	4	16.56	7	16.5	3	17.57	4	21.44	2	19.01	6	19.90	6	18.76	7	23.93	1	21.90	3	20.82	3	18.13	6	18.79	4	17.66	6	20.22	2	19.73	4
SST983	16.6	12	16.82	8	14.74	12	14.27	12	15.2	11	16.64	7	20.19	7	19.92	8	19.26	8	18.11	9	22.71	2	20.31	6	18.39	11	17.87	8	17.00	9	16.19	12	18.96	4	18.47	6
ENVIRONMENTAL MEAN	19.138		17.798		16.359		16.568		16.046		16.899		20.393		20.254		19.668		18.639		20.706		20.717		19.766		19.026		18.023		17.703		18.376		18.806	
CV (%)	7.60%		5.33%		2.87%		4.56%		6.77%		6.49%		4.72%		2.53%		1.85%		2.79%		4.78%		2.20%		6.28%		3.92%		2.41%		4.28%		5.61%		4.58%	
LSD	2.0366		1.3294		0.6575		1.0599		1.5235		1.5387		1.3488		0.7189		0.5099		0.7368		1.3886		0.6402		1.2024		0.7233		0.4211		0.7341		0.9988		0.834	

FLOUR YIELD (FLY)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	59.72	1	60.2	1	57.02	1	58.39	3	58.98	2	58.66	1	56.48	6	56.04	6	54.61	9	57.29	4	56.48	1	56.40	2	58.10	2	58.12	8	55.82	2	57.84	4	57.73	1	57.57	1
SST966	57.82	4	52.72	12	56.23	3	58.6	2	58.47	3	57.87	3	56.05	7	54.33	10	57.21	1	55.54	6	54.27	6	53.73	9	56.93	3	53.52	11	56.72	1	57.07	5	56.37	2	55.80	3
B966	58.34	2	58.1	3	54.03	7	55.79	6	56.45	6	55.11	6	59.45	1	55.90	9	56.01	3	54.34	3	52.35	10	54.57	6	58.90	1	57.00	0	55.02	6	60.06	3	54.40	8	54.84	7
B972	56.43	6	57.68	4	52.95	9	59.95	1	59.87	1	58.33	2	56.3	6	61.81	6	54.81	8	54.57	2	49.65	12	52.84	12	56.37	5	59.75	1	53.88	9	62.26	1	54.76	7	55.59	4
R2	53.18	11	59.7	2	52.78	10	54.17	8	55.28	7	54.32	9	56.87	4	50.49	11	51.68	12	53.97	8	52.66	9	54.79	5	55.03	11	55.10	10	52.23	12	54.07	10	53.97	10	54.56	8
R5	56.98	5	53.53	11	51.43	12	53.14	10	56.62	5	51.63	12	55.12	12	50.47	12	55.14	6	56.05	5	53.54	7	53.47	10	56.05	6	52.00	12	53.29	11	54.60	7	55.08	5	52.55	12
R6	52.98	12	54.82	6	52.44	11	56.57	5	54.73	9	54.01	10	57.77	2	63.40	3	55.21	4	54.95	1	55.64	2	54.56	7	55.37	8	59.11	3	53.83	10	60.76	2	55.19	4	54.29	10
A972/R2	54.55	8	55.76	5	53.4	8	57.57	4	50.17	12	53.3	11	56.02	8	61.39	7	54.39	11	53.44	9	55.61	3	55.40	3	55.30	9	58.57	5	53.90	8	56.51	6	52.89	12	54.35	9
A972/R5	58.13	3	53.65	10	54.4	6	54.02	9	57.44	4	55.72	5	55.3	10	62.71	5	55.14	5	54.32	7	52.14	11	54.82	4	56.72	4	58.18	7	54.77	7	56.17	9	54.79	6	55.27	5
A972/R6	53.64	10	53.9	9	54.65	5	56.29	7	54.45	10	55.09	7	57.59	3	62.92	4	56.55	2	53.06	10	52.69	8	58.25	1	55.61	7	58.41	6	55.60	4	54.19	8	53.57	11	56.67	2
SST972	54.64	7	54.51	7	56.44	2	53.04	11	55.23	8	56.64	4	55.95	9	64.15	1	56.02	7	50.18	12	55.57	4	53.73	8	55.30	10	59.33	2	55.73	3	51.61	12	55.40	3	55.18	6
SST983	53.88	9	54.25	8	56	4	53.03	12	53.06	11	56.02	8	55.22	11	63.74	2	54.52	10	52.11	11	55.11	5	53.14	11	54.56	12	59.00	4	55.26	5	52.57	11	54.38	9	54.06	11
ENVIRONMENTAL MEAN	55.862		55.734		54.313		55.797		55.946		55.474		56.510		58.945		55.026		56.664		53.809		54.648		56.186		57.339		54.669		56.226		54.878		55.061	
CV (%)	3.58%		6.72%		1.94%		2.19%		6.20%		2.83%		2.20%		1.84%		2.51%		0.89%		6.99%		1.41%		3.02%		4.80%		2.22%		1.66%		6.76%		2.22%	
LSD	2.8031		5.2536		1.4741		1.7116		4.863		2.1972		1.7458		1.519		1.9377		0.7089		5.2752		1.0784		1.646		2.6691		1.1761		0.9048		3.5931		1.1833	

FALLING NUMBER (HFN)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	363	7	394.67	3	388.67	2	354.00	3	404.67	6	377.00	4	384.67	9	370.33	12	380.33	10	385.00	5	410.33	1	372.67	7	373.83	9	382.50	10	384.50	5	369.50	3	407.50	2	374.83	5
SST966	331	10	387.33	5	363.67	7	338.67	6	394.67	9	342.67	9	419.33	5	427.67	9	408.00	3	383.00	8	375.33	4	401.67	3	375.17	8	407.50	6	385.83	3	360.83	6	385.00	7	372.17	7
B966	416.67	1	431.00	1	431.67	1	412.00	1	451.00	1	444.33	1	437.67	1	450.00	1	446.00	1	449.33	1	370.00	6	450.00	1	427.17	1	440.50	1	438.83	1	430.67	1	410.50	1	447.17	1
B972	392.67	3	377.67	8	366.00	6	33.00	8	426.33	2	387.67	2	401	6	412.00	11	380.00	11	405.33	2	368.67	7	401.67	2	396.83	3	394.83	9	373.00	8	367.67	4	397.50	3	394.67	2
R2	334.67	9	310.67	12	358.33	10	333.00	7	394.67	10	346.67	8	422.67	3	440.67	6	387.00	6	380.33	10	386.33	2	315.33	12	378.67	6	375.67	11	372.67	9	356.67	8	390.50	5	331.00	10
R5	385.67	4	402.33	2	362.67	9	347.33	4	404.00	7	351.00	7	435.67	2	442.33	4	412.33	2	383.00	7	378.67	3	348.00	9	410.67	2	422.33	2	387.50	2	365.17	5	391.33	4	349.50	9
R6	366.67	6	394.67	4	372.67	3	355.00	2	406.33	5	364.00	5	420.67	4	440.67	5	397.33	4	390.00	3	371.00	5	386.33	5	393.67	5	417.67	3	385.00	4	372.50	2	388.17	6	375.17	4
A972/R2	347	8	383.67	7	366.67	5	310.33	12	381.00	12	320.00	11	387.33	8	432.67	7	383.33	7	381.00	9	341.00	9	380.33	6	367.17	10	408.17	5	375.00	7	345.67	11	361.00	11	350.17	8
A972/R5	400.67	2	385.67	6	363.00	8	329.33	9	418.67	4	357.00	6	392.67	7	448.67	2	382.33	8	387.67	4	340.67	10	397.67	4	396.67	4	417.17	4	372.67	10	358.50	7	379.67	9	377.33	3
A972/R6	368.33	5	368.00	9	369.33	4	311.67	11	424.67	3	379.00	3	383.33	10	444.67	3	393.67	5	384.33	6	343.67	8	370.67	8	375.83	7	406.33	7	381.50	6	348.00	10	384.17	8	374.83	6
SST972	325.67	12	361.00	10	337.33	12	322.67	10	392.00	11	318.67	12	380.67	11	431.33	8	381.00	9	365.00	12	293.33	12	338.33	10	353.17	12	396.17	8	359.17	12	343.83	12	342.67	12	328.50	12
SST983	330	11	321.33	11	384.00	11	340.67	5	401.00	8	335.33	10	378.67	12	417.67	10	378.00	12	371.67	11	322.67	11	323.33	11	354.33	11	369.50	12	366.00	11	356.17	9	361.83	10	329.33	11
ENVIRONMENTAL MEAN	363.500		376.500		3.695		340.389		408.167		3.603		403.694		429.889		394.111		388.806		358.472		373.833		383.597		403.194		381.806		364.597		383.319		367.056	
CV (%)	5.17%		5.66%		5.89%		4.09%		2.46%		3.51%		3%		1.64%		2.04%		2.43%		6.24%		5.63%		4.49%		4.45%		4.33%		3.39%		4.75%		4.98%	
LSD	26.3423		29.8894		30.5361		19.5372		14.1741		17.7092		16.3567		9.9092		11.281		13.2447		31.3698		29.5345		16.6807		16.5739		16.0081		11.9695		17.6376		17.7292	

FLOUR PROTEIEN CONTENT (FPC)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	11.65	5	11.41	8	12.29	3	12.65	1	10.77	5	11.34	7	12.93	6	13.12	8	13.45	6	11.45	12	12.44	8	12.22	5	12.29	6	12.27	9	12.87	4	12.05	4	11.61	6	11.78	6
SST966	10.59	12	11.24	10	10.75	12	10.37	12	8.70	12	9.30	12	10.94	12	12.93	10	13.16	8	12.08	8	12.22	10	11.63	9	10.76	12	12.08	11	11.96	12	11.22	12	10.46	12	10.62	12
B966	11.36	11	11.98	3	12.51	2	10.94	10	9.83	10	12.47	3	12.72	7	17.23	1	15.16	1	13.22	3	12.92	3	14.91	2	12.03	7	14.61	1	13.83	2	12.08	3	11.37	10	13.69	2
B972	12.87	1	12.60	1	13.19	1	11.77	2	12.62	1	13.77	1	15.41	1	16.60	2	14.76	2	14.19	1	12.63	5	16.29	1	14.14	1	14.60	2	13.98	1	12.98	1	12.63	1	15.03	1
R2	11.51	10	12.07	2	11.72	10	11.73	3	10.47	7	11.16	10	11.78	11	13.01	9	13.61	4	12.29	6	12.39	9	11.93	10	11.64	11	12.64	8	12.67	7	12.01	5	11.43	7	11.55	10
R5	11.52	7	11.91	5	11.99	8	11.23	5	9.45	11	11.57	5	12.12	9	12.60	11	13.56	5	12.04	10	13.86	1	11.74	11	11.82	9	12.26	10	12.78	5	11.64	9	11.66	5	11.65	9
R6	11.51	8	11.53	6	12.00	7	11.50	4	10.51	6	13.65	2	11.90	10	12.57	12	13.79	3	14.08	2	13.63	2	12.06	8	11.71	10	12.05	12	12.90	3	12.79	2	12.07	3	12.85	3
A972/R2	11.78	4	10.76	12	12.15	6	11.21	6	9.98	9	11.20	8	13.02	5	15.32	3	12.70	10	12.37	5	12.79	4	12.18	6	12.40	5	13.04	5	12.43	9	11.79	6	11.39	9	11.69	8
A972/R5	12.01	2	11.51	7	11.96	9	11.14	7	11.52	2	11.17	9	13.80	4	14.36	7	12.57	11	12.38	4	12.62	6	12.53	4	12.90	3	12.93	6	12.27	10	11.76	7	12.07	2	11.85	4
A972/R6	11.55	6	11.35	9	12.18	4	10.95	9	11.41	3	11.62	4	12.37	8	14.49	6	13.09	9	11.76	11	12.55	7	11.37	12	11.96	8	12.92	7	12.64	6	11.36	11	11.98	4	11.49	11
SST972	11.51	9	11.14	11	11.67	11	11.04	8	11.27	4	11.43	6	14.20	3	15.20	4	12.44	12	12.28	7	11.57	12	12.15	7	12.86	4	13.17	4	12.06	11	11.66	8	11.42	8	11.79	5
SST983	11.8	3	11.93	4	12.15	5	10.87	11	10.10	8	10.83	11	14.39	2	14.77	5	13.27	7	12.04	9	11.72	11	12.65	3	13.10	2	13.35	3	12.71	6	11.45	10	10.91	11	11.74	7
ENVIRONMENTAL MEAN	11.638		11.619		12.047		11.284		10.553		11.626		12.963		14.349		13.464		12.516		12.611		12.663		12.301		12.984		12.756		11.900		11.582		12.144	
CV (%)	4.92%		5.13%		3.22%		6.11%		4.30%		8.20%		6.10%		3.90%		5.39%		3.40%		4.20%		3.36%		5.79%		4.53%		4.59%		4.78%		4.25%		6.38%	
LSD	0.8029		0.8354		0.5445		0.9662		0.6366		1.337		1.1084		0.7847		1.0182		0.5961		0.7425		0.5961		0.6903		0.5696		0.5672		0.5509		0.4771		0.7505	

ASH (ASH)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	0.58	2	0.58	1	0.53	11	0.55	4	0.55	8	0.59	2	0.56	7	0.53	11	0.57	3	0.54	6	0.76	1	0.56	6	0.57	3	0.55	9	0.55	8	0.55	5	0.66	1	0.57	3
SST966	0.52	11	0.52	9	0.52	12	0.51	12	0.56	5	0.56	10	0.62	1	0.49	12	0.57	4	0.54	7	0.58	2	0.56	5	0.57	4	0.50	12	0.54	11	0.52	10	0.57	2	0.56	7
B966	0.55	5	0.55	2	0.59	3	0.54	6	0.62	1	0.58	4	0.59	2	0.63	5	0.70	1	0.74	1	0.48	12	0.61	1	0.57	2	0.59	5	0.64	1	0.64	1	0.55	5	0.60	1
B972	0.56	4	0.52	11	0.55	6	0.53	9	0.55	7	0.6	1	0.58	4	0.58	8	0.61	2	0.58	2	0.61	7	0.58	2	0.57	5	0.55	8	0.58	2	0.56	3	0.53	8	0.59	2
R2	0.54	10	0.52	10	0.55	8	0.54	7	0.57	4	0.57	5	0.59	3	0.54	10	0.55	7	0.54	5	0.56	3	0.57	3	0.56	6	0.53	10	0.55	10	0.54	7	0.56	3	0.57	4
R5	0.55	6	0.5	12	0.54	9	0.54	5	0.57	2	0.55	11	0.57	6	0.56	9	0.57	5	0.54	4	0.53	5	0.57	4	0.56	7	0.53	11	0.56	6	0.54	6	0.55	6	0.56	9
R6	0.54	8	0.53	7	0.59	1	0.54	6	0.57	3	0.56	9	0.57	6	0.61	7	0.54	10	0.57	3	0.54	4	0.55	7	0.56	8	0.57	7	0.57	3	0.56	4	0.55	4	0.56	11
A972/R2	0.57	3	0.55	4	0.56	4	0.51	11	0.56	6	0.58	3	0.52	12	0.69	4	0.55	8	0.53	9	0.52	6	0.55	10	0.55	9	0.62	4	0.56	5	0.52	11	0.54	7	0.57	5
A972/R5	0.59	1	0.55	8	0.56	5	0.56	3	0.55	9	0.57	7	0.56	8	0.72	3	0.54	9	0.51	10	0.49	11	0.55	11	0.57	1	0.63	2	0.55	7	0.53	8	0.52	9	0.56	10
A972/R6	0.54	9	0.53	6	0.54	10	0.52	10	0.52	11	0.57	6	0.54	11	0.61	6	0.56	6	0.46	12	0.50	9	0.55	9	0.54	11	0.57	6	0.55	9	0.49	12	0.51	11	0.56	6
SST972	0.54	7	0.52	8	0.55	7	0.56	2	0.53	10	0.55	12	0.54	10	0.72	2	0.52	12	0.48	11	0.51	8	0.50	12	0.54	10	0.62	3	0.53	12	0.52	9	0.52	10	0.52	12
SST983	0.48	12	0.55	3	0.59	2	0.58	1	0.52	12	0.56	8	0.55	9	0.76	1	0.53	11	0.54	8	0.50	10	0.55	8	0.51	12	0.65	1	0.56	4	0.56	2	0.51	12	0.56	8
ENVIRONMENTAL MEAN	0.546		0.533		0.557		0.538		0.555		0.569		0.566		0.620		0.566		0.547		0.539		0.559		0.556		0.577		0.562		0.543		0.547		0.564	
CV (%)	5.43%		6.41%		6.16%		7.36%		4.51%		4.68%		7.22%		21.55%		5.77%		7.39%		13.83%		4.47%		6.30%		17.41%		5.90%		7.78%		10.37%		4.67%	
LSD	0.0416		0.033		0.0481		0.0556		0.0361		0.0373		0.0573		0.1873		0.0458		0.0667		0.1044		0.035		0.0339		0.0973		0.0321		0.041		0.0549		0.025	

WET GLUTEN CONTENT (WGC)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	35.18	3	34.14	5	36.88	3	36.66	1	31.97	6	33.57	5	37.45	5	39.94	8	37.75	6	34.10	7	35.03	6	35.52	3	36.32	4	37.04	5	37.32	5	35.38	2	33.50	6	34.54	4
SST966	31.11	11	32.28	10	30.43	12	28.65	11	23.65	12	26.97	12	27.82	12	35.56	12	36.16	8	32.57	10	33.59	9	34.24	9	29.47	12	33.92	12	33.30	12	30.61	11	28.62	12	30.60	12
B966	31.27	10	32.57	8	33.07	11	27.31	12	24.77	11	33.97	3	34.61	10	46.87	2	54.75	1	36.66	3	34.46	8	41.38	2	32.94	11	39.72	3	43.91	1	31.98	8	29.62	11	37.68	2
B972	36.92	1	36.56	2	38.19	1	32.09	6	36.18	1	38.16	1	49.39	1	48.67	1	49.39	2	38.21	2	33.41	10	48.10	1	42.66	1	42.61	1	43.79	2	35.15	3	34.80	4	43.13	1
R2	34.06	6	35.03	3	33.93	9	33.68	4	35.93	2	33.25	7	33.15	11	36.42	10	37.72	7	34.50	5	35.62	4	35.15	5	33.61	10	35.73	9	35.83	7	34.09	5	35.78	1	34.20	5
R5	34.09	5	34.6	4	35.13	7	33.07	5	26.22	10	35.6	2	34.86	9	36.38	11	39.23	5	32.77	9	38.39	2	34.87	8	34.48	8	35.49	11	37.18	6	32.92	6	32.31	8	35.24	3
R6	34.56	4	33.46	6	37.3	2	34.11	2	29.3	7	32.18	10	35.75	7	37.63	9	39.87	4	39.72	1	40.62	1	36.39	4	35.15	6	35.55	10	38.58	3	36.02	1	34.96	3	33.78	7
A972/R2	33.24	8	30.05	12	35.45	5	30.46	7	28.27	9	32.29	9	36.18	6	41.86	6	36.97	9	34.18	6	35.79	3	32.65	11	34.71	7	35.95	8	35.71	9	32.32	7	32.03	9	32.47	10
A972/R5	35.78	2	32.31	9	36.41	4	33.7	3	35.62	3	32.05	11	38.94	4	41.55	7	35.12	11	35.32	4	35.12	5	35.13	6	37.36	3	36.93	6	35.76	8	34.51	4	35.37	2	33.59	8
A972/R6	33.17	9	32.62	7	34.93	8	29.53	10	33.49	4	33.8	4	36.62	8	43.51	3	40.65	3	30.48	12	34.68	7	31.08	12	34.40	9	38.06	4	37.79	4	30.01	12	34.08	5	32.44	11
SST972	33.4	7	31.24	11	35.17	6	29.9	9	33.15	5	33.37	6	41.49	2	42.19	5	34.44	12	33.76	8	32.00	11	33.24	10	37.45	2	36.72	7	34.80	10	31.83	9	32.58	7	33.31	9
SST983	30.83	12	39.71	1	33.2	10	30.37	8	28.7	8	32.47	8	41.46	3	43.10	4	35.58	10	32.35	11	31.37	12	35.13	7	36.15	5	41.41	2	34.39	11	31.36	10	30.04	10	33.80	6
ENVIRONMENTAL MEAN	33.553		33.714		35.009		31.628		30.604		33.139		37.226		41.140		39.716		34.552		35.008		35.990		35.389		37.427		37.363		33.090		32.806		34.565	
CV (%)	6.98%		6.49%		7.96%		8.06%		13.19%		7.44%		9.95%		7.55%		13.10%		5.20%		6.26%		3.95%		8.74%		7.50%		10.96%		6.53%		9.80%		5.97%	
LSD	3.2817		3.068		3.9075		3.5726		5.659		3.4548		5.1939		4.355		7.2924		2.5172		3.0719		1.9941		2.9987		2.7209		3.9681		2.0926		3.115		1.9964	

ALVEO DISTENSIBILITY (AP-DIST)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	98.67	2	107.67	1	94.33	4	115.67	2	126.67	1	124.67	3	80.33	5	72.33	11	88.33	3	83.00	2	74.67	3	99.67	4	89.50	2	90.00	5	91.33	3	99.33	2	100.67	1	107.17	2
SST966	79.00	5	78.67	9	91.33	6	107.00	3	83.33	9	97.67	10	84.33	2	72.00	12	88.33	4	78.67	5	79.33	2	96.67	2	81.67	5	75.33	11	89.83	4	92.83	3	81.33	7	97.17	7
B966	97.33	3	100.00	3	100.33	2	93.67	5	113.33	3	126.33	2	67.33	9	75.67	9	90.00	2	80.33	3	67.33	6	79.00	10	82.33	4	87.83	6	95.17	2	87.00	5	90.33	2	102.67	3
B972	63.00	12	64.33	12	76.00	10	64.33	12	71.00	12	75.67	12	65.67	11	69.00	5	76.67	8	78.67	6	63.00	7	87.00	5	64.33	12	76.67	10	76.33	9	71.50	11	67.00	11	81.33	11
R2	74.67	8	72.33	10	79.33	9	87.00	7	85.67	7	98.00	9	99.00	1	75.67	8	93.33	1	88.00	1	90.67	1	94.67	3	86.83	3	74.00	12	86.33	6	87.50	4	88.17	4	96.33	8
R5	75.33	7	89.67	6	83.33	7	71.67	10	83.33	8	101.00	7	83.00	3	73.00	10	83.67	5	71.67	7	72.33	4	102.00	1	79.17	7	81.33	7	83.5	7	71.67	10	77.83	9	101.50	4
R6	66.67	11	79.33	8	75.00	11	67.00	11	80.67	10	112.67	5	82.33	4	81.67	7	74.33	9	80.00	4	70.67	5	83.67	7	74.50	9	80.50	8	74.67	10	73.50	9	75.67	10	98.17	6
A972/R2	72.67	9	98.67	4	85.33	3	99.67	4	112.00	4	133.00	1	77.67	7	99.00	2	83.00	6	70.67	9	59.67	9	85.00	6	75.17	8	98.83	2	89.17	5	85.17	6	86.83	5	109.00	1
A972/R5	83.67	4	91.00	5	82.67	8	91.00	6	106.33	5	122.00	4	77.67	6	98.00	4	82.67	7	69.00	10	60.00	8	79.00	9	80.67	6	94.50	3	82.67	8	80.00	7	83.17	6	100.50	5
A972/R6	78.67	6	102.67	2	84.33	6	86.33	8	97.67	6	101.67	6	67.67	8	106.00	1	62.00	12	63.67	11	58.67	10	79.67	8	73.17	10	104.33	1	73.17	11	75.00	8	78.17	8	90.67	9
SST972	71.33	10	70.33	11	73.67	12	72.33	9	77.33	11	90.67	11	63.00	12	88.00	6	71.00	11	60.67	12	52.33	12	72.00	12	67.17	11	79.17	9	72.33	12	66.50	12	64.83	12	81.33	12
SST983	141.67	1	82.33	7	147.00	1	150.33	1	123.00	2	100.00	8	67.33	10	99.00	3	73.67	10	71.00	8	55.33	11	77.67	11	104.50	1	90.67	4	110.33	1	110.67	1	89.17	3	88.83	10
ENVIRONMENTAL MEAN	83.556		86.417		90.222		92.167		96.694		106.944		76.278		85.778		80.583		74.611		67.000		85.500		79.917		86.097		85.403		83.389		81.847		96.222	
CV (%)	18.35%		12.43%		18.13%		16.45%		19.62%		22.25%		8.62%		4.14%		6.07%		5.85%		10.84%		5.05%		15.07%		9.19%		14.21%		14.99%		18.47%		18.71%	
LSD	21.4976		15.0605		22.9296		21.2571		26.5948		33.3553		9.2178		4.9804		6.8632		6.1183		10.1785		6.0563		11.6727		7.6073		11.7577		12.1122		14.6528		17.4481	

ALVEO STABILITY (AL-STAB)

	2004										2005										2004 + 2005									
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	101.00	1	77.33	10	93.00	1	85.00	3	52.33	8	58.33	4	141.33	6	213.00	1	159.33	1	177.33	4	177.00	3	140.33	3	121.17	5	145.17	1	126.17	1	131.17	2	114.67	4	99.33	4
SST966	79.67	8	92.00	5	69.67	10	60.67	10	51.00	10	48.33	10	83.33	12	190.00	3	112.33	8	168.00	6	107.33	11	109.67	7	81.50	12	141.00	3	91.00	9	114.33	8	79.17	11	79.00	9
B966	81.33	6	80.67	8	82.67	4	69.00	7	45.00	12	57.33	8	186.00	4	204.33	2	91.67	12	143.33	10	191.00	2	128.00	5	133.67	3	142.50	2	87.17	11	106.17	9	116.00	2	92.67	5
B972	70.33	10	102.00	2	88.00	2	93.00	1	58.00	6	94.33	1	191.00	3	125.33	7	129.67	4	96.33	12	215.67	1	138.00	4	130.67	4	113.67	5	104.33	3	94.67	12	136.83	1	116.17	1
R2	65.00	11	98.00	3	85.33	3	68.00	8	61.67	5	43.33	12	111.33	9	166.00	4	112.67	7	163.00	8	122.00	10	109.00	8	88.17	11	132.00	4	99.00	4	115.50	6	91.83	10	76.17	10
R5	90.00	3	68.33	11	75.67	6	60.67	9	51.67	9	62.00	3	119.67	7	157.67	5	95.67	11	170.00	5	101.33	12	86.67	12	104.83	7	113.00	7	85.67	12	115.33	7	76.50	12	74.33	12
R6	79.67	7	107.33	1	75.00	7	58.33	11	65.33	4	57.33	7	116.00	8	119.00	8	116.33	6	138.00	11	136.33	7	93.33	11	97.83	8	113.17	6	95.67	5	97.17	11	100.83	9	75.33	11
A972/R2	84.33	5	60.00	12	68.00	11	71.00	6	50.67	11	55.00	9	108.00	10	127.67	6	120.00	5	179.33	3	162.67	4	108.00	9	96.17	10	93.83	10	94.00	7	125.17	4	106.67	6	80.50	7
A972/R5	99.33	2	80.33	9	70.33	9	75.33	5	69.33	3	48.00	11	63.33	11	105.67	11	106.33	10	166.67	7	135.33	8	111.33	6	96.33	9	93.00	11	88.33	10	121.00	5	102.33	8	79.67	8
A972/R6	78.33	9	83.67	7	78.00	5	75.33	4	79.00	2	65.33	2	145.33	5	86.00	12	108.00	9	185.33	2	132.00	9	96.67	10	111.83	6	84.33	12	93.00	8	130.33	3	105.50	7	81.00	6
SST972	89.00	4	90.00	6	74.00	8	92.67	2	81.67	1	58.00	5	202.00	2	119.00	9	135.67	3	203.33	1	154.00	6	141.33	2	145.50	1	104.50	8	104.83	2	148.00	1	117.83	3	99.67	3
SST983	60.00	12	98.00	4	45.00	12	41.00	12	54.00	7	57.67	6	208.67	1	111.00	10	146.67	2	156.67	9	160.00	5	141.67	1	134.33	2	104.50	9	95.33	0	98.83	10	107.00	5	99.67	2
ENVIRONMENTAL MEAN	81.500		86.472		76.389		70.833		59.972		58.750		142.167		143.639		118.694		162.111		149.556		116.933		111.833		115.056		97.042		116.472		104.764		87.792	
CV (%)	20.05%		12.83%		20.21%		18.97%		20.63%		27.33%		15.54%		7.38%		13.31%		10.89%		12.19%		14.56%		17.12%		10.10%		16.58%		14.91%		15.61%		19.18%	
LSD	22.9096		15.5531		21.3656		18.8385		17.3465		22.5079		30.9709		14.8587		22.15		24.765		25.5539		23.8481		18.5534		11.2673		15.5983		16.8357		15.8541		16.3219	

ALVEO P/L (APL)

	2004										2005										2004 + 2005									
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	1.03	5	1.55	2	1.02	9	1.51	4	2.66	2	2.41	5	0.58	7	0.34	12	0.60	10	0.48	5	0.42	7	0.65	9	0.81	5	0.95	4	0.81	11	1.00	5	1.54	1	1.53	5
SST966	1.01	7	0.98	7	1.42	3	1.98	2	1.81	6	2.08	7	1.68	1	0.38	10	0.79	4	0.47	6	0.77	2	0.89	3	1.35	2	0.68	10	1.11	3	1.22	2	1.29	5	1.49	6
B966	1.20	2	1.28	5	1.28	5	1.44	5	2.60	3	2.29	6	0.37	9	0.38	11	0.98	1	0.57	3	0.35	10	0.65	8	0.78	8	0.83	7	1.13	2	1.01	4	1.48	3	1.47	7
B972	0.78	11	0.64	12	0.96	12	0.71	12	1.29	10	1.01	12	0.35	10	0.72	6	0.64	8	0.86	1	0.38	8	0.63	10	0.57	12	0.68	11	0.80	12	0.78	9	0.84	11	0.82	12
R2	1.16	3	0.75	11	0.97	11	1.31	6	1.40	8	2.55	4	0.93	2	0.47	8	0.86	3	0.55	4	0.78	1	0.87	4	1.04	3	0.61	12	0.91	7	0.93	8	1.09	8	1.71	4
R5	0.92	8	1.36	3	1.12	8	1.22	8	1.70	7	1.72	8	0.69	6	0.47	9	0.89	2	0.43	8	0.75	3	1.18	1	0.81	6	0.91	5	1.00	6	0.82	9	1.23	6	1.45	8
R6	0.58	12	0.75	10	1.01	10	1.17	9	1.24	11	2.80	2	0.71	5	0.68	7	0.65	7	0.59	2	0.52	4	0.90	2	0.64	10	0.72	9	0.83	10	0.88	7	0.88	10	1.85	1
A972/R2	0.87	9	1.72	1	1.42	2	1.81	3	2.70	1	2.72	3	0.74	4	0.78	4	0.70	6	0.40	10	0.37	9	0.80	6	0.81	7	1.25	2	1.06	4	1.11	3	1.54	2	1.76	3
A972/R5	1.03	6	1.22	6	1.31	4	1.29	7	1.85	5	2.91	1	0.84	3	0.94	2	0.79	5	0.42	9	0.44	6	0.72	7	0.94	4	1.08	3	1.05	5	0.86	8	1.14	7	1.81	2
A972/R6	1.04	4	1.33	4	1.13	7	1.17	10	1.39	9	1.65	9	0.46	8	1.27	1	0.62	9	0.34	11	0.45	5	0.86	5	0.75	9	1.30	1	0.87	8	0.75	11	0.92	9	1.26	9
SST972	0.86	10	0.83	9	1.15	6	0.86	11	0.70	12	1.60	10	0.31	12	0.74	5	0.53	11	0.30	12	0.35	11	0.51	12	0.59	11	0.78	8	0.84	9	0.58	12	0.53	12	1.06	10
SST983	2.60	1	0.90	8	3.76	1	3.69	1	2.33	4	1.53	11	0.33	11	0.89	3	0.51	12	0.46	7	0.35	12	0.57	11	1.46	1	0.90	6	2.14	1	2.08	1	1.34	4	1.05	11
ENVIRONMENTAL MEAN	1.091		1.108		1.379		1.514		1.807		2.106		0.666		0.671		0.711		0.468		0.496		0.770		0.878		0.889		1.046		1.001		1.151		1.438	
CV (%)	40.08%		24.69%		41.36%		35.08%		48.84%		41.53%		68.80%		10.36%		16.36%		14.46%		26.75%		16.79%		49.66%		23.89%		38.78%		40.64%		55.80%		45.78%	
LSD	0.6133		0.3835		0.8003		0.7446		1.2371		1.2268		0.642		0.0976		0.163		0.099		0.1855		0.1813		0.4247		0.2059		0.3928		0.3943		0.6223		0.6382	

ALVEO STRENGHT (A-W)

	2004										2005										2004 + 2005									
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	49.37	1	54.93	1	45.63	1	49.13	1	34.23	1	39.30	1	49.60	1	67.63	1	63.73	1	63.70	1	52.03	2	52.23	1	49.48	1	61.28	1	54.68	1	56.42	1	43.13	1	45.77	1
SST966	33.57	5	35.97	7	33.33	5	34.4	3	22.90	10	24.37	11	32.67	11	49.07	8	45.17	3	56.27	3	40.00	5	42.80	5	33.12	11	42.52	8	39.25	5	48.33	3	31.45	10	33.68	7
B966	39.47	3	44.77	2	41.3	2	33.87	4	27.63	8	36.77	4	41.33	6	64.80	2	40.87	8	48.23	7	52.63	1	38.73	7	40.40	3	54.78	2	41.08	2	41.05	7	40.13	2	37.75	4
B972	25.5	12	34.17	9	34.67	4	32.1	8	21.80	12	33.57	5	46.97	4	52.70	4	43.10	7	38.07	12	49.63	3	50.90	2	36.23	6	43.43	6	38.88	7	35.08	10	35.72	4	42.23	2
R2	27.03	11	36.63	6	31.6	8	33.3	5	28.30	7	23.83	12	47.93	3	50.67	5	48.83	2	61.07	2	47.13	4	42.67	6	37.48	5	43.65	5	40.22	4	47.18	2	37.72	3	33.25	8
R5	30.33	9	32.1	12	28.9	11	20.2	11	22.50	11	25.70	10	38.17	7	42.27	11	34.27	11	45.00	9	28.43	12	37.93	8	34.25	8	37.18	12	31.58	11	32.60	12	25.47	12	31.82	9
R6	27.17	10	38.87	5	28	12	19.57	12	26.30	9	26.07	9	36.43	9	38.17	12	35.83	10	50.53	6	34.23	10	29.57	12	31.80	12	38.52	11	31.77	10	35.05	11	30.27	11	27.82	12
A972/R2	33.37	6	32.23	11	33.3	6	33.2	6	29.70	5	37.73	3	34.60	10	53.77	3	45.13	4	53.23	4	39.57	6	36.63	9	33.98	9	43.00	7	39.22	6	43.22	4	34.63	6	37.18	5
A972/R5	36.27	4	34.9	8	29.8	9	32.13	7	32.37	4	30.57	7	30.47	12	45.50	9	38.27	9	44.00	10	35.20	8	31.80	11	33.37	10	40.20	10	34.03	9	38.07	8	33.78	8	31.18	11
A972/R6	33.27	7	43.9	3	31.97	7	31.5	10	33.63	3	30.57	6	37.33	8	44.37	10	29.83	12	41.87	11	34.07	11	32.60	10	35.30	7	44.13	4	30.90	12	36.68	9	33.85	7	31.58	10
SST972	32.63	8	32.3	10	29.2	10	31.93	9	29.63	6	29.27	8	45.10	5	49.77	6	43.37	6	52.17	5	34.27	9	43.17	4	38.87	4	41.03	9	36.28	9	42.05	5	31.95	9	36.22	6
SST983	45.17	2	39.67	4	36.47	3	36.3	2	34.1	2	38.47	2	48.37	2	49.23	7	45.00	5	47.60	8	36.60	7	45.93	3	46.77	2	44.55	3	40.73	3	42.06	6	35.35	5	42.20	3
ENVIRONMENTAL MEAN	34.428		38.386		33.697		32.303		28.592		31.350		40.747		50.661		42.758		50.161		40.317		40.431		37.588		44.524		38.228		41.232		34.454		35.890	
CV (%)	12.29%		12.61%		13.50%		13.90%		8.82%		11.70%		18.77%		4.22%		8.07%		9.89%		9.66%		7.10%		16.40%		0.31%		10.69%		11.25%		0.37%		9.33%	
LSD	5.93%		6.7869		6.3784		6.2966		3.5348		5.1419		10.7248		3.0005		4.84		6.9509		5.4614		4.0244		5.9758		4.0167		3.961		4.4937		3.1286		3.2437	

CONSISTO WATER ABSORPTION (CABS)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	57.87	7	59.83	1	59.60	3	60.07	1	60.33	1	58.63	6	59.63	5	59.47	7	60.70	1	58.13	11	58.13	3	60.70	4	58.75	7	59.65	2	60.15	1	59.10	2	59.23	1	59.67	6
SST966	57.80	8	57.43	12	57.53	12	57.50	10	56.37	12	57.90	11	56.97	12	59.57	6	60.17	3	60.17	2	58.37	2	60.80	2	57.38	12	58.50	10	58.85	6	58.83	3	57.37	10	59.35	7
B966	60.37	1	59.20	3	60.17	1	59.83	2	58.83	2	61.07	1	58.23	10	58.43	9	59.93	4	61.87	1	57.00	10	59.57	10	59.30	3	58.82	7	60.05	3	60.85	1	58.42	4	60.32	2
B972	59.30	2	59.00	6	59.83	2	58.30	4	59.40	3	59.73	3	59.83	4	58.33	11	60.40	2	59.10	6	57.80	6	61.23	1	59.57	1	58.67	8	60.12	2	58.70	4	58.60	2	60.48	1
R2	57.33	10	57.83	11	58.07	10	57.50	11	56.53	11	57.97	10	58.40	9	58.20	12	58.97	9	59.63	3	57.93	5	59.77	9	57.87	10	58.02	12	58.52	10	58.57	7	57.23	11	58.87	11
R5	58.37	5	58.47	7	58.67	5	58.03	7	56.97	10	60.30	2	59.30	8	58.37	10	59.07	7	58.40	9	57.97	4	60.13	6	58.83	5	58.42	11	58.87	5	58.22	10	57.47	9	60.22	3
R6	57.30	11	58.30	8	58.60	6	58.07	6	57.87	8	58.37	8	57.97	11	58.83	8	58.30	12	59.27	4	59.07	1	60.13	7	57.63	11	58.57	9	58.45	11	58.67	6	58.47	3	59.25	9
A972/R2	57.07	12	59.07	5	58.10	9	57.90	8	57.07	9	57.57	12	59.83	3	60.20	2	59.03	8	58.93	7	57.40	9	60.00	8	58.45	9	59.63	3	58.57	8	58.42	8	57.23	12	58.78	12
A972/R5	58.73	3	59.23	2	58.10	8	58.17	5	58.80	5	59.57	5	60.17	1	59.87	5	59.23	6	59.17	5	57.67	8	60.43	5	59.45	2	59.55	4	58.67	7	58.67	5	58.23	6	60.00	4
A972/R6	58.17	6	59.10	4	58.53	7	57.80	9	58.93	4	58.60	7	59.50	6	60.50	1	58.57	10	58.47	8	57.73	7	59.27	11	58.83	6	59.80	1	58.55	9	58.13	11	58.33	6	58.93	10
SST972	57.73	9	58.20	9	57.93	11	56.73	12	58.33	6	59.63	4	59.37	7	60.17	3	58.57	11	57.33	12	56.63	12	58.93	12	58.55	8	59.18	5	58.25	12	57.03	12	57.48	8	59.28	8
SST983	58.67	4	58.03	10	59.37	4	58.57	3	58.30	7	58.23	9	59.93	2	60.07	4	59.30	5	58.23	10	56.90	11	60.77	3	59.30	4	59.05	6	59.33	4	58.40	9	57.60	7	59.50	6
ENVIRONMENTAL MEAN	58.225		58.642		58.708		58.206		58.228		58.964		59.094		59.333		59.393		59.058		57.717		60.144		58.660		58.988		59.031		58.632		57.972		59.554	
CV (%)	1.36%		1.21%		1.21%		1.21%		1.37%		1.89%		2.08%		1.61%		0.73%		0.71%		1.46%		1.28%		1.75%		1.40%		0.98%		1.00%		1.38%		1.03%	
LSD	1.1106		0.9943		0.9955		0.9886		1.1156		1.5837		1.7193		1.3401		0.6104		0.5854		1.1811		1.0768		0.9942		0.8031		0.5616		0.5656		0.7771		0.9422	

MIXOGRAPH MIXING TIME (MMT)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	3.42	3	3.75	1	3.47	2	2.54	11	3.04	8	3.30	1	2.58	3	2.73	1	2.87	2	3.10	2	3.13	2	2.68	1	3.00	3	3.24	1	3.17	2	2.82	5	3.09	4	2.99	1
SST966	3.18	6	3.42	4	3.31	3	3.25	5	3.79	2	2.88	5	2.48	4	2.08	8	2.12	7	2.50	7	2.53	5	2.07	6	2.83	6	2.75	5	2.71	4	2.88	4	3.16	2	2.47	6
B966	3.12	8	2.94	11	2.61	10	3.26	4	3.06	8	2.55	9	1.88	10	2.07	10	2.00	8	2.03	12	2.27	9	1.65	12	2.50	11	2.50	10	2.31	10	2.65	9	2.66	9	2.10	11
B972	2.87	11	2.97	10	2.89	5	2.92	7	2.38	12	2.39	11	2.15	8	2.23	4	2.45	3	2.50	8	2.73	3	2.02	8	2.51	10	2.60	8	2.67	5	2.71	7	2.56	12	2.21	8
R2	3.13	7	3.36	5	2.73	7	2.72	8	3.78	3	2.64	8	2.88	2	2.35	2	2.15	6	2.73	4	1.92	11	2.12	5	3.01	2	2.85	2	2.44	7	2.73	6	2.85	6	2.38	7
R5	2.82	12	2.99	9	2.11	12	2.33	12	3.81	1	2.18	12	2.33	5	1.69	12	1.77	12	2.07	11	1.70	12	1.67	11	2.58	8	2.34	12	1.94	12	2.20	12	2.75	7	1.93	12
R6	2.96	10	2.92	12	2.42	11	2.55	10	3.21	6	2.54	10	2.90	1	2.26	3	1.92	10	2.70	5	1.93	10	1.78	9	2.93	4	2.59	9	2.17	11	2.63	10	2.57	11	2.16	10
A972/R2	3.77	1	3.58	2	2.88	6	3.39	3	3.59	4	2.97	4	2.28	6	2.08	9	2.33	5	2.60	6	2.65	4	2.22	4	3.03	1	2.83	4	2.61	6	3.00	3	3.12	3	2.59	4
A972/R5	3.05	9	3.00	8	2.72	8	2.93	6	2.94	10	2.67	7	1.70	12	1.94	11	1.90	11	2.37	10	2.43	8	1.73	10	2.38	12	2.47	11	2.31	9	2.65	8	2.69	8	2.20	9
A972/R6	3.38	4	3.04	7	2.69	9	2.60	9	2.66	11	2.84	6	1.90	8	2.21	5	1.95	9	2.40	9	2.47	7	2.03	7	2.64	7	2.63	7	2.32	8	2.60	11	2.58	10	2.44	6
SST972	3.63	2	3.48	3	3.57	1	3.52	2	3.27	5	3.01	3	2.22	7	2.19	6	2.98	1	3.13	1	3.17	1	2.22	3	2.92	4	2.84	3	3.28	1	3.33	1	3.22	1	2.62	3
SST983	3.27	5	3.31	6	3.12	4	3.69	1	3.23	7	3.11	2	1.87	11	2.12	7	2.38	4	2.63	3	2.52	6	2.22	2	2.57	9	2.72	6	2.75	3	3.26	2	2.86	5	2.67	2
ENVIRONMENTAL MEAN	3.217		3.230		2.878		2.976		0.032		2.758		2.265		2.162		2.235		2.581		2.454		2.033		2.741		2.696		2.556		2.776		2.842		2.395	
CV (%)	11.85%		9.21%		7.55%		19.03%		12.61%		8.18%		14.77%		11.74%		7.45%		8.44%		10.35%		6.96%		13.36%		10.10%		7.61%		15.23%		11.98%		8.06%	
LSD	0.5347		0.4172		0.3047		0.794		0.5708		0.3164		0.4091		0.3559		0.2333		0.3053		0.356		0.1983		0.355		0.2638		0.1886		0.41		0.3299		0.1871	

Table 3.12 : Genotype and environment means of individual localities planted during 2004-2005 of the WHBPT trial

TEST WEIGHT (HLM)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	74.43	7	76.14	2	78.63	1	73.43	7	78.03	2	77.02	2	80.32	1	78.09	6	78.45	7	78.47	2	75.34	10	79.83	7	77.37	1	77.11	3	78.54	5	75.66	3	76.68	7	78.42	5
SST966	75.15	4	75.75	4	78.53	2	76.11	1	78.06	1	76.70	4	77.56	4	78.24	5	79.61	4	79.03	1	80.19	1	80.05	4	76.36	3	76.99	4	79.07	2	77.57	1	79.14	1	78.38	6
SST399	74.47	5	74.06	8	75.53	10	73.17	8	74.33	11	75.70	9	76.81	6	78.32	4	74.51	12	76.83	7	74.12	12	79.06	10	75.64	6	76.19	7	75.02	12	75.00	8	74.23	12	77.38	7
B966	75.83	1	76.67	1	72.28	3	74.72	3	77.91	3	77.63	1	76.26	9	79.04	2	80.08	2	76.42	9	75.73	9	80.03	5	76.05	5	77.85	1	79.18	1	75.57	7	76.82	5	78.83	2
B972	73.43	10	73.77	10	76.47	9	72.95	9	76.60	6	75.73	8	76.42	8	73.10	12	77.83	6	76.99	5	76.13	8	78.33	11	74.92	8	73.43	11	77.15	8	74.97	9	76.36	8	77.03	8
R2	72.34	12	72.47	12	74.27	12	71.85	12	74.91	10	74.49	11	76.73	7	74.07	11	77.63	10	73.56	12	74.56	11	79.52	8	74.53	11	73.27	12	75.96	11	72.71	12	74.73	11	77.01	10
R5	73.65	9	74.06	7	75.29	11	71.99	11	75.32	9	73.80	12	74.45	11	74.47	10	77.67	9	76.83	6	77.20	6	79.32	9	74.05	12	74.26	10	76.48	10	74.41	10	76.26	9	76.45	11
R6	74.45	6	73.99	9	76.50	6	72.86	10	74.09	12	74.58	10	74.83	10	77.19	9	77.11	11	74.78	11	76.59	7	80.01	6	74.64	9	75.59	8	76.80	9	73.82	11	75.34	10	77.30	8
SST935 (A966/R2)	74.30	8	75.11	6	77.63	6	74.71	4	76.81	5	76.49	5	78.34	2	78.71	3	79.41	5	76.77	8	79.66	2	81.03	3	76.32	4	76.91	5	78.52	6	75.74	6	78.23	2	78.76	3
A966/R5	75.79	2	75.64	5	77.93	4	74.61	5	76.11	8	76.92	3	77.74	3	78.02	7	80.13	1	77.17	4	77.44	5	81.43	1	76.76	2	76.83	6	79.03	3	75.89	4	76.78	6	79.18	1
SST946 (A966/R6)	75.67	3	75.99	3	77.83	5	74.45	6	76.97	4	76.41	6	73.49	12	79.09	1	79.86	3	78.00	3	78.45	3	81.05	2	74.58	10	77.54	2	78.85	4	76.23	2	77.71	3	78.73	4
SST972	73.37	11	73.07	11	76.63	7	75.78	2	76.45	7	75.87	7	76.84	5	77.38	8	78.59	6	75.85	10	78.01	4	76.87	12	75.10	7	75.23	9	77.61	7	75.82	5	77.23	4	76.37	12
ENVIRONMENTAL MEAN	74.406		74.728		76.959		73.885		76.301		75.945		76.649		77.142		78.408		76.724		76.950		79.712		75.528		75.935		77.683		75.305		76.625		77.829	
CV (%)	0.66%		0.66%		1.06%		0.74%		0.72%		0.67%		1.52%		3.66%		0.76%		0.79%		2.75%		0.80%		1.21%		2.61%		0.96%		0.77%		2.09%		0.70%	
LSD	0.6864		0.6939		1.1434		0.7637		0.7666		0.6067		1.6354		3.9575		0.8333		0.8515		2.9708		0.8928		0.8883		1.9228		0.7242		0.8613		1.5496		0.5279	

MOISTURE (MOIST)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	11.83	2	11.90	1	11.13	3	11.20	8	11.00	10	11.30	4	11.10	8	10.63	4	10.77	3	11.33	6	11.37	1	10.63	4	11.47	3	11.27	1	10.95	3	11.27	6	11.18	2	10.97	3
SST966	10.50	12	10.63	11	10.87	10	10.97	11	11.03	8	10.73	10	11.30	4	10.43	9	10.53	10	11.33	6	11.33	2	10.47	10	10.90	11	10.53	11	10.70	11	11.15	10	11.18	3	10.60	11
SST399	10.53	11	11.00	9	10.83	12	10.93	12	11.03	7	10.70	11	11.63	1	10.67	2	11.07	1	11.40	2	11.27	3	10.83	2	11.08	10	10.83	7	10.95	2	11.17	9	11.15	4	10.77	6
B966	11.87	1	11.37	5	11.03	5	11.23	6	10.97	11	10.80	8	11.33	3	10.43	10	10.47	11	11.37	4	11.13	6	10.43	11	11.60	1	10.90	5	10.75	9	11.30	5	11.05	10	10.62	10
B972	11.60	7	11.30	6	11.00	7	11.20	7	10.93	12	11.03	5	11.00	11	10.07	12	10.37	12	10.97	11	11.07	9	10.27	12	11.30	8	10.68	10	10.68	12	11.08	12	11.00	12	10.65	9
R2	11.57	8	11.10	8	11.13	2	11.10	10	11.10	6	10.80	9	11.37	2	10.63	3	10.67	4	11.13	10	11.03	10	10.53	6	11.47	2	10.87	8	10.90	5	11.12	11	11.07	9	10.67	8
R5	11.70	3	10.97	10	10.87	11	11.13	9	11.20	2	10.67	12	11.20	6	10.57	5	10.57	9	11.27	9	11.00	11	10.50	7	11.45	5	10.77	9	10.72	10	11.20	7	11.10	8	10.58	12
R6	11.47	9	11.20	7	11.10	4	11.27	5	11.03	9	11.00	6	11.07	9	10.47	8	10.63	6	11.40	3	11.00	12	10.53	5	11.27	9	10.83	8	10.87	6	11.33	4	11.02	11	10.77	7
SST935 (A966/R2)	11.63	6	11.67	3	10.93	9	11.40	2	11.10	5	11.33	3	11.03	10	10.23	11	10.57	8	11.33	7	11.10	7	10.50	8	11.33	7	10.95	4	10.75	8	11.37	3	11.10	7	10.92	4
A966/R5	11.67	5	11.67	4	11.00	6	11.40	3	11.10	4	11.57	2	11.23	5	10.50	7	10.63	7	11.37	5	11.17	4	10.50	9	11.45	4	11.08	3	10.82	7	11.38	2	11.13	6	11.03	2
SST946 (A966/R6)	11.67	4	11.80	2	11.47	1	11.63	1	11.17	3	10.93	7	11.17	7	10.50	6	10.63	5	11.43	1	11.13	5	10.67	3	11.42	6	11.16	2	11.06	1	11.53	1	11.15	5	10.80	5
SST972	10.70	10	10.20	12	11.00	8	11.40	4	11.30	1	11.70	1	11.00	12	10.77	1	10.80	2	10.97	12	11.10	8	11.03	1	10.85	12	10.48	12	10.90	4	11.18	8	11.20	1	11.37	1
ENVIRONMENTAL MEAN	11.394		11.233		11.031		11.239		11.081		11.047		11.203		10.492		10.642		11.278		11.142		10.575		11.299		10.863		10.836		11.257		11.111		10.811	
CV (%)	2.19%		3.37%		2.70%		2.66%		2.16%		2.76%		0.94%		1.24%		0.87%		1.00%		0.95%		0.96%		1.66%		3.07%		2.28%		2.78%		2.57%		2.40%	
LSD	0.35		0.5307		0.4177		0.4191		0.335		0.4279		0.1483		0.183		0.1291		0.1586		0.1485		0.1428		0.182		0.323		0.2399		0.3032		0.2763		0.2519	

SKCS-HI (HI)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	74.70	5	67.71	9	74.92	6	67.92	9	70.52	10	64.59	9	69.93	10	70.55	9	73.43	10	78.09	11	78.01	8	67.01	10	72.32	9	69.13	9	74.18	10	73.01	11	74.27	11	65.80	11
SST966	62.84	12	64.39	11	71.23	11	64.19	11	70.31	11	77.62	1	75.30	6	72.33	6	75.00	7	82.61	6	79.82	3	66.62	11	69.07	10	68.36	10	73.11	11	73.40	10	75.06	10	72.12	3
SST399	89.83	1	80.66	1	81.55	1	76.36	1	74.99	8	57.04	12	85.90	1	78.20	1	88.39	1	81.46	9	90.5	1	82.89	1	87.87	1	79.43	1	84.97	1	78.91	2	82.75	1	69.97	6
B966	74.59	6	68.25	8	75.58	5	70.10	8	75.59	7	65.49	8	63.24	12	63.76	11	74.96	8	78.12	10	78.44	7	70.01	7	68.92	11	66.01	11	75.27	7	74.11	9	77.01	7	67.74	8
B972	77.63	3	69.26	7	78.11	3	70.76	4	77.24	4	72.09	2	71.92	9	73.23	4	77.94	4	87.36	1	78.87	6	81.70	2	74.77	4	71.25	5	78.02	4	79.06	1	78.06	4	76.90	1
R2	70.09	10	71.66	3	77.02	4	64.58	10	79.40	2	64.27	10	76.83	3	71.60	7	74.67	9	84.04	3	74.98	11	69.10	8	73.46	6	71.63	3	75.85	6	74.31	8	77.19	6	66.68	10
R5	79.10	2	74.63	2	75.34	7	70.52	6	79.46	1	66.85	4	77.00	2	73.89	2	81.41	2	84.61	2	80.19	2	76.50	4	78.05	2	74.26	2	78.38	3	77.57	4	79.83	2	71.68	4
R6	73.54	7	69.56	5	79.34	2	70.52	5	78.97	3	68.46	3	72.05	8	73.60	3	79.45	3	82.91	6	79.45	4	77.95	3	72.79	7	71.58	4	79.39	2	76.72	7	79.21	3	73.21	2
SST935 (A966/R2)	72.20	9	66.76	10	74.01	10	74.26	2	76.32	6	66.39	7	76.27	5	73.10	5	76.45	6	82.87	7	77.67	10	67.35	9	74.24	5	69.93	7	75.23	8	78.58	3	77.00	8	66.87	9
A966/R5	72.83	8	69.48	6	75.74	5	71.04	3	74.87	9	66.45	6	72.25	7	71.09	8	72.73	11	83.70	4	77.76	9	70.98	6	72.54	8	70.28	6	74.24	9	77.37	5	76.31	9	68.71	7
SST946 (A966/R6)	74.95	4	70.26	4	74.78	9	70.20	7	76.49	5	66.67	5	76.80	4	69.05	10	77.67	5	83.64	5	78.97	5	74.05	5	75.87	3	69.66	8	76.19	5	76.92	6	77.73	5	70.36	5
SST972	64.37	11	60.15	12	62.93	12	59.63	12	68.52	12	61.24	11	69.73	11	59.66	12	60.62	12	64.66	12	59.04	12	59.08	12	67.05	12	59.91	12	61.78	12	62.29	12	63.70	12	60.16	12
ENVIRONMENTAL MEAN	73.889		69.398		75.039		69.175		75.223		66.430		73.936		70.839		76.060		81.199		77.809		71.936		73.912		70.118		75.550		75.187		76.516		69.183	
CV (%)	3.42%		3.52%		3.02%		6.19%		5.05%		6.46%		4.34%		3.43%		2.82%		5.98%		4.82%		3.86%		4.05%		3.50%		3.22%		6.69%		5.18%		5.13%	
LSD	3.5465		3.4232		3.8084		6.0044		5.3293		6.013		4.4944		3.4065		3.003		6.8103		5.2557		3.8897		2.8991		2.378		2.3613		4.8710		3.841		3.4372	

SKCS-DIAMETER (DIAM)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	2.12	10	2.37	6	2.52	2	2.42	4	2.64	2	2.43	4	2.70	1	2.50	2	2.51	4	2.14	10	2.28	6	2.55	7	2.41	4	2.44	5	2.51	3	2.28	9	2.46	3	2.49	4
SST966	2.25	4	2.38	4	2.44	4	2.46	3	2.53	4	2.29	10	2.57	7	2.50	3	2.51	3	2.27	3	2.28	5	2.66	1	2.41	5	2.44	4	2.48	4	2.37	3	2.40	4	2.47	5
SST399	2.14	8	2.36	9	2.35	7	2.30	10	2.32	9	2.47	1	2.65	2	2.39	8	2.34	10	2.27	4	2.34	2	2.66	2	2.40	6	2.37	9	2.35	9	2.29	8	2.33	9	2.56	1
B966	2.23	5	2.33	10	2.36	6	2.32	9	2.41	8	2.33	8	2.42	11	2.24	12	2.44	8	2.26	5	2.28	7	2.38	12	2.33	10	2.29	11	2.40	6	2.29	6	2.35	8	2.35	12
B972	2.30	1	2.38	5	2.51	3	2.51	2	2.67	1	2.46	3	2.60	5	2.39	9	2.54	2	2.25	6	2.28	8	2.56	6	2.45	2	2.38	8	2.53	2	2.38	2	2.48	2	2.51	3
R2	2.11	11	2.44	2	2.26	10	2.33	8	2.25	10	2.35	5	2.56	9	2.43	6	2.48	5	2.13	11	2.29	4	2.58	5	2.33	9	2.44	3	2.37	8	2.23	10	2.27	10	2.46	7
R5	2.10	12	2.24	12	2.29	9	2.23	11	2.21	11	2.28	11	2.41	12	2.30	11	2.24	12	2.10	12	2.16	12	2.43	10	2.25	12	2.27	12	2.26	11	2.16	12	2.19	12	2.36	10
R6	2.13	9	2.29	11	2.19	12	2.16	12	2.16	12	2.28	12	2.49	10	2.31	10	2.30	11	2.24	8	2.24	10	2.42	11	2.31	11	2.30	10	2.25	12	2.20	11	2.20	11	2.35	11
SST935 (A966/R2)	2.27	3	2.36	8	2.37	5	2.40	6	2.48	5	2.33	9	2.56	8	2.43	7	2.46	6	2.25	7	2.27	9	2.53	9	2.42	3	2.40	7	2.42	5	2.32	5	2.38	5	2.43	9
A966/R5	2.17	6	2.43	3	2.24	11	2.40	5	2.45	7	2.34	7	2.58	6	2.45	4	2.40	9	2.28	2	2.29	3	2.59	3	2.38	8	2.44	2	2.32	10	2.34	4	2.37	6	2.47	6
SST946 (A966/R6)	2.15	7	2.36	7	2.30	8	2.37	7	2.48	6	2.34	6	2.60	4	2.45	5	2.45	7	2.20	9	2.24	11	2.55	8	2.38	7	2.41	6	2.38	7	2.29	7	2.36	7	2.44	8
SST972	2.28	2	2.68	1	2.58	1	2.55	1	2.61	3	2.47	2	2.65	3	2.60	1	2.72	1	2.38	1	2.40	1	2.58	4	2.47	1	2.64	1	2.65	1	2.47	1	2.51	1	2.52	2
ENVIRONMENTAL MEAN	2.188		2.384		2.368		2.371		2.435		2.363		2.566		2.416		2.449		2.232		2.278		2.541		2.377		2.400		2.408		2.302		2.357		2.452	
CV (%)	2.66%		4.04%		3.09%		3.13%		3.66%		2.63%		3.19%		2.34%		2.44%		3.77%		3.66%		3.75%		3.10%		3.22%		2.82%		3.41%		3.68%		3.31%	
LSD	0.0879		0.135		0.1025		0.1041		0.1248		0.097		0.115		0.0791		0.0837		0.118		0.1177		0.1337		0.0714		0.0748		0.0657		0.076		0.084		0.0787	

SKCS-GRAM (G)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	28.32	10	32.63	10	35.74	2	33.11	4	38.56	1	35.23	3	42.75	1	36.06	6	37.29	3	30.35	8	32.48	2	38.05	7	35.53	3	34.35	7	36.51	2	31.73	6	35.52	2	36.64	3
SST966	30.82	4	33.67	5	33.94	6	32.91	6	35.35	7	28.66	12	39.26	5	36.66	2	37.65	2	32.37	2	31.12	8	41.86	1	36.04	5	35.17	3	35.80	3	32.04	3	33.24	7	35.26	8
SST399	25.90	12	29.94	12	30.86	11	28.31	12	28.96	12	35.32	2	35.63	12	30.69	11	29.38	12	27.37	12	30.58	9	35.91	10	30.77	12	30.31	12	30.12	12	27.84	12	29.77	12	35.61	7
B966	30.90	3	33.02	8	33.99	5	32.98	5	34.01	8	34.02	7	35.84	11	29.08	12	34.65	9	31.40	5	31.62	6	33.62	12	33.37	8	31.05	11	34.32	6	32.19	5	32.82	8	33.82	12
B972	30.72	5	32.72	9	35.02	3	32.71	8	36.44	3	34.97	4	36.94	10	32.07	10	36.11	6	29.97	9	30.14	11	36.14	11	33.83	7	32.40	10	35.57	4	31.34	8	33.29	6	35.06	9
R2	27.62	11	33.72	4	31.37	10	30.99	9	30.87	9	32.80	9	38.34	7	36.19	5	36.33	5	29.16	10	32.36	3	39.67	2	32.98	10	34.96	5	33.85	9	30.08	10	31.61	9	36.24	5
R5	28.54	9	30.84	11	32.80	7	29.73	10	30.18	10	32.27	11	37.06	9	34.06	8	32.27	11	28.74	11	29.95	12	36.09	9	32.80	11	32.45	9	32.54	10	29.24	11	30.07	11	34.18	11
R6	28.83	8	33.52	6	29.51	12	29.26	11	30.06	11	32.55	10	37.53	8	33.27	9	33.71	10	30.98	6	30.48	10	36.30	8	33.23	9	33.39	8	31.61	11	30.12	9	30.27	10	34.42	10
SST935 (A966/R2)	30.92	2	33.37	7	34.23	4	33.33	3	35.67	6	33.22	8	38.94	6	35.48	7	36.38	4	31.47	4	31.68	5	38.86	5	34.93	6	34.43	6	35.31	5	32.40	4	33.67	4	36.04	6
A966/R5	31.21	1	35.00	2	31.88	9	33.85	2	35.78	5	34.13	6	39.97	4	36.62	3	35.82	7	31.52	3	32.30	4	39.25	3	35.59	2	35.91	2	33.85	8	32.69	2	34.04	3	36.69	2
SST946 (A966/R6)	30.07	7	33.93	3	32.08	8	32.79	7	35.82	4	34.33	5	40.09	3	36.35	4	35.66	8	30.53	7	31.26	7	38.91	4	35.08	4	35.14	4	33.87	7	31.66	7	33.54	5	36.62	4
SST972	30.42	6	38.58	1	36.98	1	35.13	1	37.04	2	35.33	1	41.04	2	37.16	1	40.51	1	33.20	1	34.11	1	38.73	6	35.73	1	37.87	1	38.75	1	34.16	1	35.58	1	37.03	1
ENVIRONMENTAL MEAN	29.521		33.412		33.200		32.092		34.062		33.569		38.624		34.474		35.481		30.589		31.507		37.698		34.073		33.943		34.340		31.341		32.785		35.634	
CV (%)	4.47%		5.35%		6.14%		4.90%		4.65%		3.55%		4.62%		3.77%		3.38%		5.18%		7.57%		4.66%		4.64%		4.54%		4.99%		5.18%		6.21%		4.38%	
LSD	1.8492		2.5046		2.8597		2.2066		2.2195		1.6692		2.5003		1.8245		1.6837		2.2234		3.3437		2.6226		1.5307		1.4931		1.6599		1.5724		1.9723		1.5057	

BREAK FLOUR YIELD (BFLY)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	20.19	3	20.00	2	18.50	1	19.04	1	18.55	2	19.44	2	17.95	9	23.02	2	20.09	2	19.40	5	21.09	2	21.18	2	19.07	5	21.51	2	19.30	2	19.22	1	19.82	1	20.31	2
SST966	20.45	1	20.14	1	17.22	4	18.17	2	18.15	3	18.90	4	18.74	5	21.06	6	18.76	5	19.91	2	18.66	4	19.50	9	19.60	3	20.60	3	17.99	4	19.04	3	18.56	5	19.20	5
SST399	19.01	5	18.98	4	16.10	6	17.50	3	20.13	1	20.05	1	16.44	11	19.37	10	17.66	9	18.42	10	17.02	12	20.12	6	17.73	11	19.17	7	17.01	9	17.96	5	18.58	4	20.08	3
B966	20.00	4	19.37	3	17.74	3	16.63	5	16.97	4	19.33	3	21.50	1	27.78	1	21.57	1	21.63	1	20.61	3	25.31	1	20.75	1	23.58	1	19.65	1	19.13	2	18.79	3	22.32	1
B972	15.22	12	17.94	6	14.03	12	14.73	12	13.82	12	16.61	12	16.15	12	18.73	12	17.51	11	17.71	12	17.24	11	20.10	7	15.69	12	18.34	9	15.77	12	16.22	12	15.53	12	17.86	10
R2	18.33	9	15.84	12	14.65	10	16.66	4	15.98	6	17.36	9	17.47	10	20.78	7	18.11	8	18.47	9	18.49	6	20.05	8	17.90	9	18.31	10	16.38	10	17.57	9	17.23	6	18.71	8
R5	18.00	10	16.37	11	14.53	11	16.13	8	15.69	8	16.60	10	18.40	6	19.87	9	17.11	12	19.66	4	18.37	8	17.52	12	18.20	8	18.12	11	15.82	11	18.01	4	17.03	9	17.06	12
R6	17.38	11	16.52	10	15.41	9	15.70	10	15.56	9	16.54	11	18.12	8	20.37	8	19.57	4	19.38	6	17.97	9	18.77	10	17.75	10	18.45	8	17.49	6	17.54	10	16.77	10	17.66	11
SST935 (A966/R2)	18.89	7	18.59	5	15.91	8	16.26	6	15.78	7	18.01	6	18.36	7	21.84	5	18.40	7	19.37	7	18.55	5	20.36	4	18.63	7	20.21	5	17.16	8	17.82	6	17.17	7	19.19	6
A966/R5	18.52	8	17.86	8	16.33	5	15.63	11	14.06	11	18.02	5	19.51	3	22.71	3	19.71	3	19.90	3	18.47	7	20.16	5	19.02	6	20.29	4	18.02	3	17.76	7	16.27	11	19.09	7
SST946 (A966/R6)	18.96	6	17.92	7	15.97	7	15.68	9	16.81	5	17.93	7	20.52	2	22.09	4	18.50	6	19.33	8	17.48	10	21.01	3	19.74	2	20.01	6	17.24	7	17.61	8	17.15	8	19.47	4
SST972	20.20	2	17.08	9	18.12	2	16.19	7	15.50	10	17.62	8	18.86	4	19.02	11	17.72	10	18.09	11	23.93	1	18.28	11	19.53	4	18.05	12	17.92	5	17.14	11	19.71	2	17.96	9
ENVIRONMENTAL MEAN	18.763		18.050		16.214		16.543		16.417		17.952		18.503		21.387		18.742		19.291		19.014		20.196		18.633		19.718		17.478		17.917		17.716		19.074	
CV (%)	5.81%		7.26%		4.59%		6.06%		8.10%		7.89%		3.39%		4.15%		2.43%		3.86%		3.05%		4.30%		5.21%		6.23%		5.16%		6.10%		6.43%		6.87%	
LSD	1.5275		1.8361		1.0428		1.4044		1.865		1.985		0.8783		1.2443		0.6397		1.0445		0.8127		1.2162		0.9411		1.1903		0.8743		1.0601		1.1032		1.27	

FLOUR YIELD (FLY)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	55.76	2	58.69	1	55.47	3	54.78	3	54.58	5	57.83	2	63.67	6	66.37	2	65.49	3	66.22	1	66.22	2	52.83	11	59.72	6	62.53	1	60.48	2	60.50	1	60.40	1	55.33	11
SST966	55.11	5	54.52	9	56.50	2	54.01	4	54.94	4	55.49	6	65.27	2	65.23	4	63.59	8	62.30	11	64.71	4	52.32	12	60.19	3	59.86	6	60.04	3	58.16	9	59.82	3	53.91	12
SST399	57.33	1	56.22	4	53.97	8	53.20	5	55.00	3	56.92	3	64.70	4	58.59	12	63.44	10	64.22	7	62.70	8	67.91	1	61.02	2	57.40	12	58.71	9	58.71	6	58.85	7	62.42	1
B966	55.75	3	56.29	3	54.19	6	52.43	8	53.46	9	56.42	5	64.01	5	66.08	5	65.71	2	64.34	5	60.25	10	66.68	3	59.88	4	60.68	4	59.95	4	58.38	7	56.88	10	61.55	2
B972	54.37	7	54.38	10	51.49	10	53.10	7	53.88	6	58.04	1	62.52	11	31.81	11	63.99	6	65.13	4	66.71	1	64.93	6	58.45	8	58.10	10	57.74	10	59.12	5	60.30	2	61.49	3
R2	50.88	12	54.71	8	50.18	12	52.27	10	52.90	10	54.60	10	62.27	12	64.22	6	63.49	9	61.96	12	63.54	7	65.47	4	56.58	12	59.46	7	56.84	11	56.93	12	58.22	8	60.03	7
R5	53.85	9	52.78	12	50.71	11	51.50	11	52.44	11	53.83	11	63.10	8	62.94	9	61.74	12	62.35	10	57.21	11	62.63	10	54.48	7	57.86	11	56.23	12	57.12	11	54.82	12	57.85	10
R6	53.30	11	54.33	11	53.18	9	50.74	12	52.25	12	53.07	12	63.06	9	63.45	8	64.66	4	65.37	2	62.18	9	64.87	7	58.18	11	58.89	8	58.92	8	58.05	10	57.22	9	59.35	9
SST935 (A966/R2)	53.92	8	56.42	2	54.00	7	56.06	1	53.65	7	55.08	7	62.82	10	66.71	1	63.92	7	63.79	9	64.51	5	65.04	5	58.37	9	61.57	2	58.96	7	59.92	2	59.08	6	60.06	6
A966/R5	53.51	10	55.45	6	55.43	4	54.90	2	53.47	8	54.90	9	63.18	7	65.98	3	64.38	5	64.27	6	65.30	3	64.29	8	58.34	10	60.72	3	59.90	6	59.59	3	59.39	5	59.60	8
SST946 (A966/R6)	56.62	4	55.42	7	54.67	5	52.38	9	55.19	2	56.00	8	66.47	1	62.04	10	63.32	11	63.98	8	63.69	6	67.37	2	61.05	1	58.73	9	58.99	6	58.18	8	59.44	4	61.18	4
SST972	54.64	6	56.10	5	56.94	1	53.16	6	56.01	1	56.59	4	64.90	3	63.60	7	65.73	1	66.31	3	65.57	12	63.75	9	59.77	5	59.85	6	61.34	1	59.23	4	55.79	11	60.17	5
ENVIRONMENTAL MEAN	54.504		55.443		53.894		53.210		53.980		55.649		63.831		63.836		64.121		64.103		62.716		63.174		59.167		59.639		59.008		58.657		58.348		59.411	
CV (%)	4.26%		2.65%		1.94%		2.92%		2.45%		2.69%		0.79%		4.32%		0.90%		1.43%		4.16%		1.13%		2.95%		3.63%		1.56%		2.27%		3.65%		1.93%	
LSD	3.2527		2.0614		1.4633		2.179		1.8519		2.0978		0.7049		3.8666		0.8094		1.2813		3.66		0.9996		1.6899		2.097		0.8914		1.2932		2.0648		1.1134	

FALLING NUMBER (HFN)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	378.33	4	367.67	8	393.67	6	341.67	6	396.33	11	384.33	5	357.00	12	328	12	382.33	10	407.00	8	356.33	11	382.00	11	367.67	11	347.83	12	388.00	7	374.33	8	377.33	11	383.17	8
SST966	345.33	10	395.33	2	472.33	1	333.00	10	390.00	12	396.67	4	443.33	5	441.33	6	403.33	6	417.33	4	375.33	9	396.67	4	244.33	7	418.33	2	437.83	2	375.17	7	382.67	10	396.67	3
SST399	343.67	11	335.67	12	437.67	3	339.67	7	401.33	10	402.67	2	425.00	8	442.67	4	399.67	7	416.67	5	380.00	4	389.67	8	384.33	9	389.17	9	418.67	5	378.17	6	390.67	9	396.17	4
B966	436.33	1	406.33	1	431.00	4	363.67	2	451.00	1	447.67	1	450.00	1	450	1	450.00	1	449.33	1	379.67	5	447.67	1	444.17	1	428.17	1	440.50	1	406.50	2	415.33	2	447.67	1
B972	374.33	8	336.33	11	377.33	9	345.67	4	424.67	7	402.00	3	390.67	10	412	11	373.33	12	412.00	6	451.33	1	394.33	7	382.50	10	374.17	11	375.33	11	378.83	5	436.00	1	396.17	2
R2	359.67	9	343.00	10	342.67	11	331.00	11	428.67	5	357.33	11	409.33	9	426.67	10	410.00	5	393.00	10	397.67	2	384.33	10	384.50	8	384.83	10	376.33	10	392.00	11	413.17	3	370.83	11
R5	360.00	8	369.33	7	381.67	8	344.67	5	430.33	4	379.67	7	447.33	3	445.67	3	391.33	9	430.00	2	377.33	8	396.00	5	403.67	6	407.50	5	386.50	9	387.33	3	403.83	6	387.83	7
R6	363.67	7	346.67	9	344.67	10	334.33	9	425.33	6	374.33	9	444.33	4	447.33	2	428.33	3	392.67	11	377.67	7	388.67	9	404.00	5	397.00	8	386.50	8	363.50	10	401.50	7	381.50	9
SST935 (A966/R2)	376.00	5	381.67	4	385.33	7	335.33	8	424.33	8	364.00	10	447.67	2	436.33	7	394.33	8	403.67	9	374.67	10	394.67	6	411.83	2	409.00	4	389.83	6	369.50	9	399.50	8	379.33	10
A966/R5	387.00	2	387.00	3	440.00	2	351.67	3	442.00	2	381.67	6	429.00	7	442	5	426.67	4	421.00	3	379.33	6	398.67	3	408.00	4	414.50	3	433.33	3	386.33	4	410.67	4	390.17	6
SST946 (A966/R6)	385.67	3	376.33	6	413.33	5	425.67	1	431.00	3	377.67	8	436.00	6	431.67	8	438.67	2	409.67	7	385.33	3	413.00	2	410.83	3	404.00	7	426.00	4	417.67	1	408.17	5	395.33	5
SST972	325.67	12	380.67	5	339.00	12	330.67	12	404.67	9	323.00	12	388.33	11	430.67	9	379.67	11	230.67	12	293.33	12	344.00	12	357.00	12	405.67	6	359.33	12	280.67	12	349.00	12	333.50	12
ENVIRONMENTAL MEAN	369.806		368.833		386.556		348.083		420.972		382.583		422.333		427.861		406.472		398.583		377.333		394.139		396.069		398.347		401.514		373.333		399.153		388.361	
CV (%)	3.71%		5.62%		8.94%		8.56%		3.46%		3.67%		2.18%		1.84%		5.65%		3.79%		4.54%		2.49%		3.08%		4.07%		7.51%		6.50%		3.99%		3.86%	
LSD	19.2558		29.088		49.6927		41.7812		20.3942		19.7077		12.9141		11.0287		32.2215		21.182		24.0069		13.7391		11.8413		15.7283		29.2226		23.5365		15.4217		14.4965	

FLOUR PROTEIEN CONTENT (FPC)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	06REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	06CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	11.73	7	11.50	6	12.14	4	11.29	4	10.38	5	10.69	9	11.12	11	13.62	5	11.64	12	11.91	11	11.28	12	12.29	3	11.43	10	12.56	5	11.89	11	11.60	10	10.83	8	11.49	8
SST966	10.53	12	11.35	8	10.88	12	10.29	10	8.94	12	11.28	6	12.59	5	13.64	6	11.82	11	12.24	10	12.10	7	11.94	6	11.56	9	12.44	6	11.35	12	11.27	12	10.52	12	11.61	6
SST399	11.24	11	10.78	10	11.91	7	11.76	2	9.62	9	10.54	10	12.82	3	12.30	12	12.15	10	12.67	9	12.01	8	10.82	12	12.03	5	11.54	12	12.03	9	12.21	5	10.82	9	10.68	11
B966	12.60	2	12.08	3	12.13	5	10.80	7	11.36	2	12.09	3	14.19	2	17.65	1	13.33	4	13.22	8	12.43	6	14.18	2	13.39	2	14.87	1	12.73	4	12.01	7	11.90	3	13.14	2
B972	12.70	1	12.11	2	13.44	1	12.15	1	11.60	1	13.09	1	16.23	1	16.61	2	14.28	1	14.24	2	13.29	3	15.86	1	14.47	1	14.36	2	13.86	1	13.19	1	12.45	1	14.47	1
R2	12.38	4	12.69	1	11.70	10	10.98	6	10.34	6	11.19	7	12.23	7	12.87	9	13.22	5	13.62	5	13.24	4	12.00	5	12.30	4	12.78	3	12.46	5	12.40	4	11.79	5	11.60	7
R5	12.47	3	11.71	5	11.84	8	10.72	8	10.86	3	11.47	5	12.67	4	12.34	11	12.91	6	14.36	1	13.73	1	12.05	4	12.57	3	12.03	10	12.38	7	12.54	3	12.30	2	11.76	5
R6	12.02	6	11.73	4	11.83	9	11.37	3	10.30	7	12.28	2	11.52	9	12.80	10	13.95	3	14.00	4	13.32	2	11.89	8	11.77	8	12.27	8	12.89	3	12.69	2	11.81	4	12.09	3
SST935 (A966/R2)	11.70	8	10.91	9	12.12	6	10.26	11	9.47	10	10.27	11	11.14	10	13.18	8	12.47	8	14.12	3	12.59	5	11.88	9	11.42	11	12.05	9	12.30	8	12.19	6	11.03	7	11.08	10
A966/R5	11.45	10	11.46	7	12.87	2	10.03	12	9.31	11	10.77	8	10.93	12	13.98	3	14.19	2	13.49	6	12.01	9	11.71	10	11.19	12	12.72	4	13.53	2	11.76	9	10.66	10	11.24	9
SST946 (A966/R6)	12.30	5	10.74	11	12.17	3	10.40	9	9.81	8	10.14	12	11.73	8	13.23	7	12.76	7	13.45	7	11.50	11	11.12	11	12.02	6	11.98	11	12.46	6	11.93	8	10.66	11	10.63	12
SST972	11.51	9	10.61	12	11.51	11	11.06	5	10.83	4	11.60	4	12.41	6	13.95	4	12.31	9	11.78	12	11.57	10	11.93	7	11.66	7	12.28	7	11.91	10	11.42	11	11.20	6	11.77	4
ENVIRONMENTAL MEAN	11.887		11.473		12.043		10.927		10.234		11.283		12.466		13.839		12.918		13.275		12.423		12.306		12.176		12.656		12.481		12.101		11.329		11.794	
CV (%)	4.69%		7.74%		3.11%		4.73%		4.65%		7.91%		4.35%		6.47%		4.86%		3.53%		3.61%		5.96%		4.43%		6.98%		4.09%		4.23%		4.01%		6.85%	
LSD	0.7824		1.2458		0.5245		0.7239		0.6675		1.2509		0.7599		1.2549		0.8798		0.6567		0.6296		1.0277		0.5226		0.8563		0.4952		0.4961		0.4408		0.7827	

ASH (ASH)

	2004										2005										2004 + 2005									
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	0.53	10	0.53	7	0.54	8	0.59	5	0.57	2	0.59	1	0.75	1	0.59	6	0.72	1	0.88	1	0.71	1	0.55	12	0.64	1	0.56	7	0.63	1	0.73	1	0.64	1	0.57	10
SST966	0.55	5	0.54	6	0.52	12	0.52	12	0.54	6	0.55	10	0.64	7	0.60	4	0.65	2	0.70	3	0.69	2	0.57	11	0.60	8	0.57	5	0.59	4	0.61	3	0.61	2	0.56	12
SST369	0.55	4	0.52	10	0.54	10	0.52	11	0.52	9	0.52	12	0.69	3	0.55	10	0.61	5	0.62	4	0.59	7	0.62	2	0.62	3	0.54	11	0.57	8	0.57	11	0.55	8	0.57	9
B966	0.56	2	0.53	9	0.61	1	0.60	1	0.59	1	0.57	4	0.67	5	0.75	1	0.64	3	0.74	2	0.61	4	0.67	1	0.61	4	0.64	1	0.63	2	0.67	2	0.60	3	0.62	1
B972	0.55	6	0.50	12	0.56	5	0.58	3	0.53	8	0.58	2	0.65	6	0.58	8	0.52	12	0.59	10	0.54	11	0.62	3	0.60	7	0.54	10	0.54	12	0.58	7	0.54	10	0.60	2
R2	0.62	1	0.55	4	0.54	9	0.59	2	0.49	12	0.57	5	0.60	10	0.60	5	0.61	6	0.60	8	0.54	10	0.59	8	0.61	5	0.57	4	0.58	7	0.60	5	0.52	12	0.58	6
R5	0.54	8	0.55	1	0.58	3	0.54	10	0.54	5	0.57	6	0.60	12	0.62	3	0.60	9	0.59	11	0.57	8	0.61	4	0.57	12	0.59	2	0.58	5	0.57	12	0.56	7	0.59	4
R6	0.56	3	0.55	3	0.55	6	0.57	8	0.55	4	0.56	8	0.69	2	0.62	2	0.60	8	0.58	12	0.55	9	0.59	7	0.63	2	0.59	3	0.56	6	0.57	10	0.55	9	0.56	7
SST935 (A966/R2)	0.55	7	0.55	2	0.53	11	0.59	4	0.57	3	0.58	3	0.63	8	0.59	7	0.62	4	0.61	6	0.59	6	0.61	5	0.59	9	0.57	6	0.57	9	0.60	4	0.58	5	0.59	3
A966/R5	0.52	11	0.52	11	0.55	7	0.57	7	0.52	11	0.56	7	0.69	4	0.54	12	0.59	10	0.59	9	0.61	5	0.60	6	0.61	6	0.53	12	0.57	10	0.58	8	0.56	6	0.58	5
SST946 (A966/R6)	0.52	12	0.54	5	0.58	2	0.57	6	0.52	10	0.56	9	0.62	9	0.55	11	0.61	7	0.61	5	0.67	3	0.59	9	0.57	10	0.55	9	0.59	3	0.59	6	0.59	4	0.58	8
SST972	0.54	9	0.53	8	0.56	4	0.56	9	0.53	7	0.55	11	0.60	11	0.57	9	0.56	11	0.60	7	0.51	12	0.58	10	0.57	11	0.55	8	0.56	11	0.58	9	0.52	11	0.57	11
ENVIRONMENTAL MEAN	0.549		0.535		0.553		0.568		0.539		0.563		0.653		0.597		0.610		0.642		0.587		0.601		0.601		0.566		0.581		0.605		0.568		0.582	
CV (%)	9.15%		6.38%		4.57%		7.41%		12.65%		4.16%		7.86%		7.13%		9.50%		8.34%		6.78%		4.15%		8.32%		6.71%		7.54%		7.88%		10.54%		4.15%	
LSD	0.0705		0.0478		0.0354		0.059		0.0956		0.0328		0.0719		0.0597		0.0813		0.0751		0.0735		0.035		0.0485		0.0368		0.0425		0.0462		0.058		0.0234	

WET GLUTEN CONTENT (WGC)

	2004										2005										2004 + 2005									
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	37.92	3	35.15	3	36.70	3	33.48	3	31.30	1	32.02	7	41.85	2	42.24	4	31.76	12	38.06	6	33.35	7	36.07	4	39.88	3	38.69	5	34.23	8	35.77	4	32.33	4	34.04	5
SST966	29.64	12	34.26	6	29.94	12	28.04	11	24.51	12	31.39	8	35.24	6	43.52	3	33.10	10	33.99	11	32.24	9	33.50	9	32.44	10	38.89	4	31.52	12	31.02	12	28.36	11	32.45	8
SST399	44.07	2	30.40	11	33.53	9	33.14	4	25.51	8	30.78	10	34.07	9	37.34	8	32.91	11	34.25	10	32.86	8	29.93	12	39.07	4	33.67	11	33.22	11	33.69	6	29.18	10	30.35	12
B966	35.27	7	32.72	7	33.12	10	28.54	9	30.67	3	32.95	5	38.35	3	55.01	1	34.23	9	36.66	8	32.10	10	38.94	3	36.81	6	43.86	1	33.68	9	32.60	9	31.39	7	35.95	3
B972	35.55	6	35.89	2	38.20	1	37.42	1	29.29	5	35.53	1	46.71	1	48.66	2	40.94	1	38.47	3	34.78	5	46.31	1	41.13	1	42.28	2	39.57	1	37.96	1	32.04	5	40.92	1
R2	45.54	1	44.36	1	34.30	8	31.35	6	28.03	7	33.16	4	34.90	7	37.04	9	36.26	5	38.37	4	37.78	3	34.41	6	40.22	2	40.70	3	36.29	6	34.86	5	32.90	3	33.79	7
R5	37.13	5	34.70	5	35.85	5	31.56	5	30.31	4	33.98	2	37.38	4	36.53	11	36.28	4	41.30	1	39.92	1	40.10	2	37.26	5	35.61	7	36.07	4	36.43	3	35.11	1	37.04	2
R6	37.26	4	34.85	4	35.45	6	33.94	2	28.59	6	32.43	6	32.07	10	37.44	7	40.47	2	40.04	2	39.20	2	35.21	5	34.66	9	36.16	6	37.96	3	36.99	2	33.90	2	33.82	6
SST935 (A966/R2)	34.06	9	31.58	9	32.38	11	27.90	12	25.42	9	30.01	11	30.50	11	37.04	10	34.55	8	38.28	5	37.33	4	33.51	8	32.28	11	34.31	10	33.47	10	33.09	7	31.37	8	31.76	10
A966/R5	33.83	10	32.15	8	38.10	2	28.18	10	24.64	11	31.33	9	29.60	12	38.27	6	40.16	3	36.77	7	33.97	6	33.08	10	31.72	12	35.21	8	39.13	2	32.47	10	29.31	9	32.21	9
SST946 (A966/R6)	35.14	8	30.51	10	35.97	4	29.49	8	25.18	10	29.08	12	34.43	8	35.45	12	34.73	7	36.32	9	31.43	12	32.12	11	34.78	8	32.98	12	35.36	5	32.90	8	28.30	12	30.60	11
SST972	33.40	11	29.87	12	34.77	7	31.07	7	30.78	2	33.66	3	36.39	5	40.36	5	35.20	6	33.22	12	32.00	11	34.16	7	34.90	7	36.11	9	34.99	7	32.14	11	31.39	6	34.06	4
ENVIRONMENTAL MEAN	36.567		33.868		34.859		31.174		27.852		32.217		35.958		40.741		35.884		37.143		34.747		35.612		36.263		37.304		35.372		34.159		31.300		33.914	
CV (%)	22.82%		13.07%		5.16%		9.25%		6.81%		7.22%		14.26%		11.56%		6.34%		5.99%		7.34%		10.54%		18.71%		12.07%		5.82%		7.76%		7.44%		9.20%	
LSD	11.6974		6.2079		2.521		4.041		2.6599		3.2613		7.1686		6.604		3.191		3.1181		3.5754		5.2649		6.5754		4.3656		1.9949		2.5672		2.2581		3.0236	

ALVEO DISTENSIBILITY (AP-DIST)

	2004										2005										2004 + 2005									
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	77.33	8	125.33	3	109.00	5	124.00	1	116.67	4	104.67	5	94.67	6	86.67	8	115.67	1	104.33	2	84.00	2	92.33	9	86.00	10	106.00	4	112.33	3	114.17	1	100.33	4	98.50	6
SST966	77.33	9	95.33	8	106.00	6	106.00	4	100.00	8	75.67	12	98.67	5	90.67	3	94.00	6	109.67	1	79.00	6	103.00	5	88.00	8	93.00	8	100.00	6	107.83	2	89.50	6	89.33	11
SST399	65.33	12	72.67	11	81.00	11	68.67	12	60.00	12	96.33	7	78.33	10	77.33	12	82.00	12	73.67	12	68.67	10	86.33	11	71.83	11	75.00	12	81.50	11	71.17	12	64.33	12	91.33	10
B966	106.00	1	126.00	2	123.00	4	111.33	3	110.00	6	116.67	1	74.33	11	86.00	9	84.00	10	79.33	9	76.67	7	92.67	8	90.17	7	107.00	3	103.50	5	95.33	4	93.33	5	105.67	3
B972	72.67	10	82.33	10	85.00	8	87.00	7	98.00	5	80.67	11	69.67	12	88.00	6	82.67	11	81.00	7	64.00	11	84.67	12	71.17	12	85.67	10	83.83	10	84.00	8	81.00	11	82.67	12
R2	84.00	7	84.00	9	84.67	9	82.33	10	93.33	10	84.00	10	99.67	4	94.33	1	110.00	2	90.67	5	84.67	1	102.00	6	91.83	4	89.17	9	97.33	7	86.50	7	89.00	8	93.00	8
R5	84.33	6	105.67	6	94.00	7	84.67	9	101.67	7	85.33	9	88.33	8	90.00	5	99.33	4	80.00	8	76.33	8	107.67	3	86.33	9	97.83	6	96.67	8	82.33	9	89.00	7	96.50	7
R6	89.67	5	105.67	7	83.67	10	85.33	8	88.33	11	99.33	6	91.67	7	80.67	11	98.00	5	78.67	10	81.00	4	103.00	4	90.67	6	93.17	7	90.83	9	82.00	10	84.67	9	101.17	5
SST935 (A966/R2)	97.33	3	124.00	4	139.00	1	94.00	6	132.00	1	106.00	4	102.33	2	80.67	4	105.67	3	95.00	4	83.00	3	108.33	2	99.83	1	107.33	2	122.33	1	94.50	6	107.50	1	107.17	2
A966/R5	93.33	4	112.00	5	134.33	3	111.67	2	121.67	3	111.00	2	100.33	3	87.33	7	85.00	9	95.00	3	79.67	5	112.00	1	96.83	2	99.67	5	109.67	4	103.33	3	100.67	3	111.50	1
SST946 (A966/R6)	100.00	2	136.00	1	138.67	2	104.00	5	129.67	2	108.33	3	82.67	9	84.67	10	90.33	7	85.33	6	75.33	9	98.00	7	91.33	5	110.33	1	114.50	2	94.67	5	102.50	2	103.17	4
SST972	71.33	11	59.67	12	64.00	12	76.67	11	114.00	5	91.00	8	119.00	1	92.67	2	88.33	8	74.67	11	52.33	12	92.00	10	95.17	3	76.17	11	76.17	12	75.67	11	83.17	10	91.50	9
ENVIRONMENTAL MEAN	84.889		102.556		103.528		94.639		105.444		96.750		91.639		87.500		94.583		87.278		75.389		96.500		88.264		95.028		99.056		90.958		90.417		97.625	
CV (%)	19.31%		12.05%		10.57%		17.87%		15.06%		21.44%		7.81%		5.14%		6.31%		7.25%		8.98%		5.50%		16.30%		11.66%		9.64%		19.42%		20.33%		17.44%	
LSD	22.9818		17.3319		15.341		23.7062		22.267		29.0867		10.0346		6.3092		8.3688		8.8662		9.49		7.6023		13.9456		11.0144		9.4431		17.1166		17.8124		16.5049	

ALVEO STABILITY (AL-STAB)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	98.00	2	61.00	10	78.33	3	80.33	5	84.67	3	65.00	4	101.00	9	131.00	2	97.33	7	94.67	12	116.33	9	148.67	1	99.50	6	96.00	7	87.83	4	87.50	9	90.50	6	106.83	1
SST966	82.00	8	78.00	5	66.33	7	53.00	12	48.67	9	75.33	1	127.67	4	123.67	5	108.33	5	100.00	11	148.67	4	115.33	3	104.83	4	100.83	6	87.33	5	76.50	12	98.67	5	96.33	3
SST399	124.00	1	99.00	1	74.00	5	97.67	1	91.67	1	65.67	3	149.33	3	112.33	8	135.00	1	173.00	1	150.00	3	105.67	6	136.67	1	105.67	3	104.50	1	135.33	1	120.83	1	85.67	4
B966	85.00	6	62.33	9	34.33	12	59.33	9	55.00	6	55.67	7	168.67	1	140.33	1	116.67	3	143.33	2	158.00	1	113.67	5	126.83	2	101.33	4	75.50	9	101.33	4	106.50	3	84.67	6
B972	84.67	7	92.33	2	53.00	9	83.67	2	60.67	5	75.00	2	153.67	2	125.33	4	115.67	4	103.67	9	144.67	5	118.33	2	119.17	3	108.83	2	84.33	7	93.67	6	102.67	4	96.67	2
R2	79.33	9	92.00	3	79.67	2	81.67	4	53.67	7	52.67	10	117.00	6	110.67	10	93.33	8	129.00	4	123.67	8	94.00	7	98.17	7	101.33	5	86.50	6	105.33	2	88.67	8	73.33	7
R5	88.00	5	77.00	6	71.67	6	62.00	8	49.00	8	52.00	11	118.00	5	96.67	12	85.67	11	118.33	7	101.00	12	74.67	11	103.00	5	86.83	10	78.67	8	90.17	8	75.00	12	63.33	10
R6	69.00	11	75.33	7	74.00	4	66.67	6	61.00	4	54.33	9	98.00	10	112.33	7	67.67	12	143.00	3	112.00	10	76.00	10	83.50	12	93.83	8	70.83	10	104.83	3	86.50	10	65.17	9
SST935 (A966/R2)	77.33	10	53.33	12	50.33	10	63.00	7	38.67	12	55.67	8	92.67	11	115.00	6	86.00	10	122.67	5	141.67	6	84.67	8	85.00	11	84.17	11	68.17	11	92.83	7	90.17	7	70.17	8
A966/R5	93.67	3	64.67	8	54.00	8	54.67	10	46.33	11	56.67	6	80.67	12	111.33	9	127.33	2	101.00	10	106.00	11	70.00	12	87.17	9	88.00	9	90.67	3	77.83	11	76.17	11	63.33	11
SST946 (A966/R6)	65.33	12	60.67	11	36.67	11	53.00	11	47.67	10	39.33	12	105.00	8	101.67	11	91.00	9	119.33	6	128.33	7	82.00	9	85.17	10	81.17	12	63.83	12	86.17	10	88.00	9	60.67	12
SST972	89.00	4	88.33	4	84.67	1	83.67	3	65.33	2	57.00	5	105.33	7	129.67	3	106.67	6	114.00	8	154.00	2	113.67	4	97.17	8	109.00	1	95.67	2	98.83	5	109.67	2	85.33	5
ENVIRONMENTAL MEAN	86.278		75.333		63.083		69.889		56.861		58.694		118.083		117.5		102.556		121.833		132.028		99.722		102.181		96.417		82.819		96.861		94.444		79.208	
CV (%)	23.52%		18.14%		22.66%		23.63%		27.20%		34.23%		7.48%		10.93%		12.65%		12.71%		17.45%		13.67%		15.61%		14.34%		18.75%		20.27%		22.08%		21.78%	
LSD	28.4465		19.1633		20.0449		23.1532		21.6873		28.1687		12.3771		18.0009		18.1962		21.7149		32.3023		19.1068		15.4556		13.4017		15.0475		18.8366		20.2084		16.7259	

ALVEO P/L (APL)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	0.83	11	2.31	2	1.81	6	2.54	2	2.24	6	2.22	5	0.94	5	0.66	11	1.20	3	1.13	2	0.72	4	0.62	12	0.88	9	1.49	3	1.51	5	1.84	1	1.48	6	1.42	6
SST966	1.00	7	1.32	8	1.91	5	2.14	5	2.18	8	1.09	12	0.77	8	0.75	6	0.88	7	1.32	1	0.53	8	0.91	7	0.89	8	1.04	8	1.40	6	1.73	3	1.36	8	1.00	12
SST399	0.54	12	0.75	12	1.15	10	0.75	12	0.76	12	1.55	10	0.52	10	0.74	7	0.61	12	0.43	12	0.46	10	0.82	9	0.53	12	0.75	11	0.88	11	0.59	12	0.61	12	1.19	10
B966	1.57	2	2.10	4	3.35	2	2.26	4	2.50	4	2.23	3	0.44	12	0.61	12	0.73	9	0.57	10	0.51	9	0.83	8	1.01	6	1.36	4	2.04	3	1.41	5	1.50	5	1.53	6
B972	0.94	9	0.97	9	1.80	7	1.22	10	2.22	7	1.29	11	0.45	11	0.72	9	0.72	10	0.79	4	0.45	11	0.72	11	0.70	11	0.85	10	1.26	9	1.01	10	1.34	9	1.01	11
R2	1.18	2	0.93	10	1.08	11	1.40	9	2.06	9	1.84	7	0.87	6	0.88	3	1.19	4	0.70	7	0.71	5	1.08	6	1.02	5	0.90	9	1.13	10	1.05	9	1.38	7	1.46	7
R5	0.98	8	1.62	7	1.49	8	1.69	6	2.38	5	1.67	8	0.76	9	0.95	1	1.17	5	0.69	8	0.79	2	1.49	2	0.87	10	1.29	6	1.33	8	1.19	6	1.59	4	1.58	5
R6	1.31	4	1.83	5	1.16	9	1.68	7	1.80	10	2.16	6	0.94	4	0.73	8	1.50	1	0.56	11	0.74	3	1.36	3	1.13	4	1.28	7	1.34	7	1.12	8	1.27	10	1.76	3
SST935 (A966/R2)	1.46	3	2.59	1	2.86	3	1.53	8	3.60	1	2.22	4	1.11	3	0.79		1.23	2	0.78	5	0.59	6	1.28	4	1.29	1	1.69	1	2.05	2	1.16	7	2.10	1	1.76	4
A966/R5	1.13	6	1.62	6	2.60	4	2.56	1	2.89	3	2.94	2	1.27	1	0.60	4	0.71	11	0.96	3	0.83	1	1.70	1	1.20	3	1.31	6	1.65	4	1.76	2	1.86	2	2.32	1
SST946 (A966/R6)	1.78	1	2.29	3	3.90	1	2.32	3	3.09	2	2.97	1	0.78	7	0.90	2	1.00	6	0.73	6	0.59	7	1.20	5	1.28	2	1.60	2	2.45	1	1.52	4	1.84	3	2.09	2
SST972	0.86	10	0.75	11	0.83	12	0.96	11	1.74	11	1.65	9	1.13	2	0.71	10	0.85	8	0.66	9	0.35	12	0.82	10	1.00	7	0.73	12	0.84	12	0.82	11	1.05	11	1.23	9
ENVIRONMENTAL MEAN	1.132		1.607		1.996		1.756		2.288		1.984		0.832		0.770		0.982		0.776		0.606		1.071		0.982		1.188		1.489		1.266		1.447		1.528	
CV (%)	47.14%		38.08%		29.78%		51.64%		32.18%		49.03%		14.57%		16.36%		17.70%		19.32%		26.68%		20.63%		43.52%		41.07%		34.20%		66.85%		56.03%		50.64%	
LSD	0.748		0.8579		0.8332		1.2709		1.0321		1.3641		0.17		0.1767		0.2436		0.2103		0.2265		0.3099		0.4141		0.4731		0.4935		0.8202		0.7856		0.7499	

ALVEO STRENGHT (A-W)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	40.67	3	44.20	2	44.53	1	46.60	1	35.00	1	37.17	1	42.40	7	58.17	1	54.97	1	50.23	4	42.70	6	61.70	1	41.63	7	51.18	1	49.75	1	48.42	1	38.85	3	49.43	1
SST966	33.63	9	38.07	8	34.70	5	31.83	5	25.77	10	30.20	5	52.63	3	49.83	4	45.13	5	54.60	1	48.20	3	50.33	2	43.13	5	43.95	5	39.92	6	43.22	2	36.98	4	40.27	2
SST399	39.37	4	37.67	10	35.27	4	32.70	4	26.47	8	31.07	3	59.13	1	41.87	9	49.67	3	51.37	3	41.93	7	41.57	8	49.25	1	39.77	9	42.57	3	42.03	4	34.20	8	36.32	6
B966	46.17	1	45.67	1	28.83	10	33.80	3	27.77	6	34.70	2	43.53	6	55.70	2	40.83	8	48.23	7	50.47	1	44.77	4	44.85	2	50.68	2	34.83	7	41.02	5	39.12	2	39.73	3
B972	33.33	10	39.40	5	27.20	12	35.60	2	27.97	5	30.37	4	41.33	9	52.70	3	41.60	7	41.67	10	43.43	5	44.83	3	37.33	10	46.05	3	34.40	10	38.63	7	35.70	5	37.60	4
R2	35.87	7	40.20	4	31.63	7	29.80	9	26.23	9	23.63	11	51.27	4	48.07	6	49.93	2	49.77	5	44.70	4	44.30	5	43.57	3	44.13	4	40.78	5	39.78	6	35.47	6	33.97	8
R5	36.43	6	38.07	7	29.23	9	22.03	12	24.97	12	22.20	12	42.37	8	37.93	11	37.83	10	40.30	11	30.37	12	38.07	9	39.40	9	38.00	10	33.53	11	31.17	12	27.67	12	30.13	12
R6	32.53	12	37.07	11	29.37	8	24.90	11	25.23	11	25.00	9	37.40	12	37.73	12	33.30	12	48.63	6	36.40	9	35.43	12	34.97	12	37.40	12	31.33	12	36.77	10	30.82	10	30.22	11
SST935 (A966/R2)	39.13	5	37.97	9	38.37	3	31.30	6	30.43	3	29.70	6	44.43	5	46.83	7	44.57	6	53.67	2	48.67	2	43.17	6	41.78	6	42.40	6	41.47	4	42.48	3	39.55	1	36.43	5
A966/R5	41.80	2	38.80	6	40.40	2	30.00	8	26.80	7	27.80	8	38.13	11	43.13	8	47.17	4	44.83	9	34.30	10	37.87	10	39.97	8	40.97	8	43.78	2	37.42	8	30.55	11	32.83	9
SST946 (A966/R6)	35.77	8	43.50	3	32.20	6	28.03	10	31.73	2	24.60	10	38.37	10	41.10	10	37.37	11	46.03	8	37.90	8	37.20	11	37.07	11	42.30	7	34.78	8	37.03	9	34.82	7	30.90	10
SST972	32.63	11	26.80	12	28.60	11	30.67	7	30.30	4	29.57	7	54.23	2	48.47	5	40.37	9	34.73	12	34.27	11	42.10	7	43.43	4	37.48	11	34.48	9	32.70	11	32.28	9	35.83	7
ENVIRONMENTAL MEAN	37.294		38.925		33.361		31.439		28.222		28.833		45.436		46.794		43.578		47.006		41.111		43.444		41.365		42.860		38.469		39.222		34.667		36.130	
CV (%)	15.02%		15.33%		12.11%		15.68%		9.21%		10.45%		9.00%		8.60%		7.62%		10.16%		10.91%		8.94%		11.66%		11.85%		10.76%		12.78%		10.66%		9.85%	
LSD	7.856		8.3637		5.665		6.9132		3.6457		4.2256		5.7327		5.8383		4.6561		6.6932		6.2867		5.448		4.7953		4.9238		4.0099		4.8596		3.5459		3.4601	

CONSISTO WATER ABSORPTION (CABS)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	58.00	10	58.93	5	60.17	3	59.50	3	59.50	3	59.00	6	60.33	5	60.67	2	60.50	7	60.63	6	59.50	8	61.03	7	59.17	8	59.80	1	60.33	3	60.07	2	59.50	1	60.02	3
SST966	56.60	12	57.67	12	57.70	11	57.30	9	57.37	9	58.10	9	60.67	3	60.30	3	60.83	5	60.90	2	59.73	3	60.80	9	58.63	12	58.98	6	59.27	11	59.10	7	58.55	9	59.46	10
SST399	58.57	7	58.03	11	58.93	8	59.80	1	57.17	10	57.93	10	59.20	12	58.70	8	60.20	8	60.00	8	59.70	6	60.87	8	58.88	10	58.37	12	59.57	9	59.00	3	58.43	10	59.40	12
B966	60.33	1	59.40	3	60.50	2	59.57	2	60.13	1	60.77	1	61.17	2	58.20	12	59.93	11	61.87	1	58.83	9	61.50	3	60.75	1	58.80	9	60.22	4	60.72	1	59.48	2	61.13	1
B972	59.30	5	59.03	4	58.60	9	59.37	4	59.90	2	59.23	4	59.90	6	58.70	9	61.03	4	59.27	11	58.57	11	60.73	11	59.60	6	58.87	7	59.82	7	59.32	6	59.23	3	59.98	5
R2	58.03	9	58.27	10	57.83	10	56.70	12	56.93	12	57.80	12	59.37	11	59.47	5	61.20	2	59.57	9	59.73	5	61.07	6	58.70	11	58.87	8	59.52	10	58.13	12	58.33	11	59.43	11
R5	59.77	3	59.57	1	59.90	5	57.67	8	56.90	4	58.27	8	59.70	8	59.73	4	61.10	3	59.43	10	58.70	10	61.60	1	59.73	5	59.70	2	60.50	2	58.55	9	59.80	6	59.93	6
R6	58.37	8	58.70	7	59.30	7	57.97	7	57.10	11	58.60	7	59.50	9	58.67	10	60.13	9	58.90	12	60.13	1	61.17	4	58.93	9	58.68	10	59.72	8	58.43	11	58.62	8	59.88	8
SST935 (A966/R2)	58.70	6	58.83	6	59.43	6	57.23	10	58.17	6	57.90	11	59.77	7	59.33	7	60.70	6	60.80	5	59.60	7	61.50	2	59.23	7	59.08	5	60.07	6	59.02	8	58.88	5	59.70	9
A966/R5	59.67	4	59.47	2	60.60	1	58.73	5	57.63	8	59.27	3	60.50	4	59.43	6	61.37	1	60.80	4	59.73	4	61.10	5	60.08	2	59.45	4	60.98	1	59.77	4	58.68	7	60.18	2
SST946 (A966/R6)	60.07	2	58.40	8	60.10	4	58.53	6	58.10	7	59.03	5	59.50	10	58.37	11	60.13	10	60.83	3	60.07	2	60.77	10	59.78	4	58.38	11	60.12	5	59.68	5	59.08	4	59.90	7
SST972	57.73	11	58.30	9	57.40	12	56.90	11	58.43	5	59.37	2	62.20	1	61.10	1	59.47	12	60.07	7	56.63	12	60.63	12	59.97	3	59.70	3	58.43	12	58.48	10	57.53	12	60.00	4
ENVIRONMENTAL MEAN	58.761		58.725		59.206		58.272		58.278		58.772		60.150		59.389		60.550		60.256		59.244		61.064		59.456		59.057		59.878		59.264		58.761		59.918	
CV (%)	1.25%		0.86%		0.57%		1.48%		1.18%		1.53%		0.79%		1.77%		1.27%		0.87%		1.69%		0.66%		1.15%		1.43%		0.68%		1.19%		1.45%		1.19%	
LSD	1.0307		0.7824		0.4762		1.2132		0.9649		1.2576		0.6663		1.4737		1.0811		0.7334		1.4059		0.5654		0.6603		0.8196		0.5688		0.6827		0.8274		0.6885	

MIXOGRAPH MIXING TIME (MMT)

	2004												2005												2004 + 2005											
GENOTYPE	04BLM	R	04REITZ	R	04KRSTD	R	04BULTF	R	04BAINS	R	04CLOC	R	05BLM	R	05REITZ	R	05KRSTD	R	05BULTF	R	05BAINS	R	05CLOC	R	4/5BLM	R	4/5REITZ	R	4/5KRSTD	R	4/5BULTF	R	4/5BAINS	R	4/5CLOC	R
ELANDS	3.61	3	3.98	1	3.42	2	3.54	2	2.90	9	3.21	1	2.47	3	3.26	1	2.77	2	3.03	1	2.60	4	3.07	1	3.04	1	3.62	1	3.10	2	3.29	1	2.75	8	3.14	1
SST966	3.47	4	3.39	2	3.33	4	3.69	1	4.05	2	3.16	3	2.43	5	2.09	6	2.33	6	2.23	9	2.47	6	2.33	4	2.95	5	2.74	2	2.83	4	2.96	3	3.26	2	2.75	2
SST399	3.71	1	3.39	3	3.23	5	3.10	8	4.20	1	2.86	5	2.22	7	1.92	10	2.97	1	2.70	2	2.57	5	2.50	2	2.97	3	2.66	4	3.10	1	2.90	4	3.38	1	2.68	4
B966	3.03	9	2.94	11	2.68	8	3.13	7	2.17	12	2.50	10	1.76	9	2.12	4	2.27	7	2.03	10	2.17	10	2.00	12	2.39	8	2.53	8	2.48	8	2.58	10	2.17	12	2.25	11
B972	2.95	11	3.25	4	2.64	10	2.86	10	2.39	11	2.40	11	1.74	10	2.10	5	2.23	9	2.60	3	3.17	1	2.23	7	2.35	10	2.67	3	2.44	10	2.70	7	2.78	7	2.32	10
R2	3.39	5	3.16	6	2.89	7	3.20	6	3.42	3	2.75	8	2.52	2	1.68	12	2.43	5	2.40	7	2.30	7	2.20	8	2.95	4	2.42	11	2.66	6	2.80	6	2.86	5	2.48	8
R5	2.71	12	3.00	9	2.23	12	2.68	11	2.77	10	2.18	9	1.40	11	1.78	11	2.00	11	1.80	12	1.77	12	2.05	11	2.06	12	2.39	12	2.12	12	2.19	12	2.27	11	2.11	12
R6	3.20	7	3.07	7	2.68	9	2.47	12	3.27	6	2.63	9	1.40	12	2.21	3	1.97	12	2.57	4	2.00	11	2.05	10	2.30	11	2.64	5	2.31	11	2.52	11	2.64	10	2.34	9
SST935 (A966/R2)	3.36	6	3.05	8	2.48	11	3.48	3	3.27	5	2.93	4	2.46	4	1.93	9	2.43	4	2.47	6	2.63	3	2.37	3	2.91	6	2.49	9	2.46	9	2.97	2	2.95	4	2.65	5
A966/R5	3.05	8	3.00	10	3.03	6	3.45	4	3.13	8	2.80	7	2.00	8	1.96	8	2.13	10	2.00	11	2.23	9	2.27	5	2.53	8	2.48	10	2.58	7	2.72	8	2.68	9	2.54	6
SST946 (A966/R6)	2.98	10	2.78	12	3.33	3	2.90	9	3.35	4	2.85	6	2.67	1	2.35	2	2.27	8	2.53	5	2.23	8	2.17	9	2.83	7	2.56	7	2.80	5	2.72	9	2.79	6	2.51	7
SST972	3.63	2	3.21	5	3.45	1	3.42	5	3.13	7	3.18	2	2.39	6	2.07	7	2.64	3	2.37	8	3.17	2	2.25	6	3.01	2	2.64	6	3.00	3	2.89	5	3.15	3	2.72	3
ENVIRONMENTAL MEAN	3.258		3.185		2.949		3.152		3.170		2.788		2.121		2.122		2.362		2.396		2.442		2.289		2.689		2.653		2.665		2.773		2.806		2.539	
CV (%)	9.28%		7.73%		7.31%		11.89%		12.45%		11.02%		13.37%		7.59%		6.12%		13.43%		6.01%		5.22%		10.22%		7.98%		6.89%		13.24%		10.77%		9.30%	
LSD	0.3781		0.3451		0.3022		0.5256		0.5534		0.431		0.3977		2.122		2.362		0.4508		0.2057		0.1674		0.2663		0.2052		0.1774		0.3558		0.2929		0.2289	

CHAPTER 4

STABILITY PERFORMANCE OF SOUTH AFRICAN HYBRID BREAD WHEAT

4.1 INTRODUCTION

Hybrids in general have proven to be more consistent in yield performance over seasons and localities than commercial standard, pure line cultivars (Jordaan *et al.*, 1999). Purchase *et al.* (2000a) reported that hybrids and long growth period pure line cultivars generally had superior adaptation to high yield potential conditions.

Where quality is concerned, a consistent grade over years and the ability of the grain to meet the farmer and processor's requirements will depend on the cultivar and the environment in which the crop is grown. Factors contributing to variation in wheat quality are important for the production of high quality grain. Three sources of variation in plant characteristics have been identified namely genotypes, environment and the interaction between the two.

Around the world, researchers found that environmental conditions influence the milling and baking quality of conventional wheat cultivars (Baenziger *et al*., 1985; Van Deventer, 1986; Van Lill and Purchase, 1995; Gaines *et al*., 1996; Crossa *et al.*, 1998; Koekemoer, 2003). Positive and negative heterosis was reported in hybrid quality characteristics, but most hybrids tended to be intermediate between the parents (Borghi and Perenzin, 1994; Oury *et al.*, 1995; Borghi *et al.*, 1988; Cukadar *et al.*, 2001) and no reports were found on the quality stability performance of hybrids.

The Wheat Technical Committee, representative of all parties, farmers, wheat breeders and members of the baking and milling industries, control the cultivar release procedure in South Africa. The process extends over a period of three years where wheat samples of a minimum of five localities are evaluated each year. Candidate cultivars are compared to standard cultivars and have to be within acceptable limits of the standard's quality grown in the same environment. The effect of cultivar,

environment and the interaction, receives no attention. As a result, the end-use quality of the commercial crop often varies over environments and years. To develop high yielding and acceptable end-use quality cultivars is a challenge to the breeder, but should be an important breeding goal if premiums could be paid for certain cultivars that fulfill in this goal.

In this chapter the aim was to determine the stability of the genotypes planted over six environments with specific attention to the hybrids, males and females of which the hybrids consisted, compared to a stable conventional variety like Elands.

4.2 MATERIALS AND METHODS

4.2.1 Genotypes

South African winter and facultative bread wheat cultivars and hybrids, including their parental lines, were obtained from the 2004 and 2005 Winter and Intermediate Hybrid Performance Trials of SENSAKO. A total of 12 genotypes consisting of mostly facultative genotypes were included in the IHBPT trial (Intermediate Hybrid Performance Trial) and 12 genotypes consisting of mostly winter genotypes were included in the WHBPT trial (Winter Hybrid Performance Trial).

The 12 facultative bread wheat genotypes included Elands (conventional quality standard), SST966 (winter hybrid), B966 (female), B972 (female), R2 (male), R5 (male), R6 (male), hybrid lines A972/R2, A972/R5, A972/R6, SST972 and SST983. The 12 winter bread wheat genotypes included were Elands (conventional quality standard), SST966 (winter hybrid), SST399 (winter conventional variety), B966 (female), B972 (female), R2 (male), R5 (male), R6 (male), hybrid lines and cultivars SST935, A966/R5, SST946 and SST972. The genotypes, their growth habit, release date and origin are the same as in Tables 3.1 and Table 3.2 in Chapter 3.

4.2.2 Field trials

The same field trials as in Chapter 3 were used to determine the AMMI stability value from. The list of localities was given in Table 3.3.

4.2.3 Laboratory methods

All material was evaluated for quality traits, which included test weight, moisture content, SKCS kernel size, break flour yield, flour yield, Hagberg falling number, ash content, wet gluten content, alveograph, consistograph water absorption and mixograph mixing time. Methods of determining each of these quality characteristics were discussed in Chapter 3, paragraph 3.2.4.

4.2.4 Environmental conditions

See environmental description of the Free State in Chapter 3, paragraph 3.2.4. The same conditions for the years 2004 and 2005 apply as described in Chapter 3 and the rainfall in Table 3.3. The Free State is one of the major production regions of bread wheat in South Africa and economic yields are realized if sufficient spring rainfall occurs. Unfortunately this area is prone to variable yields over years and sub-regions due to variation in environmental conditions. The same is true for quality as with yield and therefore breeding stable cultivars with regard to quality should receive special attention.

4.2.5 Statistical analysis

4.2.5.1 AMMI Stability Value (ASV)

All statistical analyses were performed, using Agrobase (1999). The AMMI analysis of variance was performed on the combined data for the two years, where every locality by year combination was treated as a separate environment. Stability analysis was calculated and presented in Table 4.1 and Table 4.2. These IPCA 1 and IPCA 2 stability scores were used to calculate the AMMI stability value (ASV) as suggested by Purchase (2000b).

This ASV was calculated as follow:

$$ASV = \frac{SS\ IPCA\ 1}{SS\ IPCA\ 2}\ (IPCA\ 1)^2 + (IPCA2)^2$$

Where, ASV = AMMI stability value, SS = sum of squares, IPCA 1 = interaction of principal component analysis one, IPCA 2 = interaction of principal component analysis two.

4.3 RESULTS AND DISCUSSION

4.3.1 AMMI stability values

The stability of wheat quality characteristics over years and environments is important to the industries, whose processing technology requires consistent raw material in order to produce high quality end products.

IPCA 1 scores of a genotype from the AMMI analysis indicate the stability of the genotype over environments. The higher the relative IPCA 1 score (negative or positive) of a certain genotype, the more specifically adapted it is to certain environments. Genotypes are most stable over all environments when the IPCA 1 scores are close to zero. Purchase (1997) indicated that it is important to take not only the IPCA 1 score into consideration, because some genotypes were significantly

Table 4.1: AMMI Stability values and rankings of the Intermediate Hybrid Performance Trial (IHBPT 04+05).

GENOTYPE	HLM	Rank	SKCSDIAM	Rank	SKCSG	Rank	SKCS_HI	Rank	BFLY	Rank	FLY	Rank	HFN	Rank	ASTR	Rank	ASH	Rank	CABS	Rank	MMT	Rank
ELANDS	1.73	12	2.28	1	3.11	6	0.53	2	1.14	5	4.22	12	7.13	10	3.41	11	0.85	12	1.83	8	1.04	12
SST966	0.85	7	2.32	5	2.94	5	4.63	11	1.38	9	4.09	10	6.29	9	1.39	5	0.35	11	1.32	6	0.83	9
B966	1.64	10	2.35	7	3.17	7	7.06	12	2.48	12	4.10	11	3.48	5	2.91	10	0.09	1	0.71	3	0.86	10
B972	0.78	3	2.31	4	3.99	10	2.25	9	0.60	2	1.15	6	3.95	6	1.34	3	0.34	10	2.26	9	0.71	7
R2	1.16	9	2.30	2	3.88	9	1.90	8	1.31	8	0.60	1	7.30	11	2.00	8	0.28	9	2.46	11	0.98	11
R5	0.79	4	2.38	9	1.88	3	1.29	7	0.22	1	1.42	8	5.21	7	1.37	4	0.26	8	0.62	2	0.54	5
R6	0.83	6	2.31	3	3.44	8	1.08	5	0.83	3	0.61	2	1.97	3	0.97	1	0.22	6	1.54	7	0.36	3
A972/R2	0.88	8	2.37	8	1.18	2	1.20	6	1.26	6	0.88	4	5.47	8	1.83	7	0.21	5	13.71	12	0.72	8
A972/R5	0.41	2	2.34	6	2.65	4	1.08	4	1.44	11	1.39	7	1.80	2	1.04	2	0.11	2	1.10	4	0.36	4
A972/R6	0.21	1	4.51	10	1.04	1	0.64	3	0.92	4	1.06	5	2.07	4	1.56	6	0.16	3	0.44	1	0.26	1
SST972	1.68	11	7.97	11	9.29	11	0.25	1	1.44	10	1.42	9	1.53	1	2.03	9	0.17	4	1.23	5	0.27	2
SST983	0.81	5	16.05	12	16.21	12	2.71	10	1.30	7	0.67	3	15.20	12	3.49	12	0.23	7	2.40	10	0.56	6

Table 4.2: AMMI Stability values and rankings of the Winter Hybrid Performance Trial (WHBPT 04+05).

GENOTYPE	HLM	Rank	SKCSDIAM	Rank	SKCSG	Rank	HFN	Rank	ASTR	Rank	ASH	Rank	MMT	Rank	WGC	Rank
ELANDS	1.77	12	0.51	12	0.71	6	7.13	10	3.42	11	0.85	12	1.04	12	1.71	5
SST966	0.85	7	0.16	3	2.26	11	6.29	9	1.40	5	0.35	11	0.83	9	1.96	6
SST399	1.67	10	0.45	9	2.10	10	3.48	5	2.91	10	0.09	1	0.86	10	2.63	9
B966	0.77	3	0.40	8	2.31	12	3.95	6	1.34	3	0.34	10	0.71	7	4.55	12
B972	1.19	9	0.48	10	1.87	9	7.30	11	2.00	8	0.28	9	0.98	11	3.55	10
R2	0.82	5	0.33	7	1.62	8	5.21	7	1.37	4	0.26	8	0.54	5	3.76	11
R5	0.84	6	0.18	5	0.69	5	1.97	3	0.97	1	0.22	6	0.36	3	1.49	3
R6	0.90	8	0.49	11	0.98	7	5.47	8	1.84	7	0.21	5	0.72	8	2.54	8
SST935 (A966/R2)	0.39	2	0.12	1	0.51	2	1.80	2	1.04	2	0.11	2	0.36	4	1.67	4
A966/R5	0.22	1	0.17	4	0.53	3	2.07	4	1.56	6	0.16	3	0.26	1	2.10	7
SST946 (A966/R6)	1.73	11	0.14	2	0.49	1	1.53	1	2.03	9	0.17	4	0.27	2	0.90	1
SST972	0.79	4	0.26	6	0.64	4	15.20	12	3.49	12	0.23	7	0.56	6	1.16	2

affected by the IPCA 2 factor. He then suggested using the AMMI stability value (ASV) formula to achieve this. With this method, the distance from zero is determined in a two-dimensional scattergram of IPCA 1 scores against IPCA 2 scores (Purchase et al., 2000b).

The AMMI stability values were calculated in the manner proposed by Purchase (1997) and presented in Table 4.1 and Table 4.2 for the Facultative (IHBPT) and Winter (WHBPT) genotypes.

Table 4.1 and 4.2 indicates that ash (ASH) and mixograph mixing time (MMT) was the most stable of all the measured characteristics over environments and both trials. The most unstable of all characteristics was Hagberg Falling number (HFN) over environments and both trails.

The ASV in Table 4.1 and Table 4.2 over both trials confirmed that the new generation hybrids were more stable over all characteristics than the older generation hybrids and compared to other genotypes, even more stable than the pure line Elands and SST399.

The facultative trial revealed that the hybrid A972/R6 as well as the male R6, were the most stable genotypes over all characteristics measured. They were followed by the hybrid A972/R5 as well as its male R5. The poorest stability was revealed by the hybrids SST966, A972/R2 and SST983. The females together with the pure line Elands revealed intermediate type of stability. The hybrid A972/R5 had stable values for HLM, HFN, ASTR and ASH. The hybrid A972/R6 revealed stable values for the characteristics HLM, SKCSG, SKCS_HI, ASH, CABS and MMT. The male R6 revealed stability for SKCSDIAM, BFLY, FLY, HFN, ASTR and MMT. The male R5 was stable for SKCSG, BFLY, CABS.

The winter trial revealed that the hybrid SST935 (A966/R2), SST946 (A966/R6), A966/R5 followed by the male R5 were the most stable over all characteristics measured. The worst stability was revealed by the pure line Elands, female B972 and males R2 and R6. The hybrids SST972 and SST966 showed the poorest stability of the group hybrids evaluated. The female B966 revealed intermediate type of stability,

which was not the case for B972 which showed no stability over all characteristics measured in this winter trail. The female B966, being a winter growth type, was the more stable of the two females, B966 and B972. The hybrid SST935 (A966/R2) revealed stability for the characteristics HLM, SKCSDIAM, SKCSG, HFN, ASTR, ASH. SST946 (A966/R6) had stable SKCSDIAM, SKCSG, HFN, MMT and WGC. The hybrid A966/R5 had stable values for HLM, SKCSG, ASH and MMT. The characteristics HFN, ASTR, MMT and WGC were stable for the male line R5.

4.4 CONCLUSIONS AND RECOMMENDATION

In general it could be said that within each of the two trials the hybrids did have the best stability performance over all characteristics measured of the total group of genotypes evaluated. They also outperformed the pure line cultivar Elands when stability performance was considered. The male and female lines performed intermediate in terms of stability for the characteristics measured. The male genepool was overall more stable than the female genepool.

This was confirmed when SST966 (winter growth type) was evaluated within the winter genepool, where it performed better than when evaluated with the intermediate genepool. The same was true for SST972 (intermediate growth type) which performed better with the intermediate genepool than with the winter genepool. This confirms that it is important to evaluate and select stable genotypes for quality characteristics from the facultative group compared to standards from the facultative genepool as the growth period of the genotype influence the quality depending on the year or environment effect.

When SKCSG and SKCSDIAM of the winter and facultative trial are compared it becomes evident that both characteristics were more stable in the winter hybrid performance trial. This could relate to the fact that Purchase (2000a) reported superior adaptation of hybrids and long growth period cultivars to high yield potential conditions.

With global warming becoming an important factor to deal with, erratic environmental conditions are becoming more visible, and therefore stability performance should be an

important breeding goal for quality characteristics and stable hybrid standards should also be included as representatives of the growth types evaluated.

CHAPTER 5

CHARACTERIZATION OF FALLING NUMBER AND SPROUTING TOLERANCE IN SOUTH AFRICAN HYBRID BREAD WHEAT

5.1 INTRODUCTION

South African hybrid cultivars have a tendency to sprout in certain years, but it is not known whether this is due to environmental and/or genetic factors. The contribution of the male and female parents is unknown, due to the fact that only the hybrids are commercially planted and harvested by the farmers.

Environmental conditions during seed development are known to strongly influence the level of sprouting tolerance (Takahashi, 1980). Resistance to pre-harvest sprouting (PHS) is expressed as a quantitative character and is affected by environment x genotype interaction (G X E) (Hagemann and Ciha, 1987). It is difficult to effectively screen for pre-harvest sprouting (PHS) tolerance in the field because of rainfall variability in most environments. Varying maturity dates characteristic of lines and hybrids in most plant breeding programs also confound interpretation of dormancy in segregating and advanced lines under naturally occurring rainfall.

Rain simulation facilities, as used in this study, have been developed by researchers to remove the confounding effects of the environment after physiological maturity (Mares, 1989; Barnard, 2001). When using rain simulation, it is critical that all material be harvested at the same stage of development (harvest ripeness), stabilized at the same moisture content (12%), and stored at low temperatures (-20^{o}C or lower) prior to evaluation in the rain simulator. Low temperature storage ensures that all enzymatic activity in the seed is halted. Spikes from plants with different maturity dates can then be evaluated together in the rain simulator. Temperature, humidity and spike wetting are strictly controlled in the simulator, and spikes are evaluated for visible germination after a fixed number of days. This method is very effective for identifying dormant progeny when dormancy is present in the physiologically mature grain. However, the expression of dormancy at maturity is often suppressed by rainfall during the three weeks prior to maturity.

Some researchers use rain shelters during the three weeks prior to maturity to protect field-grown plants from the effects of rainfall (Trethowan, 1995). However, temperature fluctuations during the later stages of grain filling cannot be controlled in the field. Rain simulators are effective in controlling environmental influences affecting expression of grain dormancy.

Researchers also use the Hagberg falling number test (AACC, 1983) to measure enzymatic activity in the harvested grain. This test measures the level of starch degradation caused by germination enzymes and is therefore strongly correlated with PHS. PHS of grain during wet harvest conditions leads to high levels of ∂-amylase, which are detrimental to end-use quality (Mcaig and De Pauw, 1992) and thus high quality grain must have low ∂-amylase activity, which is usually measured by the FN test (Lunn *et al*., 2001a). High ∂-amylase (low FN) can be caused by any one or combination of the following:

- Retained pericarp ∂-amylase which results from a failure of the normal, maturation dependent destruction of low pI (pericarp, "green", developmental) ∂-amylase that is always present in the maternal seed coat of the developing grain (Olered and Jönsson, 1978). It appears to be associated with environmental conditions such as frost, low temperature, low light intensity or with conditions that interfere with the normal course of the grain development and ripening.
- Pre-ripeness sprouting which results from the premature germination of ripening wheat grain. Trials conducted in northern Japan reported this phenomenon in grain that showed symptoms of black point (Nakatsu et al., 1996). The condition can also be induced in the later stages of ripening by a combination of moist and cool temperature.
- Post ripeness sprouting (pre-harvest sprouting) is the most common cause of high amylase in wheat and is caused when ripe wheat is subjected to prolonged wet conditions (Lunn *et al.,* 2001b).
- Late maturity ∂-amylase (LMA) is found in specific genotypes in some environments (Mrva and Mares, 2001).

Irrespective of the causes of low FN (including pre-harvest sprouting), high levels of ∂-amylase leads to starch breakdown which affects the quality of end-use products negatively. The HFN test is relatively fast and easy; however grain must be harvested in sufficient quantity and milled to produce a minimum of 7 g of flour. HFN is effective for screening large breeding populations compared to the laborious and time consuming rain simulation evaluation.

Some genotypes are more susceptible to pre-harvest sprouting and it was noted in the national cultivar evaluation trials that hybrid wheat cultivars, of all cultivars planted had the highest tendency to sprout (personal communication - A. Barnard, Small Grain Institute). This was very seasonal, and in some years the sprouting and/or falling number was no problem at all. This urged further research into the origin of the pre-harvest sprouting susceptibility in hybrid wheat and its parents. The breeder could develop sprouting tolerant hybrids, but should consider that genetic improvement is complex and time-consuming in hybrids and influenced by both the male and female parent.

South African producers are currently compensated for their produce in accordance with the Wheat Grading Regulations as stipulated in the amended Agricultural Product Standards Act of 1990 (Act no. 119) (Anonymous, 2003). Accordingly, a HFN of at least 220 s is required for Grade B1, B2 and B3. Should a producer have wheat with sufficient protein levels and hectolitre mass to obtain grade B1, but the wheat is downgraded to grade B4 due to a HFN of below 220 s, a loss of more than R 180 (± $29) per ton could be expected (personal communication – N. van der Merwe, Small Grain Institute). Furthermore, a visual inspection of the grain is done and a tolerance of 2% sprouted kernels is allowed.

Sprouted wheat grain affects the milling and baking quality of wheat negatively. The test weight and flour milling yield of sprouted grain are considerably lower than those of non-sprouted grain. Bread produced from sprouted grain has poor loaf volume, and crumb structure tends to be wet and sticky (Barnard, 2001). The release of sugars by ∂-amylase activity aids the fermentation process of bread. Presence of these sugars results in sticky crumbs of poor resilience and texture. Caramelization furthermore results in dark crusts (Gooding and Davies, 1997). As sugars combine with some

amino-acids by the Mailard reaction, the crumb is turned brown (Kent and Evers, 1994). The sticky crumb also results in difficulties with mechanical cutting, as loaves are deformed as they pass through the slicer and slice thickness becomes irregular (Chamberlain *et al*., 1982). Bakery type flour has a HFN between 200 and 250 s. Below 150 s the bread crumb becomes sticky. Above 350 s, bread volume is diminished and a dry crumb results, unless the defect is balanced by the addition of malt (Perten, 1964). No literature is available on sprouting of hybrid wheat, therefore the aim of this study was to determine the sprouting and ∂-amylase activity in South African hybrid wheat.

5.2 MATERIALS AND METHODS

5.2.1 Genotypes

The preharvest sprouting trial planted at Bethlehem consisted of 25 winter and facultative bread wheat genotypes (Table 5.1).

Scale used to score sprouting from 1 (most left head) to 8 (most right head).

Table 5.1: Facultative and winter wheat genotypes

ENT	ID/GENOTYPE	NAME	ORIGINATING INSTITUTION	RELEASE DATE	SPROUTING TOLERANCE
1	COMMERCIAL FACULTATIVE HYBRID-1	A972/R41 (SST972)	SENSAKO	1997	REASONABLE
2	COMMERCIAL WINTER HYBRID-2	A966/R41 (SST966)	SENSAKO	1996	MEDIUM SUSCEPTIBLE
3	COMMERCIAL WINTER HYBRID-3	A936/R41 (SST936)	SENSAKO	1983	REASONABLE
4	FACULTATIVE HYBRID LINE-1	A23094/R41	SENSAKO		UNKNOWN
5	FACULTATIVE HYBRID LINE-2	A183/R41	SENSAKO		UNKNOWN
6	FACULTATIVE HYBRID LINE-3	A972/R2	SENSAKO		UNKNOWN
7	COMMERCIAL WINTER HYBRID-4	A966/R2 (SST935)	SENSAKO	2003	POOR
8	WINTER HYBRID LINE-4	A936/R2	SENSAKO		UNKNOWN
9	WINTER HYBRID LINE -5	A23094/R2	SENSAKO		UNKNOWN
10	WINTER HYBRID LINE-6	A183/R2	SENSAKO		UNKNOWN
11	COMMERCIAL WINTER HYBRID-5	A966/R6 (SST946)	SENSAKO	2004	REASONABLE
12	RESTORER WINTER MALE LINE	R2	SENSAKO		SUSCEPTIBLE STANDARD = 8
13	RESTORER FACULTATIVE MALE LINE	R41	SENSAKO		UNKNOWN
14	RESTORER WINTER MALE LINE	R6	SENSAKO		UNKNOWN
15	FACULTATIVE FEMALE FERTILE B-LINE	B972	SENSAKO		UNKNOWN
16	FACULTATIVE FEMALE FERTILE B-LINE	B966	SENSAKO		UNKNOWN
17	FACULTATIVE FEMALE FERTILE B-LINE	B936	SENSAKO		UNKNOWN
18	FACULTATIVE FEMALE FERTILE B-LINE	B23094	SENSAKO		UNKNOWN
19	FACULTATIVE FEMALE FERTILE B-LINE	B183	SENSAKO		UNKNOWN
20	FACULTATIVE PURE LINE/CONV. VAR.**	BETTA-DN	SGI*	1993	TOLERANT
21	FACULTATIVE PURE LINE/CONV. VAR.**	ELANDS	SGI*	1998	TOLERANT STANDARD
22	FACULTATIVE PURE LINE/CONV. VAR.**	SST124	SENSAKO	1987	REASONABLE
23	FACULTATIVE PURE LINE/CONV. VAR.**	SST334	SENSAKO	2003	EXCELLENT
24	FACULTATIVE PURE LINE/CONV. VAR.**	SST322	SENSAKO	2002	EXCELLENT
25	FACULTATIVE PURE LINE/CONV. VAR.**	PAN3349	SENSAKO	1997	POOR

*SGI = SMALL GRAINS INSTITUTE, **CONV. VAR. = CONVENTIONAL VARIETY

5.2.2 Field trials

The trial was conducted in the dryland, summer rainfall region (Bethlehem, Eastern Free State) of South Africa during the wheat cropping cycles of 2004 and 2005. The planting date of the Eastern Free State trial was before 10 July to fulfill vernalization

requirements of the winter types. Bethlehem is known to produce excellent sprouting data as a result of the effect the cooler environment has on the ∂-amylose activity (Barnard and Ybema, 1999). Experimental plots consisting of five rows (5 m in length, with a 40 cm inter row spacing) were planted, using a randomized complete block design with three replicates. A total of 200 kg ha^{-1}, 6:2:1 (31), at a rate of 41 kg ha^{-1} nitrogen, 20 kg ha^{-1} phosphate and 10 kg ha^{-1} potassium fertilizer was applied with planting.

5.2.3 Laboratory methods

Characteristics measured included the pre-harvest sprouting score determined in the rain simulator and the selected quality characteristics (with special attention to HFN) determined on the grain of the remaining plots harvested after the last treatment (physiological maturity plus 21 days) heads were cut. Therefore quality measurements were determined after exposure to the natural environment.

5.2.3.1 Sprouting evaluation in the rain simulator

Hand harvested spike bundles/samples and quality samples were obtained separately for each of the 25 entries from all three replications. Each of the 75 samples contained 10 heads per sample. Due to the variation in year effects, growth period and vernalization requirements of the facultative and winter wheat varieties, each sample of each genotype was taken at physiological maturity. Thereafter each genotype/entry was separately cut with 7 days intervals from each physiological maturity date noted for each genotype. Thus a sample of each entry, from each replication was collected at physiological maturity, and then 7, 14 and 21 days after physiological maturity of each genotype. These samples were placed in a freezer to ensure that all enzymatic activity was stopped until they were screened for their ability to tolerate a specified amount of simulated rainfall. The spikes were subjected to simulated rainfall for 72 h in a rain simulator (McMaster and Derera, 1976) where a misty spray was applied overhead, while the trays rotated at a uniform speed. According to this technique, heads are cut at physiological maturity, placed in the freezer and the erect spikes per replicate were randomly placed on perforated trays. After the 72 h, spikes were evaluated on a scale from 1 (no visible sprouting) to 8 (fully sprouted) (Barnard *et al.*, 1997). This study

made small adaptations in the standard method by cutting more than one treatment, with weekly intervals from the physiological maturity date.

5.2.3.2 Quality evaluation of remaining harvested grain exposed to the environment

The remaining plots of wheat in the field were harvested with a combine and cleaned before quality evaluation. The trial was exposed to natural environmental influences while the other spike bundles were exposed to optimum rain simulation.

Test weight was determined using a Franklin chondrometer. Grain samples of 1.3 kg were milled with a CD-1 mill. First break (break flour yield) and flour yield was then determined.

Grain samples of 7 g were milled with a CYCLOTEC 1093 sample mill (0.5 mm sieve) after which Hagberg Falling Numbers (HFN, s) were determined (AACC, 1983). Special attention was given to HFN as a result of its relationship with sprouting and the mutual effect both have on ∂-amylase activity.

Single kernel characteristics were determined using the SKCS 4100 (Perten Instruments, Springfield, IL). This instrument measures characteristics like kernel diameter (average diameter of 300 kernels), hardness index (the index as percentage of the pressure of two rollers to crush 300 kernels) and kernel weight (the average weight of 300 kernels in mg). Protein-, ash- and wet gluten content were analyzed with the NIT (FOSS 1241).

Water absorption was evaluated with the Chopin consistograph 4604 because of reports that the consistograph water absorbtion value was correlated more accurately with what was found in the industry and it is a quicker method to use (personal communication, Jan Cilliers, SENSAKO Bethlehem).

Mixograph development time (MDT, min) was determined with a 10 g National mixograph (National Mfg., Lincoln, Nebraska) (AACC, 1983). Other rheological analyses were performed according to the approved methods (AACC, 1983) and included the Chopin alveograph determinants: dough strength (AS, cm^2), alveograph

stability (ASTAB, mm), alveograph distensibility (AD, mm) and the ratio of stability to distensibility (P/L).

5.2.4 Environmental conditions

Wheat cultivation under dry land conditions in the summer rainfall region of South Africa accounts for approximately 50% of the total annual bread wheat production (South African Grain Laboratory, 2002) of 2.1 million metric ton produced in the country. This is obtained by growing mainly winter and facultative cultivars in the Free State province (Barnard *et al*., 1999) which is planted in the autumn and winter months on residual soil moisture.

5.2.4.1 Year 2004

Trails in the Eastern Free State were the worst in years. Conditions during planting were acceptable, emergence was good but drought during the growing season put stress on the plants. The average long term rainfall for Bethlehem is 713 mm and during 2004 a total of 705 mm was recorded. From October the spring rainfall started again and a total of 33 mm of rain fell for October and 64.4 mm was noted for November. A total of 211 mm rain was recorded for December, which was higher than the long term values for the month. The trial was harvested before any rain fell in January.

5.2.4.2 Year 2005

Planting conditions for the 2005 season were good. The average long term rainfall for Bethlehem is 725 mm and during 2005 a total of 944 mm was recorded. Emergence was good and no further rain fell during the growing season till mid-November when 95 mm was recorded. During December the rainfall went below the long term figures and 48 mm was recorded for the month. Until the last harvesting took place in January, a total of 100 mm rain was recorded on the trial for the month.

5.2.5 Statistical analysis

5.2.5.1 Analysis of variance (ANOVA)

Combined analysis of variance for the sprouting score and quality characteristics was performed on three replications of the trial. Analyses were done for 2004 and 2005. The cultivar means for all the characteristics were used to compare the performance of the genotypes using Agrobase (1999).

5.2.5.2 Calculation of mid-parent and high-parent heterosis

Mid-parent heterosis was determined by comparing the performance of the hybrid to the average performance of its parents: (Parent 1+ Parent 2)/2 = average performance of the parents and is then compared to the performance of the hybrid. High-parent heterosis was determined by comparing the performance of the hybrid to the performance of the better parent of the hybrid.

This study proposed another method where heterosis was determined by comparing the performance of the hybrid to the performance of the best standard used for the characteristic measured, in this case Elands. This was as a result of the situation mostly caused by highly competitive and successful research in the public sector achieving genetic improvement of wheat at a constant rate by using conventional techniques and procedures. This was done on the averages of 2004 and 2005 combined data for both sprouting score (all treatments combined) and the Hagberg Falling Number (HFN). Percentage heterosis was calculated as follows:

H_{MP} (mid parent heterosis) = $\frac{F1 - (P1+P2)/2}{(P1+P2)/2} \times \frac{100}{1}$

where P1 is the value of the one parent (female) and P2 the value of the other parent (male) and F1 the average value of the F1 – hybrid.

5.2.5.3 Correlation matrix

The correlation matrix was performed on the sprouting score at physiological maturity plus 21 days (PM+21D) in combination with the analyzed quality data which was harvested after the PM+21D heads were cut from the plot. This was done over the 2004 and 2005 year period using Agrobase (1999).

5.3 RESULTS AND DISCUSSION

5.3.1 Combined analysis of variance

5.3.1.1 Sprouting tolerance score

The occurrence of pre-harvest sprouting is erratic and is as difficult to predict as rainfall in the summer rainfall region of South Africa. Farmers harvest their wheat during this rainfall period and expose them to the risk of sprouting in certain years. Plant breeders are therefore obligated to provide farmers with genetic protection as far as possible, especially in those areas prone to sprouting. Bethlehem, which forms part of the Eastern Free State and summer rainfall region is at risk to receive rain during the harvest period in December.

The analysis of variance was done on the sprouting score of each genotype exposed to rain simulation at physiological maturity (treatment 1), seven days after physiological maturity (treatment 2), 14 days after physiological maturity (treatment 3), 21 days after physiological maturity (treatment 4) and an average of scores from all treatments combined together.

Table 5.2: Mean squares for sprouting score for twenty five wheat genotypes at four different harvesting dates during 2004

	PREHARVEST SPROUTING SCORE FROM RAIN SIMULATION							
	Treatments Combined			Treatments Separated				
	T1+2+3+4	T1+2+3+4		T1/T2/T3/T4	T1/fm	T2/fm+7d	T3/fm+14d	T4/fm+21d
SOURCE	df	MS	SOURCE	df	MS	MS	MS	MS
Total	299		Total	74				
Replicates	2	0.494*	Replicates	2	0.987**	0.021	0.228	0.007
Genotype	24	40.614**	Genotype	24	13.102**	13.304**	22.258**	11.215**
Treatment	3	196.661**	Residual	48	0.150	0.057	0.227	0.203
Genotype by Treatment	72	6.421**						
Residual	198	0.162						

Table 5.3: Mean squares for sprouting score for twenty five wheat genotypes at four different harvesting dates during 2005

	PREHARVEST SPROUTING SCORE FROM RAIN SIMULATION							
	Treatments Combined			Treatments Separated				
	T1+2+3+4	T1+2+3+4		T1/T2/T3/T4	T1/fm	T2/fm+7d	T3/fm+14d	T4/fm+21d
SOURCE	df	MS	SOURCE	df	MS	MS	MS	MS
Total	299		Total	74				
Replicates	2	1.142	Replicates	2	1.920*	5.804	1.48	0.384
Genotype	24	25.933**	Genotype	24	4.729**	8.902**	15.041**	10.113**
Treatment	3	239.190**	Residual	48	0.553	2.411	0.736	1.002
Genotype by Treatment	72	4.284**						
Residual	198	1.225						

Table 5.4 : Mean squares for sprouting score for twenty five wheat genotypes at four harvesting dates for 2004 and 2005.

	PREHARVEST SPROUTING SCORE FROM RAIN SIMULATION							
	Treatments Combined			Treatments Separated				
	T1+2+3+4	T1+2+3+4		T1/T2/T3/T4	T1/fm	T2/fm+7d	T3/fm+14d	T4/fm+21d
SOURCE	df	MS	SOURCE	df	MS	MS	MS	MS
Total	599		Total	149				
Replicates	2	0.183	Replicates	2	2.816*	2.836	0.353	0.169
Genotype	24	60.378**	Genotype	24	13.557**	17.137**	30.143**	17.703**
Treatment	3	406.142**	Year	1	22.737**	34.608**	53.342**	1.320
Year	1	22.881**	Genotype by Year	24	4.274**	5.069**	7.155**	3.625**
Genotype by Treatment	72	6.054**	Residual	98	0.346	1.270	0.499	0.594
Genotype by Year	24	6.17**						
Treatment by Year	3	29.709**						
G X T X Y	72	4.651**						
Residual	398	0.697						

df = Degrees of Freedom
MS = MEAN SQUARE
** Significant at P < 0.01.
* Significant at P < 0.05.
G X T X Y = Genotype by Treatment by Year
T1+2+3+4 = Four treatments combined
T1/T2/T3/T4 = Separate treatments
T1 = Treatment 1 = Heads cut at fisiological maturity
T2 = Treatment 2 = Heads cut at fisiological maturity plus 7 days
T3 = Treatment 3 = Heads cut at fisiological maturity plus 14 days
T4 = Treatment 4 = Heads cut at fisiological maturity plus 21 days

Table 5.5: Genotype means of the sprouting trial planted during 2004

ENTRY	GENOTYPE	T1/ PM	T-2/ PM+7D	T3/ PM+14 D	T4/ PM+21 D	T1 to 4	RK
1	A972/R41 (SST972)	3.30	1.90	1.87	5.57	3.16	10
2	A966/R41 (SST966)	3.07	2.57	7.00	7.13	4.94	20
3	A936/R41 (SST936)	3.23	2.27	6.60	5.90	4.50	15
4	A23094/R41	2.77	1.17	1.40	6.23	2.89	9
5	A183/R41	6.03	2.57	1.93	7.50	4.51	16
6	A972/R2	1.43	3.27	7.00	8.00	4.93	19
7	A966/R2 (SST935)	3.83	8.00	8.00	8.00	6.96	23
8	A936/R2	1.07	1.60	5.60	8.00	4.07	13
9	A23094/R2	7.10	6.37	8.00	8.00	7.37	24
10	A183/R2	6.37	3.93	5.23	8.00	5.88	22
11	A966/R6 (SST946)	1.70	1.70	6.00	6.93	4.08	14
12	R2	7.83	8.00	8.00	8.00	7.96	25
13	R41	4.83	1.87	5.57	8.00	5.07	21
14	R6	2.40	3.07	7.00	6.90	4.84	18
15	B972	1.63	1.00	1.57	5.00	2.30	6
16	B966	3.20	1.20	5.00	6.43	3.96	12
17	B936	1.40	1.07	1.07	5.57	2.28	5
18	B23094	1.00	1.00	1.67	5.53	2.30	7
19	B183	6.53	4.50	1.80	6.33	4.79	17
20	BETTA-DN	1.70	1.00	1.00	4.23	1.98	3
21	ELANDS	1.03	1.00	1.00	1.13	1.04	1
22	SST124	1.77	1.00	1.00	5.10	2.22	4
23	SST334	2.20	1.00	1.23	5.63	2.52	8
24	SST322	1.43	1.00	1.03	1.07	1.13	2
25	PAN3349	1.97	1.77	3.00	8.00	3.68	11
C.V.		12.29%	9.38%	12.09%	7.20%	10.13%	
LSD		0.5309	0.3279	0.6527	0.6163	0.2716	

C.V. = Coefficient of variance

LSD = Least significant differences
RK = Ranking
T1/PM = Treatment-1 / Physiological Maturity
T2/PM+7D = Treatment-2 / Physiological Maturity + 7 DAYS
T3/PM+14D = Treatment-3/ Physiological Maturity + 14 DAYS
T4/PM+21D = Treatment-4/ Physiological Maturity + 21 DAYS

Table 5.6: Genotype means of the sprouting trial planted during 2005

ENTRY	GENOTYPE	T1 / PM	T-2/ PM+7D	T3/ PM+14 D	T4/ PM+21 D	T1 to 4	RK
1	A972/R41 (SST972)	1.87	5.07	3.87	6.33	4.28	14
2	A966/R41 (SST966)	1.47	2.27	2.93	8.00	3.67	10
3	A936/R41 (SST936)	1.47	2.00	3.47	5.53	3.12	5
4	A23094/R41	1.67	2.13	2.47	8.00	3.57	9
5	A183/R41	2.73	3.47	5.80	6.73	4.68	15
6	A972/R2	2.40	6.07	6.13	7.00	5.40	17
7	A966/R2 (SST935)	3.47	4.00	8.00	8.00	5.87	20
8	A936/R2	3.47	5.53	7.33	8.00	6.08	22
9	A23094/R2	4.40	4.27	8.00	8.00	6.17	23
10	A183/R2	2.40	5.20	7.33	7.33	5.57	19
11	A966/R6 (SST946)	3.00	1.80	8.00	7.33	5.03	16
12	R2	5.67	6.53	8.00	8.00	7.05	25
13	R41	3.27	6.20	6.73	8.00	6.05	21
14	R6	5.00	4.20	8.00	8.00	6.30	24
15	B972	1.13	1.13	1.40	2.07	1.43	1
16	B966	1.73	2.87	3.33	8.00	3.98	13
17	B936	1.78	4.13	2.77	4.48	3.29	7
18	B23094	1.42	1.27	2.12	8.00	3.20	6
19	B183	2.78	5.70	7.33	6.25	5.52	18
20	BETTA-DN	1.57	2.35	3.12	7.00	3.51	8
21	ELANDS	1.00	1.27	2.57	3.03	1.97	2
22	SST124	1.00	2.28	4.07	4.73	3.02	4
23	SST334	1.60	2.42	5.02	5.67	3.68	11
24	SST322	1.75	1.67	4.73	3.37	2.88	3
25	PAN3349	1.33	4.00	5.87	4.02	3.80	12
C.V.		31.32%	44.21%	16.71%	15.55%	25.36%	
LSD		1.0184	2.1265	1.1748	1.3708	0.7468	

Table 5.7 : Genotype means of the sprouting trial planted during 2004 and 2005

ENTRY	GENOTYPE	T1 / PM	T-2/ PM+7D	T3/ PM+14 D	T4/ PM+21 D	T1 to 4	RK
1	A972/R41 (SST972)	2.58	3.48	2.87	5.95	3.72	16
2	A966/R41 (SST966)	2.27	2.42	4.97	7.57	4.30	12
3	A936/R41 (SST936)	2.35	2.13	5.03	5.72	3.81	14
4	A23094/R41	2.22	1.65	1.93	7.12	3.23	17
5	A183/R41	4.38	3.02	3.87	7.12	4.60	10
6	A972/R2	1.92	4.67	6.57	7.50	5.16	7
7	A966/R2 (SST935)	3.65	6.00	8.00	8.00	6.41	3
8	A936/R2	2.27	3.57	6.47	8.00	5.08	9
9	A23094/R2	5.75	5.32	8.00	8.00	6.77	2
10	A183/R2	4.38	4.57	6.28	7.67	5.73	4
11	A966/R6 (SST946)	2.35	1.75	7.00	7.13	4.56	11
12	R2	6.75	7.27	8.00	8.00	7.50	1
13	R41	4.05	4.03	6.15	8.00	5.56	6
14	R6	3.63	3.70	7.45	7.50	5.57	5
15	B972	1.38	1.07	1.47	3.53	1.87	24
16	B966	2.47	2.03	4.17	7.22	3.97	13
17	B936	1.59	1.92	2.60	5.03	2.78	19
18	B23094	1.21	1.13	1.89	6.77	2.75	20
19	B183	4.66	4.57	5.10	6.29	5.15	8
20	BETTA-DN	1.63	1.68	2.06	5.62	2.75	21
21	ELANDS	1.02	1.13	1.78	2.08	1.50	25
22	SST124	1.38	1.64	2.53	4.92	2.62	22
23	SST334	1.90	1.71	3.13	5.65	3.10	18
24	SST322	1.59	1.33	2.22	2.88	2.01	23
25	PAN3349	1.65	2.88	4.43	6.01	3.74	15
C.V.		21.29%	37.17%	15.57%	12.16%	20.03%	
LSD		0.5642	1.0805	0.6775	0.7392	0.3975	

5.3.1.1.1 Four treatments combined (treatments 1 to 4)

a. Year 2004

The analysis of variance of sprouting score for 2004 revealed significant differences for replicates. These differences could be due to the F2 segregating grain or heads that were evaluated in the trial and it could also be that some heads started to sprout while some did not. All genotypes in the trial were not genetically pure for the sprouting characteristic which became more evident when they were exposed for longer periods. Highly significant mean squares were noted for genotype, treatment and genotype by treatment (Table 5.2).

b. Year 2005

Highly significant mean squares for sprouting score were revealed for genotype, treatment and the interaction between genotype by treatment (Table 5.3). The genotype means for sprouting score over treatments one to four ranged from 1.04 (Elands) to 7.96 (R2) in 2004 and from 1.43 (B972) to 7.05 (R2) in 2005 (Table 5.6). The genotype grand means were 3.974 for 2004 and 4.365 for 2005 and differed significantly between the two years. In terms of sprouting resistance the female B972 and conventional cultivar, Elands were the best and they did not differ significantly from each other when the different treatments were combined for 2005. The conventional cultivars, SST322, SST124 and Betta-DN performed well whereas SST334 and PAN3349 did not show the same level of tolerance. The females, with exception of B972, which also had good sprouting tolerance were B23094, B936. B966 still performed within the acceptable range (score of below four) but not as well as the first group of females. B183 was the only female which was unacceptable. In general the females' sprouting levels were as good as that of the conventional cultivars, as in practice these programs are handled as one and it became evident that selection for the sprouting characteristic was done. The sprouting score over treatments for the male group during 2005 revealed that they grouped together and that they, in general, did not have good sprouting resistance, in fact the male R2 had the lowest sprouting tolerance so far recorded in this evaluation program. The hybrids had intermediate tolerance which depended on the sprouting score of the male and female combined in the hybrid.

c. Year 2004 and 2005 combined

Genotype, treatment, year, interactions between genotype and treatment, genotype by year, treatment by year and genotype by treatment by year mean squares for sprouting score were highly significant (Table 5.4).

Variation in score was attributed to the different sprouting tolerance levels between the years and treatments. Over the two year period the grand mean was 4.169. R2 differed significantly from most combinations containing R2 (Table 5.7). R2 as male parent combined with any of the A-line parents, had high scores for sprouting tolerance, which means poor tolerance to sprouting. Although the hybrid combinations had significantly lower sprouting scores than R2, these results reflect the negative effect R2 had on the hybrid combinations. In general, the male lines had poor sprouting tolerance with high scores ranging between 5.56 and 7.50. In the female lines there was a higher level of sprouting tolerance, where B972 had a very low score of 1.87, thus excellent sprouting tolerance, which did not significantly outperform Elands (standard for very good sprouting tolerance). Although B972 has very good sprouting tolerance, it had very little effect in the hybrids. When combined with the poor males, like R2 for instance, it was totally down-graded to an unacceptable level. The only exception was the combination of SST972 where the female A972 was combined with the male R41 which had, although not acceptable, the lowest sprouting score of all males. Of all the males, R41 had the lowest score and therefore the best sprouting tolerance in the male genepool, and did not score significantly higher than R6.

Most females grouped together with the conventional varieties, except B183 and B966. The hybrids followed with the males in between. If selection would have been done on this data (over treatments for the years combined 2004 and 2005) Elands, B972, SST322, SST124, BETTA-DN, B23094, B936, SST334, A23094/R41, SST972, PAN3349, SST936, B966 would be selected. The only female which did not perform acceptably was B183. The four treatments (PM, PM+7 days, PM+14 days, PM+ 21 days) revealed significant differences between the four treatments. Most of the variation in score was obtained at physiological maturity treatment and physiological maturity plus 7 days treatment, where the average scores were significantly lower over both years compared to all other treatments. The average score consecutively increased from 2.76 (PM), 3.03 (PM+7D), 4.54 (PM+14D), 6.34 (PM+21D) over the four treatments during 2004 and 2005 combined.

5.3.1.1.2 Treatment one (physiological maturity)

a. Year 2004

Mean squares for replicates were highly significant for sprouting score for the heads cut at physiological maturity and exposed to the rain simulator. Sprouting score mean squares were also highly significant for genotypes.

b. Year 2005

Significant differences were recorded between the replicates but highly significant differences were revealed by genotype for sprouting score in 2005.

c. Year 2004 and 2005 combined

Significant differences for replicates were revealed for sprouting score when heads were cut at physiological maturity. Highly significant differences were found for genotype, year and the interaction between genotype by year. Treatment one (heads cut at physiological maturity) was not suitable to record sprouting score as too much variation existed between replicates. It became clear from Table 5.5, 5.6, 5.7 that the scores for treatment one, gave overall low sprouting scores which would result in most genotypes being selected. The data over treatments or for treatment three and four are much more reliable to select from. Selection at treatment one did not discriminate well enough between genotypes and did not reveal their true sprouting status.

5.3.1.1.3 Treatment two (physiological maturity plus seven days)

a. Year 2004

Genotype mean squares were highly significant. Most genotypes had acceptable low sprouting scores and most would have been selected for acceptable sprouting, except the female B183, the hybrids A23094/R2 and SST935 (A966/R2) that both contained R2 as male parent (Table 5.5). The male parent R2 consistently performed poorly and showed poor sprouting tolerance over years and treatments.

b. Year 2005

Starting from the second treatment, there were no significant differences between replicates. Highly significant differences for genotypes were found. Most genotypes

would have been selected except SST935, PAN3349, B936, R6, A23094/R2, SST972 (A972/R41), A183/R2, A936/R2, B183, A972/R2, R41 and R2.

c. Year 2004 and 2005 combined

Mean squares for genotype and year and interaction between the two were highly significant. If selection was done on this data the female B183, the males R41, R6, R2 and the hybrid combinations A972/R2, A183/R2, SST935 (A966/R2), A23094/R2 would not have been selected. The biggest proportion of genotypes still had tolerance to sprouting and would have made selection (Table 5.7).

5.3.1.1.4 Treatment three (physiological maturity plus 14 days)

a. Year 2004

Genotype mean squares were highly significant. Genotypes that would have been discarded were B966, A183/R2, R41, A936/R2, SST946 (A966/R6), SST936 (A936/R41), A972/R2, SST966 (A966/R41), R6, A23094/R2, SST935 (A966/R2), and again the male R2 (Table 5.5).

.

b. Year 2005

Highly significant mean squares were evident for genotype. The grand mean was higher for 2005 than 2004. Sixty percent of the genotypes would be discarded from treatment three if selection was applied. The genotypes to be discarded include B183, R41, R6, R2, A183/R41, A972/R2, SST935 (A966/R2), A936/R2, A23094/R2, A183/R2, SST946 (A966/R6), SST124, SST334, SST322 and PAN3349 (Table 5.6).

c. Year 2004 and 2005 combined

Mean squares for genotype, year and the interaction between genotype and year were highly significant. Year still had an effect on the genotypes and therefore multi-year data should be used to do selections. For the two year period the following genotypes would be discarded B183, B966, R41, R6, R2, A183/R41, A972/R2, SST936 (A936/R41), SST966 (A966/R41), SST935 (A966/R2), A936/R2, A23094/R2, A183/R2, SST946 (A966/R6) and PAN3349.

5.3.1.1.5 Treatment four (physiological maturity plus 21 days)

a. Year 2004

Highly significant differences were revealed for sprouting score during 2004 at treatment four. Only two genotypes resulted in low enough sprouting scores to be selected and included the conventional cultivars Elands and SST322 (Table 5.5).

b. Year 2005

Highly significant mean squares were recorded for genotype sprouting score at treatment four. Only three genotypes would be selected and scored below four for sprouting and they were B972, Elands and SST322.

c. Year 2004 and 2005 combined

Highly significant differences were recorded for genotype and the interaction between genotype and year. The variation in scores were the lowest at PM+21 days where it seemed if the scores actually “stabilized” the most, compared to all the other treatments.

Year did not have a significant effect in this treatment (Table 5.4). This is the only treatment where year did not significantly influence the values, and could be recommended as the best treatment to use to eliminate seasonal effects and that selection could be done on one year data. Each genotype at the four different treatments had the highest sprouting score at PM+21 days, where all of the entries had significantly lower scores at the other treatments especially at physiological maturity where very low scores were noted for all genotypes except R2, the combination hybrid lines A23094/R2, A183/R2, A183/R41, the female line B183 and other male line R41 which all started off with a high score of 4 and above at physiological maturity. Elands, the tolerant standard for sprouting tolerance, and SST322 maintained their low scores over all four treatments which complied with classification status of the cultivars in the national cultivar trials (personal communication, A. Barnard). The research done by Barnard *et al.* (1997) on sprouting tolerance in South African wheat, was done on heads cut at physiological maturity dates, which indicated that the lowest variation in data was found when heads were cut at PM+14 (Treatment 3) and especially at PM+21 days (Treatment 4). Some lines which showed tolerance at physiological maturity did not maintain the tolerance like Elands, throughout all the treatments.

Some showed tolerance at physiological maturity and then suddenly lost the tolerance at the next treatment date. Therefore one can say that a genotype with high tolerance to sprouting can maintain its tolerance till 14 or 21 days after physiological maturity. Measuring sprouting tolerance by using a different treatment than physiological maturity can also exclude the effects the environment could have during seasons. The question also rises whether selection should be done on a specific treatment or the combination of the treatments. Treatment 4 would identify parents which could definitely be used as crossing parents to improve sprouting tolerance. A cultivar like SST935 for instance would be planted in the Western Free State where sprouting is not a problem like in the Eastern Free State and though sprouting is a problem in this cultivar it is not exposed to high risk environments. Cultivars could thus be sorted into certain groups as a score per treatment to explain their ability to tolerate sprouting over a certain period. This could give an indication of the endurance ability of a genotype to tolerate sprouting.

5.3.1.1.6 Grouping of genotypes per treatment

The analysis of variance for 2004 showed highly significant mean squares for genotypes, treatment and the interaction between genotype and treatment. Between the four treatments highly significant differences were recorded between all treatments: physiological maturity (PM), PM+7days, PM+14days, PM+21days. The PM+21 days treatment revealed least variable scores and thus gave more consistent and stable data. Some genotypes did vary over treatments especially the intermediate tolerant or susceptible group.

The analysis of variance for 2005 showed significant differences for genotypes, treatment and the interaction between genotype and treatment. Between the four treatments significant differences were recorded between all treatments: physiological maturity (PM), PM+7days, PM+14days, PM+21days. The PM+21 days treatment again revealed least variable scores and thus gave more consistent and stable data like the situation in 2004.

The genotypes per treatment revealed that if cultivars could be classed over the two year period, certain lines and cultivars consistently performed good or poor over all treatments and these genotypes could be classed as truly tolerant and really

susceptible. This was observed over the 2004 and 2005 period. By looking at each genotype per treatment over both years, cultivars can be further classed according to their ability to sustain their tolerance, as some loose their tolerance after the first, second or third week. It would seem that within the current tolerant class one can divide it further into more than one tolerant group. This could also be communicated to producers to harvest groups with a “susceptible” or shorter tolerance period prior to the more tolerant groups. This was valid for both years. Some genotypes in the more intermediate tolerant or intermediate susceptible group, showed more variable data. This could be due either to environmental influences or to the fact that genotypes were not genetically pure for the sprouting characteristic evaluated.

When summarizing the genotypes per treatment, 19 of the 25 (76%) genotypes could be selected or scored as tolerant according to their average score over two years. After the following treatment (PM+7days), 18 of 25 (72%) genotypes could be classed as tolerant. For the third treatment, 14 days after physiological maturity, only 12 of the 25 (48%) genotypes remained tolerant. The last and least variable score, namely 21 days after physiological maturity left only three genotypes as tolerant to sprouting, which resulted in a very low (12%) tolerance level. A genotype was scored as tolerant below a score of four.

When the interaction between genotype and year was investigated on the averages of genotypes over the two years, no definite pattern was observed and all entries were significantly different for 2004 and 2005. Only the hybrid combinations A183/R41, A972/R2, A183/R2, the female parent B966 (which is the female of the very stable hybrid SST966) and the cultivar PAN3349 did not differ significantly over the two years.

The four different treatments over both years 2004 and 2005 gave significantly different scores for all treatments except for treatment PM+21 days where a constant mean average was recorded over both years and did not differ significantly.

Table 5.8: Grouping of genotypes scored per the four treatments for 2004, 2005 combined.

Times Scored as tolerant out of the four treatments	ENTRY NO	Genotypes
4/4 treatments scored as tolerant = excellent	21	Elands
	24	SST322
	15	B972
3/4 times scored as tolerant = good	1	SST972
	2	SST966
	4	A23094/R41
	17	B936
	18	B23094
	20	BETTA-DN
	22	SST124
	23	SST334
2/4 times scored as tolerant = acceptable	3	SST936
	5	A183/R41
	8	A936/R2
	11	SST946
	14	R6
	16	B966
	25	PAN3349
1/4 times scored as tolerant = poor	6	A972/R2
	7	SST935
0/4 times scored as tolerant (susceptible group) = unacceptable	9	A23094/R2
	10	A183/R2
	12	R2
	13	R41
	19	B183

* Tolerant status was given when the genotype had a score below four.

5.3.1.1.7 Heterosis of sprouting score

Table 5.9: Mid- and high parent heterosis percentages of sprouting score for 11 hybrids on the combined treatments during 2004 and 2005

Entry	Genotype	F1 Score	Female	Male	MPH*	% Het	HPH**	% Het	BSH**	% Het
1	A972/R41(SST972)	3.72	1.87	5.56	3.72	0.50	1.87	185.00	1.05	267.00
2	A966/R41(SST966)	4.30	3.97	5.56	4.77	-46.50	3.97	33.00	1.05	325.00
3	A936/R41(SST936)	3.81	2.78	5.56	4.17	-36.00	2.78	103.00	1.05	276.00
4	A23094/R41	3.23	2.75	5.56	4.16	-92.50	2.75	48.00	1.05	218.00
5	A183/R41	4.60	5.15	5.56	5.36	-75.50	5.15	-55.00	1.05	355.00
6	A972/R2	5.16	1.87	7.50	4.69	47.50	1.87	329.00	1.05	411.00
7	A966/R2(SST935)	6.41	3.97	7.50	5.74	67.50	3.97	244.00	1.05	536.00
8	A936/R2	5.08	2.78	7.50	5.14	-6.00	2.78	230.00	1.05	403.00
9	A23094/R2	6.77	2.75	7.50	5.13	164.50	2.75	402.00	1.05	572.00
10	A183/R2	5.73	5.15	7.50	6.33	-59.50	5.15	58.00	1.05	468.00
11	A966/R6(SST946)	4.56	3.97	5.57	4.77	-21.00	3.97	59.00	1.05	351.00

Hybrids are used to exploit heterosis and to identify or select genotypes which show hybrid vigor. With the overdominance hypothesis, heterozygosity is necessary for the full expression of heterosis; the heterozygote outperforms either homozygote. Hybrid vigor could be seen as the increase in size, vigor, or productivity of a hybrid plant over the average or mean of its parents (mid-parent value). High-parent heterosis could also be measured, or the best standard heterosis, which would indicate if a hybrid performed better than a certain standard used to evaluate the measured characteristic. Otherwise genetic improvement would not be fast enough to keep up with conventional varieties.

Mid-parent heterosis indicated that the average of the population of the hybrids was the same as the performance of its parents. Mid-parent heterosis further revealed that seven of the hybrids had lower scores than the average of its parents and three hybrids had higher scores than the average of its parents, and one hybrid had exactly the same score as the average of its parents. High-parent heterosis revealed that all females, except B183, outperformed the hybrids with lower scores to sprouting and thus higher tolerance to sprouting. This could also be to the relative same scores both the male and female had in the combination A183/R41.

By taking the score of both the parents the sprouting score of the hybrid could largely be predicted as this was found to be intermediate between those of the parents (Table 5.4). All the females had lower scores than the males, which indicated that males contributed little to sprouting tolerance. The male line R2 should be discarded from the program due to its poor sprouting tolerance and if males were subjected to strict selection it should be possible to breed sprouting tolerant hybrids. Although no reports were found on the sprouting tolerance of hybrids, these results were in line with quality reports by other authors (Pickett and Galwey, 1997; Oury *et al*., 1995; Borghi and Perezin, 1994; Borghi *et al*., 1988).

Only three hybrids had a low enough sprouting score (below four) as a result of the very low score of the female parents A972, A936, A23094 (high parent heterosis score below 2.78). One combination alone had a mid-parent heterosis score of below four, which was the combination of the cultivar SST972 (A972/R41) and was a result of the very high sprouting resistance contribution of the female A972 in combination with the best male. The very high mid-parent heterosis scores of all the combinations containing R2, was a result of the poor sprouting tolerance of R2. When comparing sprouting scores (over all the treatments) with mid-parent heterosis values it becomes clear that even though all females, except A183, had very low sprouting scores, hybrids would not have tolerance to sprouting when males contribute so poorly to tolerance.

5.3.1.2 Combined analysis of variance on Hagberg falling number (HFN)

Combined analysis of variance was done on Hagberg falling number (HFN) of grain harvested after completing the cutting of heads for the FM + 21 days treatment (Treatment 4). The HFN was done to identify genotypes that had inherent low falling numbers and to determine the condition of grain harvested at physiological maturity plus 21 days. The falling number method used to estimate ∂-amylase activity in wheat grain, was officially introduced into the South African grading rules during 1998. Prior to this, sprouting degree was determined by visual inspection. A limit of 2% sprouted kernels is still used as an acceptable amount.

Table 5.10: Mean squares for quality characteristics (grain harvested at FM+21d) of twenty five wheat genotypes during 2004

17 QUALITY CHARACTERISTICS (HARVESTED 21 DAYS AFTER FISIOLOGICAL MATURITY) FOR 2004																		
SOURCE	df	HLM	MOIST	SKCSDIAM	SKCSG	SKCS_HI	BFLY	FLY	FPC	HFN	ASH	WGC	ADIST	ASTR	ASTAB	APL	CABS	MMT
Total	74	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
Replicates	2	0.811	0.253*	0.011	2.651	2.450	3.849	2.213	0.490	3121.853*	0.005	17.982	393.396**	132.811*	1053.678	0.032	3.812**	0.191
Genotype	24	6.910**	0.153**	0.029**	13.869**	119.747**	12.047**	19.595**	2.178**	2538.231**	0.003	29.270**	206.069**	96.341**	1114.721*	0.067**	4.414**	1.378**
Residual	48	0.471	0.050	0.007	2.728	6.761	2.842	4.516	0.522	631.381	0.002	9.303	63.577	28.562	545.189	0.022	0.705	0.134

Table 5.11: Mean squares for quality characteristics (grain harvested at FM+21d) of twenty five wheat genotypes during 2005

17 QUALITY CHARACTERISTICS (HARVESTED 21 DAYS AFTER FISIOLOGICAL MATURITY) FOR 2004																		
SOURCE	df	HLM	MOIST	SKCSDIAM	SKCSG	SKCS_HI	BFLY	FLY	FPC	HFN	ASH	WGC	ADIST	ASTR	ASTAB	APL	CABS	MMT
Total	74	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
Replicates	2	2.939	0.098*		1.268	9.150	0.840	3.880	5.953**	159.853	0.002	60.200*	83.853*	112.000*	154.413	0.004	0.473	0.036
Genotype	24	14.419**	0.133**	0.389**	34.971**	162.668**	17.047**	20.036**	3.580**	19895.472**	0.005**	74.801**	462.420**	495.819**	6604.753**	0.060**	4.845**	11.917**
Residual	48	0.986	0.021	0.056	2.907	9.142	1.132	2.602	0.408	349.159	0.002	14.247	24.270	25.431	482.913	0.004	0.629	1.967

Table 5.12: Mean squares for quality characteristics (grain harvested at FM+21d) of twenty five wheat genotypes for 2004 and 2005.

17 QUALITY CHARACTERISTICS FROM FIELD-HARVESTED TRIAL (21 DAYS AFTER FISIOLOGICAL MATURITY) FOR BOTH YEARS 2004 AND 2005																		
SOURCE	df	HLM	MOIST	SKCSDIAM	SKCSG	SKCS_HI	BFLY	FLY	FPC	HFN	ASH	WGC	ADIST	ASTR	ASTAB	APL	CABS	MMT
Total	149	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS	MS
Replicates	2	1.553	0.295**	0.006	3.664	7.607	4.082	2.906	2.709**	1312.127	0.006	15.280	169.901*	11.889	784.707	0.020	0.832	0.077
Genotype	24	16.202**	0.194**	0.254**	37.433**	265.136**	25.280**	30.535**	3.139**	14304.51**	0.004**	55.655**	371.514**	342.466**	4319.442**	0.082**	6.530**	1.559**
Year	1	186.707**	161.139**	12.661**	2328.225**	520.429**	7.190	193.802**	83.477**	1820944.86**	0.131**	539.905**	2165.544**	128.529*	221875.74**	2.931**	42.987**	94.296**
Entry by Year	24	5.127**	0.093**	0.164**	11.407**	17.279**	3.813*	9.096**	2.619**	8129.193**	0.003	48.416**	296.975**	249.694**	3400.032**	0.046**	2.729**	0.316**
Residual	98	0.758	0.036	0.031	2.765	7.871	1.958	3.551	0.532	520.460	0.002	12.818	49.299	31.199	512.201	0.013	0.724	0.088

df = Degrees of Freedom
MS = MEAN SQUARE
** Significant at P < 0.01.
* Significant at P < 0.05.

Table 5.13: Genotype means of the falling number (HFN, in seconds) trial planted during 2004 and 2005

ENTRY	GENOTYPE	HFN 04	RK	HFN 05	RK	HFN 04+ 05	RK
1	A972/R41 (SST972)	351.00	16	129.00	14	240.00	14
2	A966/R41 (SST966)	383.33	6	165.33	10	274.33	10
3	A936/R41 (SST936)	318.33	24	157.33	12	237.83	15
4	A23094/R41	329.33	22	201.33	8	265.33	11
5	A183/R41	350.33	17	93.67	16	222.00	17
6	A972/R2	348.00	18	20.00	24	184.00	24
7	A966/R2 (SST935)	355.33	14	67.67	20	211.50	19
8	A936/R2	347.33	19	84.33	19	215.83	18
9	A23094/R2	346.33	20	67.00	21	206.67	20
10	A183/R2	352.67	15	26.67	22	189.67	23
11	A966/R6 (SST946)	377.00	8	114.00	15	245.50	12
12	R2	333.00	21	26.67	23	179.83	25
13	R41	315.33	25	92.00	17	203.67	21
14	R6	374.67	9	89.67	18	232.17	16
15	B972	357.33	13	217.33	6	287.33	7
16	B966	411.00	2	154.33	13	282.67	9
17	B936	370.33	11	197.33	9	283.83	8
18	B23094	360.67	12	235.00	5	297.83	6
19	B183	319.00	23	164.00	11	241.50	13
20	BETTA-DN	387.00	5	260.67	2	323.83	3
21	ELANDS	400.33	3	249.33	4	324.83	2
22	SST124	372.67	10	255.00	3	313.83	4
23	SST334	400.33	4	203.00	7	301.67	5
24	SST322	426.33	1	266.00	1	346.17	1
25	PAN3349	378.67	7	20.00	25	199.33	22
	C.V. %	6.93%		13.13%		9.04%	
	LSD	34.4105		25.5892		21.8718	

C.V. = Coefficient of variance
LSD = Least significant differences
RK = Ranking

The HFN was done on the grain that remained in the plot after the FM + 21D treatment's rain simulator heads were cut (Table 5.5). The analysis of variance revealed highly significant differences for genotype and year and the interaction between the two. Most genotypes did not have HFN's above 250 s and for selection purposes lines with values above 250 s would be selected. Lines that could be selected for acceptable HFN's were SST322, Elands, Betta-DN, SST124, SST334,

B23094, B972, B936, B966, SST966 and A23094/R41. Huge differences in years were observed and in 2004 all lines had HFN's above 250 s and this was not the case for 2005 when much lower values were found and only SST322, SST124, Elands and Betta-DN had values above 250 s. This could be due to the 100 mm rain that fell on the 2005 trial just before harvest during January in 2006 (2005 season).

The same trend was observed with the sprouting scores in the rain simulator as genotypes grouped together in the same way. The conventional varieties had the best HFN followed by the females, except again B183 which had lower HFN. This was in accordance with the sprouting tolerance level which was also lower than the rest of the females. However it would seem that year has a significant effect on the HFN values. It would therefore not be possible to select lines for HFN on one year data and this should be done annually. In contrast with the HFN, observations from the sprouting scores gave the same data trend for 2004 and 2005.

The male R-lines had the lowest falling number with the line R2 the lowest ranking. Combinations with this male also showed negative effects when used in hybrids. The male R6 outperformed R41 for the combined years, followed by R2. During 2005, when circumstances were advantageous for low HFN values, the R6 (89.67) and R41 (92.00) male lines did not differ significantly. In 2005 R2, again the poorest performer of all males, had a very low HFN of 26.67. None of the hybrids had acceptable falling number values during 2005, with A23094/R41 as the best hybrid combination. All hybrid combinations with R2 as male ranked low from position 19 till 24 with very poor values ranging from 20 to 84.33. The conventional variety PAN3349 had the lowest value of all genotypes during 2005 (HFN = 20 sec's).

Table 5.14: Heterosis values of HFN for 11 hybrids on the combined treatments during 2004 and 2005

Entry	Genotype	F1 Score	Female	Male	MPH	% Het	HPH	% Het	BSH	% Het
1	A972/R41 (SST972)	240.00	287.33	203.67	245.50	-550	287.3	-4733	346.17	-10617
2	A966/R41 (SST966)	274.33	282.67	203.67	243.17	3116	282.7	-834	346.17	-7184
3	A936/R41 (SST936)	237.83	283.83	203.67	243.75	-592	283.8	-4600	346.17	-10834
4	A23094/R41	265.33	297.83	203.67	250.75	1458	297.8	-3250	346.17	-8084
5	A183/R41	222.00	241.50	203.67	222.59	-58.50	241.5	-1950	346.17	-12417
6	A972/R2	184.00	287.33	179.83	233.58	-4958	287.3	-10333	346.17	-16217
7	A966/R2 (SST935)	211.50	282.67	179.83	231.25	-1975	282.7	-7117	346.17	-13467
8	A936/R2	215.83	283.83	179.83	231.83	-1600	283.8	-6800	346.17	-13034
9	A23094/R2	206.67	297.83	179.83	238.83	-3216	297.8	-9116	346.17	-13950
10	A183/R2	189.67	241.50	179.83	210.67	-2099.50	241.5	-5183	346.17	-15650
11	A966/R6 (SST946)	245.50	282.67	232.17	257.42	-1192	282.7	-3717	346.17	-10067

Average mid-parent heterosis revealed that the performance of the hybrids were almost the same as the average performance of its parents. Evaluation of each hybrid's mid-parent heterosis revealed that most hybrids had lower HFN's (negative mid-parent heterosis) than the average performance of its parents, except for SST972, SST966 and A183/R41. Again, just as the case was with the sprouting scores, high-parent heterosis revealed that when the performance of the hybrid was compared with the better parent, the best parent was a female every time. This again shows the positive effect the females had on higher HFN.

Pre-harvest sprouting susceptibility reduces yield, lowers test weight, and adversely affects the milling and baking quality of harvested grain (Trethowan, 1995). Pre-harvest sprouting is strongly correlated with the Hagberg falling number test (AACC, 1983) and measures the level of starch degradation caused by germination enzymes (Trethowan, 1995; Barnard *et al*., 2005).

All the heads cut at the different dates (PM, PM+7D, PM+14D, PM+21D) which was exposed to the rain simulation, was hand threshed and HFN was done on the grain

obtained from the sprouted heads. All genotypes (which resulted in a sufficient amount of flour to do HFN on) originating from the grain of the sprouted heads, gave a constant low HFN of 47 s over all three replicates, except the one replication (bloc three) of Elands which resulted in a HFN of 118 s. These data are not shown due to the insufficient amount of flour produced for the genotypes included in the study. All sprouted heads had low falling numbers and sprouted grain did not have acceptable HFN at any time at any of the treatments which was understandable under the perfect conditions for sprouting and high ∂-amylase activity. This was in accordance with research done by Barnard (2001) where HFN was correlated with the pre-harvest sprouting score. This was only true for sprouted grain obtained from the simulator and not for field grown grain which was evaluated for HFN. A cultivar like Tugela-Dn in South Africa has very poor sprouting tolerance but has some of the highest HFN values of all cultivars in certain years where the occurrence of sprouting is low. This could explain the variability in HFN scores over years of the same genotype and could explain why HFN should not be used to select for sprouting tolerance directly from field samples. The long term solution would be to develop cultivars which are able to tolerate and resist the damaging effects of rain during the period between ripeness of maturity and the completion of the harvest.

5.3.1.3 Correlations

Correlations were performed on the sprouting score at physiological maturity plus 21 days (PM+21D)(Treatment 4) in combination with the analyzed quality data which was harvested after the FM+21D heads were cut from the plot. Correlations between the HFN and other quality data were also evaluated.

The data obtained from grain analyzed for quality characteristics and the heads cut at PM+21D did not correlate at all, as these were totally different sets of tests. HFN and the sprouting score did not correlate (Table 5.13), although Barnard *et al.* (2005) reported a highly significant positive correlation between pre-harvest sprouting resistance and ∂-amylase activity. According to Upadhyay and Paulsen (1988) ∂-amylase is not an appropriate selection criterion for pre-harvest sprouting resistance because of the low correlation with visual sprouting after simulated rain. Barnard *et al.*

Table 5.15 Correlation matrix for rain simulated treatment 4 (FM+21days) in combination with field harvested 17 quality characteristics, and between field harvested HFN and 17 quality characteristics for 2004 and 2005 combined

	FM+21D	HLM	MOIST	SKCSDIAM	SKCSG	SKCS_HI	BFLY	FLY	FPC	HFN	ASH	WGC	ADIST	ASTR	ASTAB	APL	CABS
HLM	-0.3855																
	0.0000																
MOIST	0.0354	-0.4305															
	0.6693	0.0000															
SKCSDIAM	-0.0769	-0.2811	0.6803														
	0.3530	0.0005	0.0000														
SKCSG	0.0332	-0.4067	0.7715	0.8192													
	0.6883	0.0000	0.0000	0.0000													
SKCS_HI	-0.3775	0.4912	-0.2369	-0.2750	-0.4979												
	0.0000	0.0000	0.0037	0.0007	0.0000												
BFLY	0.2569	-0.1758	0.1522	-0.0372	0.0897	-0.4978											
	0.0016	0.0326	0.0648	0.6537	0.2780	0.0000											
FLY	-0.2354	0.1235	0.4516	0.3776	0.3584	0.0215	0.3574										
	0.0040	0.1347	0.0000	0.0000	0.0000	0.7949	0.0000										
FPC	0.0605	-0.2892	0.4117	0.4191	0.4921	-0.1448	-0.0525	-0.0075									
	0.4653	0.0004	0.0000	0.0000	0.0000	0.0790	0.5261	0.9281									
HFN	-0.2404	0.6918	-0.8362	-0.6243	-0.7356	0.3859	-0.0871	-0.2350	-0.4060								
	0.0032	0.0000	0.0000	0.0000	0.0000	0.0000	0.2925	0.0040	0.0000								
ASH	0.1903	-0.3449	0.4149	0.3110	0.3908	-0.1976	0.0282	-0.0176	0.5551	-0.4834							
	0.0206	0.0000	0.0000	0.0001	0.0000	0.0160	0.7337	0.8319	0.0000	0.0000							
WGC	0.0215	-0.1902	0.2348	0.2887	0.3047	0.0193	-0.0766	0.0365	0.8012	-0.2415	0.5693						
	0.7951	0.0206	0.0041	0.0004	0.0002	0.8158	0.3551	0.6594	0.0000	0.0031	0.0000						
ADIST	-0.1597	0.4721	-0.3282	-0.2513	-0.3048	0.3538	-0.0529	-0.1058	0.1176	0.5250	-0.0713	0.1449					
	0.0526	0.0000	0.0000	0.0021	0.0002	0.0000	0.5231	0.2006	0.1547	0.0000	0.3893	0.0788					
ASTR	-0.2710	0.3030	0.0604	0.0041	-0.0103	0.2823	-0.1339	0.0753	0.3604	0.2103	0.0104	0.2572	0.6295				
	0.0009	0.0002	0.4659	0.9604	0.9014	0.0005	0.1047	0.3630	0.0000	0.0103	0.9002	0.0016	0.0000				
ASTAB	-0.0258	-0.4459	0.6741	0.5523	0.6246	-0.2809	0.0519	0.3006	0.4249	-0.7346	0.3412	0.2512	-0.5599	0.0196			
	0.7552	0.0000	0.0000	0.0000	0.0000	0.0005	0.5311	0.0002	0.0000	0.0000	0.0000	0.0021	0.0000	0.8130			
APL	-0.0941	0.4979	-0.6256	-0.4555	-0.5348	0.3057	-0.0222	-0.2083	-0.2578	0.7081	-0.2689	0.1354	0.7855	0.1612	-0.8332		
	0.2552	0.0000	0.0000	0.0000	0.0000	0.0002	0.7889	0.0111	0.0016	0.0000	0.0010	0.1008	0.0000	0.0503	0.0000		
CABS	0.0444	-0.0853	0.3480	0.3150	0.3934	-0.0629	0.0753	0.2052	0.3878	-0.3222	0.2881	0.2900	0.2744	0.1567	0.1726	0.0243	
	0.5917	0.3028	0.0000	0.0001	0.0000	0.4478	0.3628	0.0124	0.0000	0.0001	0.0004	0.0003	0.0007	0.0571	0.0359	0.7693	
MMT	-0.2612	0.5191	-0.7456	-0.6139	-0.7061	0.3193	-0.0827	-0.1624	-0.5767	0.7898	-0.5732	-0.4179	0.2648	0.0988	-0.6042	0.5253	-0.4592
	0.0013	0.0000	0.0000	0.0000	0.0000	0.0001	0.3179	0.0486	0.0000	0.0000	0.0000	0.0000	0.0011	0.2323	0.0000	0.0000	0.0000

(2005) also reported that moderate correlations were found typical of complex inherited traits.

HFN correlated highly significantly with HLM (positive), moisture content (negative), SKCS weight and diameter (negative), with alveograph stability (negative), alveograph P/L (positive) and with mixograph mixing time (positive). Barnard *et al.* (2005) reported significant correlations with grain hardness and diameter.

5.4 CONCLUSIONS AND RECOMMENDATIONS

With so many influences contributing to the variation in pre-harvest sprouting and FN evaluations, special selection techniques should be incorporated, for example to exclude environmental effects. In addition more than three years data from the field will be better to deliver accurate data. Data used from rain simulation facilities, gathered from interval sampling (physiological maturity, 7 days, 14 days, 21 days) could supply accurate and repeatable data especially when cut from 14 and 21 days after physiological maturity. It can be concluded that effects of the environment was excluded from the actual sprouting scores obtained from treatment four (PM+21D), reflecting the true sprouting status of the genotypes and not masked or influenced by year effects. Overall, year did not change the genetic trend of every genotype showed. This was not true for HFN values determined, as year had a significant influence and different trends were observed for the characteristic during the two years.

From other research the conclusion could be made that by knowing the quality and characteristics of the cultivar together with the implementation of correct or required agricultural practices, it would seem plausible that HFN could be managed within the seasonal limitations set. Under extreme wet conditions, little can be done aside from planting pre-harvest sprouting tolerant material to assure a sound HFN, but even with highly tolerant material, pre-harvest sprouting is still a possibility, as any cultivar will germinate if favourable conditions prevail. It is, however, important to understand why and under what circumstances certain cultivars produce low HFN in the absence of pre-harvest sprouting. Once this is understood, agricultural production practices together with cultivar choice can be utilized to ensure that the optimum HFN could be

obtained within seasonal specifications. Certain cultivars should be given priority with harvesting in order to ensure a sound wheat crop at the silo as some genotypes are able to resist the damaging effects of the environment for a shorter period than others, while some like Elands, SST322 and B972 are able to resist damaging effects of the environment for long periods.

With absolute certainty it can be said that the male genepool, from which the hybrids were compiled, mainly contributed to the poor sprouting tolerance of the hybrids. Combining males and females with excellent sprouting tolerance could therefore provide highly tolerant hybrids. This was also true for the HFN values obtained. Conventional varieties and female genotypes had overall good sprouting tolerance and HFN's, with the exception of B183 and PAN3349.

CHAPTER 6

GENERAL CONCLUSIONS AND RECOMMENDATIONS

Major variation within the data was recorded for many of the measured characteristics in this study, especially for the winter hybrid performance trial. Grain that originates from the F1 hybrid is actually F2 generation grain and this could be one of the explanations why so much variation was observed. The hybrid product that a producer will be delivering at the silo will be F2 grain and therefore the breeder is forced to evaluate the quality of the F2 grain in order to develop hybrids with acceptable and stable quality characteristics for the processing industry. The males that were included had good anther extrusion and were highly capable of restoring fertility in the females. The males were subjected to less extensive quality testing than the female lines and in some instances the quality traits of the males were inferior to that of the females and conventional cultivars, which were selected for in the same program. This discrepancy between the male and female genepools probably contributed to the variation found in the data. The females underwent strict selection where males should have undergone more strict quality selection from the F5 generation, especially for poor falling number. The milling characteristics revealed less variation than the rheological data and therefore use of more than two year data is recommended when evaluating the rheological characteristics except mixograph mixing time and alveograph strength.

In most cases the mid- and high-parent heterosis for both trials was in the same direction. Test weight revealed positive mid- and high parent heterosis over the two year period for both the facultative and winter hybrid performance trial. This is an encouraging trend because higher test weight achieved by the hybrid over its parents would have a positive influence in terms of flour yield, although this was not the case in this study due to the negative heterosis for flour yield and hardness. Positive heterosis was also expressed for kernel weight and size over the two years for both the facultative and winter hybrids performance trials. Still it must be considered that the males again produced smaller and lighter kernels and could benefit from strict selection pressure to improve heterosis. Stringent seed selection should also be applied in the early segregating stages in the male program to solve this problem. Negative heterosis was reported for hardness index in both 2004 and 2005 for the facultative

hybrid performance trial. The males produced softer kernels than the rest of the genotypes. In order to improve this tendency a minimum hardness level must be set for the parents to be developed in the male breeding program, the resultant hybrids will benefit from a combination of harder males and females and the effect on flour yield be evaluated. Flour yield revealed negative heterosis and in spite of higher test weight of the hybrids compared to their parents, the hybrids produced lower flour yields than their parents. Although millers can make adaptations in the conditioning process to improve flour yields, it is of the utmost importance that selection pressure must be applied to improve hybrid flour yield by means of improving the flour yield levels of the males.

Heterosis of falling number explained the huge problem farmers had in certain years with falling number as negative heterosis values were found for hybrids in both the facultative and winter hybrid performance trials. The males tended to have low falling numbers which urged the improved selection pressure for increased falling numbers in the male and female program, as this will positively improve the grading of the producer's harvests. The negative heterosis for ash regarding both the intermediate and winter hybrid performance trial is encouraging because lower ash values produced by hybrids indicates a higher milling efficiency and improved brightness of the flour. Alveograph strength resulted in negative heterosis and thus stronger types could be used as parents, the hybrids tended to have lower alveograph strength values. When trying to improve alveograph strength values it should be done without losing extensibility in the dough.

Hybrids expressed negative heterosis for water absorption and the hybrids tended to have lower water absorption levels than the parents. This is to be expected because the hybrids produced softer grains. Again the males contributed to low absorption levels and should undergo stricter selection for improved hardness. The hybrids had positive heterosis for mixing time over both the facultative and winter hybrid performance trial. The characterization of the hybrid parents should favor parents with shorter mixing times otherwise mixograph mixing times will be increased. This is very important as the hybrids should fall within the optimum mixing time set by the industry of between 2.4 and 3.2 minutes. When using pure line cultivars as standard check to compare with male and female lines, the male line needs to firstly be a good pollinator

and then have acceptable quality combined with a quality acceptable female and when the desired heterosis is achieved, the hybrid should show good quality expression.

In general it could be said that within each of the two trials the hybrids had the best stability performance for all characteristics measured of the total group of genotypes evaluated. They also outperformed the pure line cultivar Elands, when stability performance was considered. Although the quality was inferior to that of the female pool, the quality expression of the male pool was more stable than that of the female pool. Stability performance varied for the different hybrids within each performance trial, namely SST966 (winter growth type), when evaluated within the winter genepool performed better than when included in the facultative germplasm pool. The same was true for SST972 (facultative growth type) which performed better with the facultative genepool than with the winter genepool. This again confirms that it is important to evaluate and select genotypes for quality characteristics from the facultative group compared to standards from the facultative genepool. SKCSG and SKCSDIAM were more stable in the winter hybrid performance trial. This is probably because of the fact reported by Purchase (1997) of superior adaptation of hybrids and long growth period cultivars to high yield potential conditions. The male breeding program should include standard pure line cultivars and females for comparison to improve quality selection within each growth type. With global warming becoming an important factor to deal with, erratic environmental conditions are becoming more visible, and therefore stable performance should be an important breeding goal for quality characteristics and a stable hybrid standard should also be included which is representative of the growth types evaluated. Winter and facultative types could not be combined in one trial and should be evaluated in separate trials.

With so many influences contributing to the variation in pre-harvest sprouting and FN evaluations, special selection techniques should be incorporated, for example to eliminate environmental effects. In addition, more than three years data from the field will improve the accuracy of the generated data. Data generated by the rain simulation facility in order to replicate sprouting under field conditions, was determined for several intervals namely; physiological maturity, 7 days, 14 days, 21 days after physiological maturity. Sampling at 14 and 21 days after physiological maturity produced the most accurate and repeatable results. It can be concluded that effects of the environment

was excluded from the actual sprouting scores obtained from treatment four (PM+21D), reflecting the true sprouting status of the genotypes and not masked or influenced by year effects. In the past when evaluating sprouting in the rain simulator, heads were cut at physiological maturity whereas this study recommends looking at cutting heads at a later stage rather than physiological maturity. Overall, the seasonal (year) effect did not change the observed genetic trends of the genotypes. This was not true for the HFN values, as season had a significant influence and two different trends were observed for this characteristic during the two years of testing.

With knowledge of the quality characteristics of the cultivar together with the implementation of correct agricultural practices, it would seem plausible that HFN could be managed within the seasonal limitations set. Under extreme wet conditions, little can be done aside from planting pre-harvest sprouting tolerant material to assure a sound HFN, but even with highly tolerant material, pre-harvest sprouting is still a possibility, as any cultivar will germinate if favorable conditions prevail. It is, however, important to understand why and under what circumstances certain cultivars produce low HFN in the absence of pre-harvest sprouting. Once this is understood, agricultural production practices together with cultivar choice can be utilized to ensure that the optimum HFN could be obtained within seasonal specifications. Certain cultivars should be given priority with harvesting in order to ensure a sound wheat crop at the silo as some genotypes are able to resist the damaging effects of the environment for a shorter period than others, while some like Elands, SST322 and B972 are able to resist damaging effects of the environment for long periods.

With absolute certainty it can be said that the male genepool, from which the hybrids were compiled, mainly contributed to the poor sprouting tolerance of the hybrids. Combining males and females with excellent sprouting tolerance could therefore provide highly tolerant hybrids. This was also true for the HFN values obtained. Conventional cultivars and female genotypes had overall good sprouting tolerance and HFN’s, with the exception of B183 and PAN3349.

In general the males had poor quality in comparison with the females and conventional cultivars and should undergo stricter selection procedures for quality, especially in characteristics like falling number where the hybrids revealed negative heterosis.

By knowing the parents and the effects of heterosis on the quality characteristics, it would be possible to predict quality in the hybrids.

CHAPTER 7

SUMMARY

The objectives of this study were to determine the quality characteristics of hybrid wheat in South Africa, the influence of the male and female parents on quality and to assess heterosis in hybrid wheat quality. The stability performance of the hybrids, their parental lines and conventional cultivars were also determined. A further objective was to assess sprouting tolerance in hybrid wheat. Twelve hard red genotypes were planted at six locations throughout the Free State in separate winter and facultative trials, during 2004 and 2005. A separate sprouting and falling number trial consisting of 25 genotypes was planted at Bethlehem during 2004 and 2005 to evaluate the sprouting and falling number problem in hybrid wheat and included males, females, hybrids and conventional cultivars. Heads were cut at physiological maturity and thereafter with seven day intervals, for evaluation in a rain simulation facility.

Mean squares were highly significant for genotype, environment and year for test weight, SKCS kernel size, Hagberg falling number, ash, alveograph strength and mixograph mixing time in both trials. Highly significant differences were seen for hardness index, break flour yield, flour yield, consistograph water absorption in the IHBPT trial and wet gluten content in the WHBPT trial. The males mainly contributed to poor quality, with the females and conventional cultivars having acceptable quality. The hybrids made up from high quality parents, had better quality in general. Positive heterosis was expressed for test weight, SKCS kernel size and mixing time and negative heterosis for falling number, ash and alveograph strength for both the intermediate and winter trials. Negative heterosis was revealed for hardness index, flour yield and consistograph water absorption in the Intermediate trial and wet gluten content in the winter trial. AMMI stability values confirmed that hybrids had the best stability performance, even more stable than Elands. The males and females performed intermediate with the male genepool being more stable than the female one. The sprouting trial revealed that the male genepool mainly contributed to the poor sprouting tolerance of the hybrids. Combining males and females with good sprouting tolerance provided tolerant hybrids. This was also true for falling number. The method of evaluating sprouting was also revised and should be applied to ensure true tolerant types are selected and to exclude environmental affects.

HOOFSTUK 7

OPSOMMING

Die doel van hierdie studie was on Suid Afrikaanse winter en fakultatiewe basterkoring te bestudeer ten opsigte van hul bak-en maalkwaliteit en stabiliteit in vergelyking met hul ouers en ander konvensionele cultivars. ‘n Aparte uitloopproef is ontleed om die oorsprong van basters se uitloopprobleme te bepaal. Twaalf harde, rooi genotipes per winter en fakultatiewe proef is gedurende 2004 en 2005 op ses lokaliteite in die Vrystaat geplant. ‘n Aparte uitloop en valgetal proef bestaande uit 25 genotipes inluitende basters, wyfies, mannetjies en konvensionele cultivars is op Bethlehem geplant gedurende 2004 en 2005 om die oorsprong van die uitloop en valgetal probleem in die baster koring vas te stel. Die ryp are is op fisiologies ryp geoes met 7 dae intervalle daarna, en in die reensimuleerder geëvalueer.

Die gemiddelde kwadrate was betekenisvol vir genotipes, omgewings en jaar vir hektolitermassa, korrelgewig en–grootte, Hagberg valgetal, as, alveo sterkte en mengtyd in beide proewe. Hoogs betekenisvolle verskille is gekry vir hardheid, breekmeel, meelopbrengs en waterabsorpsie in die fakultatiewe proef en vir nat gluten in die winterproef. Die mannetjies het hoofsaaklik swakker kwaliteit gehad met die wyfies en konvensionele cultivars wat beter kwaliteit getoon het. Positiewe heterose is gevind vir hektolitermassa, korrelgrootte en gewig en mengtyd asook negatiewe heterose vir valgetal, as en alveo sterkte in beide proewe. Negatiewe heterose is gesien vir hardheid, meelopbrengs en waterabsorpsie in die intermediere proef en vir nat gluten in die winterproef. Die AMMI analise het bevestig dat basters die beste stabiliteit getoon het, selfs meer as Elands. Die mannetjies en wyfies het intermediêre stabiliteit getoon en mannetjies was meer stabiel as die wyfies. Die mannetjie genepoel het hoofsaaklik bygedra tot swakker uitloop weerstand. Deur tolerante mannetjies en wyfies te kombineer kan basters met beter toleransie teen uitloop verkry word. Dieselfde is gevind ten opsigte van die valgetal. Die metode om die uitloop te evalueer is ook verfyn om te verseker dat werlik tolerante tipes geselekteer word en om die effekte van jaar uit te skakel.

REFERENCES

AMERICAN ASSOCIATION OF CEREAL CHEMISTS (AACC), 1983. Falling number determination. Method 56-81B. 8th Edn. The Association: St. Paul, Minnesota.

AGROBASE, 1999. User's guide and command reference. Agronomix software. Pnc. R3N054 Canada.

AGROBASE, 2000. Agronomic Software Inc. Winnipeg, Manitoba, Canada.

ANDREWS, J.L., SKERRITT, J.H., 1996. Wheat dough extensibility screening using a two-site enzyme-linked immonusorbent assay (ELISA) with antibodies to low molecular weight glutenin subunits. *Cereal Chem.* 73(5): 650-657.

ANGUS, W.J., 1997. Hybrid wheat – a dream or reality? *Aspects of Applied Biology* 50: 15-22.

ANONYMOUS, 2003. Regulations relating to the grading, packing and marketing of wheat intended for sale in the Republic of South Africa: Amendment. Agricultural product Standards Act, 1990 (Act no. 119 of 1990). Government Gazette, Vol. 458, 29 August 2003. No. 25370.

BAENZIGER, P.S., CLEMENTS, R.L., MCINTOSCH, M.S., YAMAZAKI, W.T., STIRLING, T.M., SAMMONS, D.J., JOHNSON, J.W., 1985. Effect of cultivar, environment, and their interaction and stability analysis on milling and baking quality of soft red winter wheat. *Crop Sci.* 25: 5-8.

BAKER, R.J., TIPPLES, K.H., CAMPBELL, A.B., 1971. Heritabilities of and correlations among quality traits in wheat. *Can. J. Plant Sci.* 51: 441-448.

BARLOW, K.K., BOTTROSE, M.S., SIMMONDS, D.H., VESK, M., 1973. The nature of starch-protein interface in wheat endosperm. *Cereal Chem.* 50: 443-454.

BARABÁS, Z., 1973. Method of producing hybrid wheat by means of marker genes. *Cereal Res. Comm.*, 1: 45.

BARNARD, A., PURCHASE, J.L., SMITH, M.F., VAN LILL, D., 1997. Determination of the pre- harvest sprouting resistance of South African winter wheat (*Triticum aestivum L.*) cultivars. *S. Afr. J. Plant and Soil* 14(1): 4-8.

BARNARD, A., BOTHA, A.H., DU PLESSIS, J.C., HATTING, H.A., 1999. Report on the national wheat cultivar evaluation programme under dryland conditions in the summer rainfall region. Small Grain Institute annual report, pp. 1-2.

BARNARD, A., YBEMA, S., 1999. Valgetal afgraderingsfaktor vir koring. *Koringfokus* 17(2): 7-9.

BARNARD, A., 2001. Genetic diversity of South African winter wheat cultivars in relation to preharvest sprouting and falling number. *Euphytica* 119: 107-110.

BARNARD, A., BURGER, E., 2002. Handleiding vir die verbouiing van koring in die Somerreëngebied. LNR Kleingraaninstituut, Bethlehem, South Africa, pp. 17.

BARNARD, A., VAN DEVENTER, C.S., MAARTENS, H., 2005a. Comparison between methods for estimating sprout damage in wheat. *S. Afr. J. Plant and Soil* 22(1): 44-48.

BARNARD, A., VAN DEVENTER, C.S., MAARTENS, H., 2005b. Genetic variability of preharvest sprouting – the South African situation. *Euphytica* 143: 291-296.

BAOQI, S., AIMIN, Z., BONJEAN, A.P., 2001. In: A.P. Bonjean, W.J. Angus (Eds.). The World Wheat Book. Lavoisier Publishing Inc. Paris. pp. 694-698.

BASS, E.J.,1988. Wheat flour milling. In: Y. Pomeranz (Ed.). Wheat: Chemistry and Technology. Volume II. Third Edition. American Association of Cereal Chemists, Inc., St. Paul, Minnesota, USA, pp. 1-68.

BASSET, L.M., ALLAN, R.E., RUBENTHALER, G.L., 1989. Genotype x environment interaction of soft white winter wheat quality. *Agron. J.* 81: 955-960.

BEDO, Z., LANG, L., SUTHER, J., MOLNAR-LANG, M., 2001. In: A.P. Bonjean, W.J. Angus (Eds.). The World Wheat Book. Lavoisier Publishing Inc. Paris. pp. 213-215.

BEQUETTE, R., FISHER L., 1980. DeKalb Hybrid Wheat, Inc; Contrib. *Ann. Wheat Newsletter* 26: 32-33.

BERGMAN, C.J., GUALBERTO, D.G., CAMPBELL, K.G., SORRELS, M.E., FINNEY, P.L., 1998. Genotype and environment effects on wheat quality traits in a population derived from soft by hard cross. *Cereal Chem.* 75(5): 729-737.

BHATT, G.M., DERERA, N.F., 1975. Genotype x Environment interaction for, heritabilities of and correlations among quality traits in wheat. *Euphytica* 24: 597-604.

BIETZ, J.A., 1988. Genetic and biochemical studies of non-enzymatic endosperm proteins. In: E.G. Heyne (Ed.). Wheat and wheat improvement. 2nd ed. Agron. Monogr. 13, ASA, CSSA and SSA, Madison, WI, pp. 215-242.

BOGGINI, G., 1975. Effects of cytoplasm and restorer genes on fertility of hybrid wheats (*T. aestivum*). *Genet. Agr*. 29(3-4): 309-315.

BOLAND, O.W., WALCOTT, J.J., 1985. Levels of heterosis for yield and quality in an F1 hybrid wheat, *Australian J. Agric. Res.* 36: 545-552.

BONJEAN, A.P., DOUSSINAULT, G., STRAGLIATI, J., 2001. In: A.P. Bonjean, W.J. Angus (Eds.). The World Wheat Book. Lavoisier Publishing Inc. Paris. pp. 161.

BORGHI, B., BONALI, F., BOGGINI, G., 1973. Induction of male sterility in wheat with Ethepron for hybrid seed production. Proc. 4th Int. Wheat Genet. Symp. Missouri. Agr. Exp. Stat. Columbia, USA, pp. 337-343.

BORGHI, B., PERENZIN, M., NASH, R.J., 1988. Agronomic and qualitative characteristics of ten bread wheat hybrids produced using a chemical hybridizing agent. *Euphytica* 39: 185-194.

BORGHI, B., PERENZIN, M., NASH, R.J., 1989. Combining ability estimates in bread wheat and performance of 100 F1 hybrids produced using a chemical hybridising agent. *J. Genet. & Breed.* 43: 11-16.

BORGHI, B., PERENZIN, M., 1990. Yield and yield stability of conventional varieties and F1 bread wheat hybrids. *J. Genet. Breed.* 44: 307-310.

BORGHI, B., PERENZIN, M., 1994. Diallel analysis to predict heterosis and combining ability for grain yield, yield components and bread-making quality in bread wheat (*T. aestivum*). *Theor. Appl. Genet.* 89, 975-981.

BRANLARD, G., DARDEVET, M., 1985. Diversity of grain protein and bread wheat quality. II. Correlation between high molecular weight subunits of glutenin and flour quality characteristics. *J. Cereal Sci.* 3: 345-354.

BRIGGLE L.W., CURTIS B.C., 1987. Wheat Worldwide. Wheat and Wheat Improvement. Second Edition.

BRUNS, R., PETERSON C.J., 1998. Yield and stability factors associated with hybrid wheat. *Euphytica* 100: 1-5.

CAMPBELL, C.A., READ, D.W.L., 1968. Influence of air temperature, light intensity and soil moisture on the growth, yield, and some growth analysis characteristics of Chinook wheat grown in the growth chamber. *Can. J. Plant Sci.* 48: 299-311.

CANADA- ALBERTA FARM BUSINESS MANAGEMENT INITIATIVE, 1999. Wheat other than durum. Http://www.cadvision.com/violetbook/swht2.ht

CARVER, B.F., KLATT, A.R., KRENZER, E.G., 2001. In: A.P. Bonjean, W.J. Angus (Eds.). The World Wheat Book, pp. 455-456. Lavoisier Publishing Inc. Paris. pp. 455-456.

CHAMBERLAIN, N., COLLINS, T.H., MCDERMOTT, E.E., 1982. The influence of alpha-amylase on loaf properties in the UK. In: Proceedings of the 7th World Cereal and Bread Congress. International Association of Cereal Science and Technology, Vienna, pp. 841-845.

CHARLES, S.G., PATRICK, L.F., GORDON, R., 1996. Milling and baking qualities of some wheats developed for Eastern or North-western regions of the United States and grown at both locations. *Cereal Chem.* 73(5): 521-525.

CISAR G., COOPER, D.B., 1999. Hybrid wheat. In: B.C. Curtis (Ed.). Wheat production and improvement, FAO Plant Production and Protection Series, FAO, Rome.

COLT, V., 1990. The genes encoding wheat storage proteins: towards a molecular understanding of bread-making quality and its genetic manipulation. In: J.K. Setlow (Ed.). Genetic engineering: Principles and methods, vol. 12. Plenum Press, New York, pp. 225-304.

COSTA, J.M., KRONSTAD, W.E., 1994. Association of grain protein concentration and selected traits in hard red winter wheat populations in the Pacific Northwest. *Crop Sci.* 25: 435-440.

COX, M.C., QUALSET, C.O., RAINS, D.W., 1985. Genetic variation for nitrogen assimilation and translocation in wheat. II/ Nitrogen assimilation in relation to grain yield and protein. *Crop Sci*. 12: 120-129.

CROSSA, M.V.J., SAYRE, K., REYNOLDS, M., RAMIREZ, M.E., TALBOT, M., 1998. Interpreting genotype x environment interaction in wheat by Partial least square Regression. *Crop Sci*. 38: 679-689.

CUKADAR, B., PEÑA, R.J., VAN GINKEL, M., 2001. Yield potential and bread-making quality of bread wheat hybrids produced using genesis, a chemical hybridizing agent. In: Z. Bedo, L. Lang (Eds.). Wheat in a Global Environment. Kluwer Academic Press, The Netherlands, pp. 541-550.

DELWICHE, S.R., 1995. Single wheat kernel analysis by Near-infrared transmittance: Protein content. *Cereal Chem.* 72(1): 11-16.

DELWICHE, S.R., 2000. Wheat endosperm compressive strength properties as affected by moisture. *Trans ASAE* 43(2): 365-373.

DOBRASZCZYK, B.J., 1994. Fracture mechanics of vitreous and mealy wheat endosperm. *J. Cereal Sci.* 19: 273-282.

DONELSON, J.R., GAINS, C.S., ANDREWS, L.C., FINNEY, P.F., 2002. Prediction of test weight from a small vloume specific gravity measurement. *Cereal Chem.* 79(2): 227-229.

DU PLESSIS, J.P., AGENBAG, G.A., 1994. Reaksie van twee lentekoringkultivars op stikstof-en swaelbemesting in die Swartland. II. Opbrengs en bakkwaliteit. *S. Afr. J. Plant Soil* 11 (4): 189-195.

EAVIS R.M., BATCHELOR S.E., MURRAY F., WALKER K.C., 1996. Hybrid breeding of wheat, barley and rye: Development to date and future prospects. Res. Rev. no. 35. Home-Grown Cereals Authority, London.

EDWARDS, I.B., 1987. Breeding hybrid varieties of wheat, In: W.P. Feistritzer, A. Fenwick Kelly (Eds.). Hybrid seed production of selected cereal, oilseed and vegetable crops, FAO Plant Protection Paper 82, Food and Agriculture Organization of the United Nations, Rome, pp. 3-25.

EDWARDS, I.B., DORLENCOURT, G., 1994. Hybrid wheat – current status and future role in European wheat production, Melhoramento, 33, pp. 87-104.

EDWARDS, I.B., 2001. In: A.P. Bonjean, W.J. Angus (Eds.). The World Wheat Book. Lavoisier Publishing Inc. Paris. pp. 1019.

EGGIT, P.W.R. AND HARLEY, A.W., 1975. Extration rates – milling processiong implications. In: Spicer (Ed.). Bread. Social, Nutritional and Agricultural aspects of wheaten bread. Applied Science Publishers, London, pp. 219-234.

EVANS, L.T., WARDLAW, I.F. FISHER, R.A., 1975. Wheat. In: L.T. Evans (Ed.). Crop physiology – some case histories. Cambridge University Press, Cambridge. pp. 101-149.

FANG, Q., HAQUE, E., SPILLMAN, C.K., REDDY, P.V., STEELE, J.L., 1998. Energy requirements for size reduction of wheat using a roller mill. *Trans ASAE* 41(6): 1713-1720.

FELDMAN, M., LUPTON, F.G.H., MILLER, T.E., 1995. Wheats. In: J. Smart, N.W. Simmonds (Eds.). Evolution of Crop Plants, Longman Group Ltd., London, pp. 184-192.

FINNEY, K.F., SHOGREN, M.D., 1972. A ten-grammixograph for determining and predicting functional properties of wheat flours. *Baker Digest* 46: 32-35.

FINNEY, K.F., YAMAZAKI, W.T., YOUNGS, V.L., RUBENTHALER, G.L., 1987. Quality of hard, soft and durum wheats. In: E.G. Heyne (Ed.). Wheat and wheat improvement 2nd ed. ASA-CSSA-SSSA Publishers, Madison, WI USA, pp. 677-748.

FOWLER, D.B., DE LA ROCHE, I.A., 1975. Wheat quality evaluation. 1. Influence of genotype and environment. *Can. J. Plant Sci.* 55: 263-267.

FOWLER, A.A., PRIESTLEY, R.J., 1991. Quality as the customer sees it. *Food Industries of South Africa* 44(6): 29-35.

GAINES, C.S., 1991. Associations among quality attributes of red and white soft wheat cultivars across locations and crop years. *Cereal Chem.* 68(1): 56-59.

GAINES, C.S., FINNEY, P.F., FLEEGE, L.M., ANDREWS, L.C., 1996. Redicting a hardness measurement using the Single-Kernel Characterisation System. *Cereal Chem.* 73(2): 278-283.

GALLAIS, A., 1989. Lines versus hybrids – The choice for the optimum type of variety. *Vorträge f. Pflanzenz*. 16: 69-80.

GIBSON, L.R., MCCLUSKEY, P.J., TILLEY, K.A., PAULSEN, G.M., 1998. Quality of hard red winter wheat grown under high temperature conditions during maturation and ripening. *Cereal Chem.* 75: 421.

GLENN, G.M., JOHNSTON, R.K., 1994. Water vapor diffusivity and vitreous and mealy wheat endosperm. *J. Cereal Sci.* 20: 275-282.

GOBIN, P., DUVIAU, M.P., WONG, J.H., BUCHANAN, B.B., KOBREHEL, K., 1996. Change in sulfhydryl-disulfide status of protein status during conditioning and milling. *Cereal Chem.* 73(4): 495-498.

GOODING, M.J., DAVIES, W.P., 1997. Wheat production and utilization. Systems, quality and the environment. University Press, Cambridge.

GRAYBOSCH, R.A., PETERSON, D.J., SHELTON, D.R., BAENZIGER, P.S., 1996. Genotypic and environmental modification of wheat flour protein composition in relation to end-use quality. *Crop Sci*. 36: 296-300.

GUPTA, R.B., BEKES, F., WRIGLEY, C.W.,MOSS, H.J., 1990. Prediction of wheat dough quality on the basis of LMW and HMW glutenin subunit composition. In: Sixth assembly of the Wheat Breeding Society of Australia. Sept, 1990, Tamworth, NSW, Australia, pp. 217-225.

HAGBERG, S., 1960. A rapid method for determining alpha-amylase activity. *Cereal Chem.* 37: 218-222.

HAGEMANN, M.G., CIHA, A.J., 1987. Environmental x genotype effects on seed dormancy and after-ripening in wheat. *Agron. J.* 79: 192-196.

HALLORAN, G.M., 1981. Grain yield and protein relationships in a wheat cross. *Crop Sci.* 21: 699-701.

HALVERSON, J., ZELENY, L., 1988. Criteria of wheat quality. In: Y. Pomeranz, (Ed.). Wheat: Chemistry and Technology. Volume 1. Third Edition. American Association of Cereal Chemists, Inc., St. Paul, Minnesota, USA, pp. 15-45.

HAZEN, S.P.,WARD, R.W., 1997. Variation in soft winter wheat characteristics measured by the Single Kernel Characteristation System. *Crop Sci.* 37: 1079-1086.

HOSENEY, R.C., 1994. Principles of cereal science and technology. Second edition. American Association of Cereal Chemists, St Paul, Minnesota, USA.

HOU, G., YAMAMOTO, H., NG, P.K.W., 1996. Relationships of quality of glutenin subunits of selected U.S. soft wheat flours to rheological and baking properties. *Cereal Chem.* 69: 148.

HUEBNER, F.R., GAINES, C.S., 1992. Relationship between wheat kernel hardness, environment and gliadin composition. *Cereal Chem.* 69(2): 148-151.

JALALUDDIN, M.D., HARRISON, S.A., 1989. Heritability, genetic correlation and genotype x environment interactions of soft red winter wheat yield and test weight. *Cereal Res. Comm.* 17(1): 43-49.

JENNER, C.F., 1991. Effects of exposure of wheat ears to high temperature on dry matter accumulation and carbohydrate metabolism in the grain of two cultivars. II. Carry-over effects. *Aust. J. Plant Physiol.* 18: 179-190.

JENSEN, S.A., MUNCK, L., KRUGER, J.E., 1984. A rapid fluorescence method for assessment of preharvest sprouting of cereal grains. *J. Cereal Sci*. 2: 187-201.

JORDAAN, J.P., ENGELBRECHT, S.A., MALAN, J.H., KNOBEL, H.A., 1999. Wheat and heterosis, In: J.G. Coors, S. Pandey (Eds.). Genetics and exploitation of Heterosis in Crops, American Society of Agronomy, Madison, WI, pp. 411-422.

KENT, N.L., EVERS, A.D., 1994. Kent's Technology of Cereals. Pergamon Press, Oxford.

KHATHAR, B.S., BELL, A.E., SCHOFELD, J.D., 1994. The dynamic rheological properties of gluten and gluten sub-fractions from wheat of good and poor bread-making quality. *J. Cereal Sci*. 22: 29-44.

KILBORN, R.H., BLACK, H.C., DEXTER, J.E., MARTIN, D.G., 1982. Energy consumption during flour milling: Description of two measuring systems and the influence of wheat hardness on energy requirements. *Cereal Chem.* 59(4): 384-288.

KIMBER, G., SEARS, E.R., 1987. Evolution in the genus *Triticum* and the origin of cultivated wheat. In: E.G. Heyne, (Ed.). Wheat and Wheat Improvement, 2nd ed Am Soc Agron, Madison, WI. Pp. 154-164.

KOEKEMOER, F.P., 1996. Inheritance of protein related characteristics in spring wheat. MSc thesis. University of the Orange Free State, Bloemfontein.

KOEKEMOER, F.P., 2003. Genetic variability of South African spring wheats for milling and breadmaking quality. PhD Thesis. University of the Orange Free State, Bloemfontein.

KOSMOLAK, F.G., DYCK, P.L., 1981. Milling and baking qualities of ten spring wheat cultivars from the people's Republic of China. *Cereal Chem.* 58(3): 246-247.

KRUGER, J.E., TIPPLES K.H., 1982. Comparison of the Hagberg Falling number and modified grain amylase analyzer methods for estimating sprout damage in rye. *Can. J. Plant Sci.* 62: 839-844.

KULKARNI, R.G., PONTE, J.G., KULP, K., 1987. Significance of gluten content and mixogram properties of wheat cultivars. *Cereal Chem.* 64(1): 1-3.

LABUSCHAGNE, M.T., CLAASSEN, A., VAN DEVENTER, C.S., 1997. Biscuit-making quality of backcross derivatives of wheat differing in kernel hardness. *Euphytica* 96: 263-266.

LANG, L., BALLA, L., BEDO, Z., 1989. Hybrid wheat breeding and its perspective. *Sverigesw Utsädesförenings Tidskrift* 99: 121-124.

LEVY, A.A., FELDMAN, M., 1989. Intra- and inter-population variations in grain protein in wild tetraploid wheat. *Triticum turqidum* var dicoccoides. *Euphytica* 42: 251-258.

LOCHNER, H., 2003. Vrystaters se koringplanne duister. Landbouweekblad, 25 April 2003: 18.

LÖFFLER, C.M., BUSH, R.H., 1982. Selection for grain protein, grain yield and nitrogen partitioning efficiency in hard red spring wheat. *Crop Sci*. 22: 591-595.

LUNN, G.D., KETTLEWELL, P.S., MAJOR, B.J., SCOTT, R.K., 2001a. Effects of pericarp alpha-amylase activity on wheat (*Triticum aestivum*) Hagberg falling number. *Ann. Appl. Biol.* 138: 207-214.

LUNN, G.D., MAJOR, B.J., KETTLEWELL, P.S., SCOTT, R.K., 2001b. Mechanisms leading to excess alpha-amylase activity in wheat (*Triticum aestivum*) grain in the U.K. *J. Cer. Sci*. 33: 313-329.

LYON, D.J.,SHELTON, D.R., 1999. Fallow management and nitrogen fertilizer influence winter wheat kernel hardness. *Crop Sci*. 39: 448-452.

MACRITCHIE, F., DUCROS, D.L., WRIGLEY, C.W., 1990. Flour polypeptides related to bread wheat quality. In: Y. Pomeranz (Ed.). Advances in Cereal Science and Technology, Volume 10. AACC, St. Paul, MN., pp. 79-146.

MACRITCHIE, F., 1999. Wheat proteins: Characterization and role in flour functionality. *Cereal Foods World* 44(4): 188-193.

MAILHOT, W.C. AND PATTON, J.C., 1988. Criteria for flour quality. In: Y. Pomeranz (Ed.). Wheat: Chemistry and Technology. Volume II. Third edition. American Associaton of Cereal Chemists, Inc., St. Paul, Minnesota, USA, pp. 69-90.

MAMUYA, I.N., 2000. Genotype x environment interaction for quality parameters of irrigated spring wheat. MSc. Agric. Thesis, University of Orange Free State.

MARSHALL, D.R., MARES, D.J., MOSS, H.J., ELLISON, F.W., 1986. Effects of grain shape and size on milling yields in wheat. II. Experimental studies. *Aust. J. Agr. Res.* 37(4): 331-342.

MARES, D.J., 1989. Preharvest sprouting damage and sprouting tolerance: Assay methods and instrumentation. In: N.F. Derera (Ed.). Preharvest field sprouting in cereals. CRC Press, Boca Raton, FL. pp. 129-170.

MCAIG, T.N., DE PAUW, R.M., 1992. Breeding for preharvest sprouting tolerance in white-seed-coat spring wheat. *Crop Sci*. 32: 19-23.

MCDONALD, A.A., 1994. Classification and grading In: W. Bushuk and V.F. Rasper (Eds.). Wheat production: Properties and quality. Chapman & Hill, London, pp. 37-46.

MCMASTER, G.J., DERERA, N.F., 1976. Methodology and sample preparation when methods and instrumentation. In: N.F. Derera (Ed.). Preharvest field sprouting in methods for estimating sprout damage in wheat. *S. Afr. J. Plant Soil.* 2005, 22(1).

MIHALJEV, I., KOVACEV-DJOLAI, M., 1978. Inheritance of grain protein content in a diallel wheat cross. In: S. Ramanujam (Ed.). Fifth International Wheat Genetics Symposium, New Delhi, India. pp. 755-761.

MILLER, B.S., POMERANZ, Y., AFEWORK, S., 1984. Hardness texture of hard red winter wheat grown in a soft wheat area and a soft red winter wheat grown in a hard wheat area. *Cereal Chem.* 61(2): 201-203.

MILLAR, S.J., WHITWORTH, M.B., EVERS, A.D., 1997. Image analysis, the prediction and assessment of wheat quality and milling properties. Proceedings of the International Wheat Quality Conference, Manhattan, Kansas, USA, 18-22 May, pp. 141-152.

MIRI, R.K., AMAWATE, J.S., JAIN, H.K., 1970. NP 839, NP883 and NP 880: New sources of fertility restoration in male sterile wheat, *Wheat Inf. Serv*., 31: 9-11.

MORRIS, C.F., DEMACON, V.L., GIROUX, M.J., 1999. Wheat grain hardness among chromosome 5D homozygous recombinant substitution lines using different methods of measuring. *Cereal Chem.* 76(2): 249-254.

MRVA, K., MARES, D.J., 2001. Induction of late maturity ∂-amylase in wheat by cool temperature. *Aust. J. Agric. Res.* 52: 477-484.

NAEEM, H.A., DARVEY, N.L., GRAS, P.W., MACRITCHIE, F., 2002. Mixing properties and functionality changes in storage proteins during dough development of triticale-wheat flour blends. *Cereal Chem.* 79(3): 332-339.

NAKATSU, S., MIYAMOTO, H., AMANO, Y., 1996. Variation for alpha-amylase activity and dormancy in Hoddaido wheat varieties. In: K. Noda and D.J. Mares (Eds.). Proceedings of the Seventh International Symposium on Pre-harvest Sprouting in Cereals. Center for Academic Societies Japan, Osaka, pp. 411-418.

NEALES, T.F., ANDERSON, M.J., WARDLAW, I.F., 1963. The role of the leaves in the accumulation of nitrogen by wheat during ear development. *Aust. J. Agric. Res.* 14: 725-736.

NEL, M.M., AGENBAG, G.A., PURCHASE, J.L., 1998. Sources of variation for yield, protein content and hectolitre mass of spring wheat (*Triticum aestivum* L.) cultivars fo the Western and Souther Cape. *S. Afr. J. Plant Soil* 15(2): 72-79.

O'BRIEN, L., MORELL, M., WRIGLEY, C., APPELS, R., 2001. In: A.P. Bonjean, W.J. Angus (Eds.). The World Wheat Book. Lavoisier Publishing Inc. Paris. pp. 627-628.

OBUCHOWSKI, W., BUSHUK, W., 1980. Wheat hardness: Effects of debranning and protein content. *Cereal Chem.* 57(6): 426-428.

OHM, J.B., CHUNG, O.K., DEYOE, C.W., 1998. Single-Kernel characteristics of hard winter wheats in relation to milling and baking quality. *Cereal Chem.* 75(1): 156-161.

OLERED, R., 1967. Development of alpha-amylase and falling number in wheat and rye during ripening. *Vaxtodling* 23: 1-106.

OLERED, R., JŐNSSON, G., 1970. Electrophoretic studies of alpha-amylase in wheat II. *J. Sci. Food Agric.* 21: 385-392.

OLERED, R., JŐNSSON, G., 1978. Electrophoretic studies of ∂-amylase in wheat II. *J. Sci. Food Agric.* 21: 385-392.

OLIVER, J.R., BLAKENEY, A.B., ALLEN, H.M., 1993. The colour of flour streams as related to ash and pigment contents. *J. Cereal Sci.* 17: 169-182.

OSBORNE, B.G., 1991. Measurement of hardness of wheat endosperm by near infrared spectroscopy. *Postharvest News and Information* 2(5): 331-334.

OURY, F.X., ROUSSET, M., BERARD, P., PLUCHARD, P., DOUSSINAULT, G., 1995. Bread- making quality of hybrids: effect of high molecular weight glutenins in a state of heterozygoty. *Can. J. Plant Sci.* 75: 633-642.

PARK, W.J., SHELTON, D.R., PETERSON, C.J., MARTIN, T.J., KACHMAN, S.D., WEHLING, R.L., 1997. Variation in polyphenol oxidase activity and quality characteristics among hard red white wheat and hard red winter wheat samples. *Cereal Chem.* 74(1): 7-11.

PAYNE, P.I., NIGHTINGALE, M.A., KRATTIGER, A.F., HOLT, L.M., 1987. The relationship between HMW glutenin subunit composition and the bread-making quality of British grown wheat varieties. *J. Sci. Food Agric.* 40: 51-65.

PAYNE, T.S., TANNER, D.G., ABDALLA, O.S., 1996. Current issues in wheat research and production in Eastern, Central and Southern Africa: Changes and challenges, In: D.G. Tanner, T.S. Payne, O.S. Abdalla (Eds.). The Ninth Regional Wheat Workshop for Eastern, Central and Southern Africa, Addis Ababa, Ethiopia, pp. 59-63.

PERENZIN, M., PONGA, N.E., BORGHI, B., 1992. Combining ability for breadmaking quality in wheat. *Can. J. Plant Sci.* 72: 743-754.

PERENZIN, M., CORBELLINI, M., ACCERBI, M., VACCINO, P., BORGHI, B., 1997. Bread wheat: F1 hybrid performance and parental diversity estimates using molicular markers. *Euphytica* 100: 273-279.

PERTEN, H., 1964. Application of the Falling Number method for evaluating alpha-amylase activity. *Cereal Chem.* 41: 127-140.

PETERSON, C.J., MOFFATT, J.M., ERICKSON, J.R., 1997. Yield stability of hybrid vs, pureline hard red winter wheats in regional performance trials. *Crop Science* 37:116-120.

PICKETT, A.A., 1993. Hybrid wheat – results and problems. In: Advances in plant breeding, Supplement 15, Paul Parey Scientific Publishers, Berlin and Hamburg, pp. 1-259.

PICKETT, A.A., GALWEY, N.W., 1997. A further evaluation of hybrid wheat, *Plant Varieties and Seeds* 10:15-32.

PINTHUS, M.J., 1973. Lodging in wheat, barley and oats. The phenomenon, its causes and preventative measures. *Adv. Agron*. 25: 209-253.

PLANCHON, C., 1969. Photosynthetic activity and yield of soft wheat (*Triticum aestivum* L.). *Genet. Agr.* 23: 485-490.

POEHLMAN. J.M., SLEPER D.A., 1995. Breeding field crops. Fourth Edition. Iowa State University Press, Ames, Iowa. pp. 259-269.

POMERANZ, Y., PETERSON, C.J., MATTERN, P.J., 1985. Hardness of winter wheats grown under widely different climatic conditions. *Cereal Chem.* 62(6): 463-467.

POMERANZ, Y., MATTERN, P.J., 1988. Genotype x environment interaction effects on hardness estimates in winter wheat. *Cereal Foods World* 33(4): 371-374.

POMERANZ, Y., WILLIAMS, P.C., 1990. Wheat hardness: its genetic, strutural and biochemical background, measurement and significance. In: Y. Pomeranz (Ed.). Advances in cereal science and technology. Volume X. American Association of Cereal Chemists, Inc., St. Paul, Minnesota, USA.

PORSCHE, W., TAYLOR, M., 2001. In: A.P. Bonjean, W.J. Angus (Eds.). The World Wheat Book. Lavoisier Publishing Inc. Paris. pp.187,190.

POSNER, E.S., HIBBS A.N., 1997. Wheat flour milling. American Association of Cereal Chemists, St. Paul, Minnesota, USA.

PRAKASA RAO, V.S., JAIN, H.K., 1977. Male sterility and fertility restoration in bread wheat, *Indian J. Genet.*, 37: 114-123.

PRESTON, K.R., MORGAN, B.C., DEXTER, J.E., 1995. Influence of protein segregation on the quality characteristics of Biggar and Genesis Canada Prairie spring wheat. *Can. J. Plant Sci.* 75: 599-604.

PUMPHREY, F.V.,RUBENTHALER, G.L., 1983. Lodging effects on yield and quality of soft white wheat. *Cereal Chem.* 60: 268-270.

PURCHASE, J.L., 1997. Parametric analysis to describe genotype x environment interaction and yield stability in winter wheat. PhD Thesis. University of the Free State, Bloemfontein.

PURCHASE, J.L., HATTING, H., VAN DEVENTER, C.S., 2000a. Genotype x environment interaction of winter wheat (*Triticum aestivum* L.) in South Africa: I. AMMI analysis of yield performance. *S. Afr.J. Plant Soil* 17(3): 97-100.

PURCHASE, J.L., HATTING, H., VAN DEVENTER, C.S., 2000b. Genotype x environment interaction of winter wheat (*Triticum aestivum* L.) in South Africa: I. Stability analysis of yield performance. *S. Afr.J. Plant Soil* 17(3): 97-100.

RAJARAM, S., VAN GINKEL, M., 2001. In: A.P. Bonjean, W.J. Angus (Eds.). The World Wheat Book. Lavoisier Publishing Inc. Paris. pp. 601, 602.

RATNALIKAR, V.P., SING, U.S., 1998. Role of industry in promoting hybrids in self-pollinated crops. In: S. Nagarajan, G. Singh, B.S. Tyagi, (Eds.). Wheat: Research Needs Beyond 2000 AD, Narosa Publishing House, New Delhi, India, pp. 130-135.

ROBERT, A.G., PETERSON, C.J., SHELTON, D.R., BAENZIGER, P.S., 1996. Genotype and environmental modification of wheat flour protein composition in relation to end-use quality. *Crop Sci*. 36: 296-300.

ROGERS, D.E., HOSENEY, R.C., LOOKHART, G.L., CURRAN, S.P., LIN, W.D.A., SEARS, R.G., 1993. Milling and cookie baking quality of near-isogenic lines of wheat differing in kernel hardness. *Cereal Chem.* 70(2): 183-187.

RUSMINI, B., 1967. Una prova su ibridi F1 di frumento. *Sem. Elette*, 13: 2-7.

SAGL- SOUTH AFRICAN WHEAT CROP QUALITY REPORT. SOUTH AFRICAN GRAIN LABORATORY. 2002, 2004 and 2005.

SHEBESKI, L.H., 1966. Quality and yield studies in hybrid wheat (*Triticum aestivum* L.). *Can J. Genet. Cytol.* 8: 375-386.

SHEWRY, P.R., TATHAM, A.S., BARRO, F., BARCELO, P., LAZZERI, P., 1995. Biotechnology of bred maiking: Unravelling and manipulating the multi-protein gluten complex. *Bio/Technology* 13: 1185-1190.

SIMMONDS, D.H., 1989. Wheat proteins: their chemistry and nutritional potential. In: L.T. Evans, W.P. Peacock (Eds.). Wheat science – today and tomorrow, Cambridge Univesity Press, Cambridge, pp. 129-148.

SPIES, R., 1990. Application of rheology in the bread wheat industyr. In: H. Faridi and J.M. Faubion (Eds.). Dough rheology and baked product texture. Van Nosstrand Reinhold, New York, pp. 343-361.

STENVERT, N.L., 1972. The measurement of wheat hardness and its effect on milling characteristics. *Australian Journal of Experimental Agriculture an Animal Husbandry* 12: 159-164.

STEVE, F.S., ROBERT, K.B., PATRICK, L.F. EDWARD, E.G., 1995. Relationship of test weight and kernel properties to milling and baking quality in soft wheat. *Crop Sci.* 35: 949-953.

STODDARD, F.L., MARSHALL, D.R., 1990. Variability in grain protein in Astralian hexaploid wheats. *Aust. J. Agr. Res.* 41: 277-288.

TAKAHASHI, N., 1980. Effect of environmental factors during seed formation on preharvest sprouting. *Cereal Res. Commun.* 8: 175-183.

TRETHOWAN, R.M., PFEIFFER, W.H., PENA R.J., ABDALLA., 1993. Preharvest sprouting tolerance in three triticale biotypes. *Austr. J. of Agric. Res.* 44: 1789-1798.

TRETHOWAN, R.M., 1995. Evaluation and selection of bread wheat (*Triticum aestivum* L.) for preharvest sprouting tolerance. *Austr. J. of Agric. Res.* 46: 463-474.

UPADHYAY, M.P., PAULSEN, G.M., 1988. Heritabilities and genetic variation for preharvest sprouting in progenies of Clark's Cream white winter wheat. *Euphytica* 38: 93-100.

VAN DEVENTER, C.S., 1986. Genotipe x omgewingsinteraksie by winterkoring in die Oranje-Vrystaat. *S. Afr. J. Plant Soil* 3(3): 147-148.

VAN LILL, D., 1992. Environmental effects on yield and bread-making quality of some South African wheat cultivars. PhD Thesis, University of Stellenbosch.

VAN LILL, D., PURCHASE, J.L., 1995. Directions in breeding for winter wheat yield and quality from 1930 to 1990. *Euphytica* 82: 79-87.

VAN LILL, D., SMITH, M.F., AGENBAG, G.A., DE VILLIERS, O.T., 1995. Multivariate assessment of environmental effects on hard red winter wheat. I.Principal-components analysis of yield and bread-making characteristics. *S. Afr. J. Plant Soil* 12(4): 158-163.

VAN LILL, SMITH, M.F., 1997. A Quality strategy for wheat (*Triticum aestivum* L.) where growth environments predominates. *S. Afr. J. Plant Soil* 14: 183-191.

WALKER, C.E., HAZELTON, J.L., 1996. Dough rheological tests. *Cereal Foods World* 41(1): 23-28.

WILLIAMS, P., 1998. Applications of Perten SKCS 4100 in flour-milling. Presentation to the 10th Annual Conference and Exposition, Association of Operative Millers, Middle East and East Africa Section, Nairobi, Kenya. November, 1998.

WILSON, J.A., 1968. Problems in hybrid wheat breeding, *Euphytica* 17: 13-33.

WILSON P., DRISCOLL, C.J., 1983. Hybrid wheat. In: R. Frankel (Ed.). Heterosis, reappraisal of theory and practice, *Monographs on Theoretical and Applied Genetics* 6: 94-123.

WYLIE, S., 2002. Wheat hardness affects milling. *World Grain* 20(2): 58-62.

YAMADA, T., 1994. Genetic resources and breeding of wheat and barley in Japan. *Wheat Information Service* 79: 1-17.

YAMAZAKI, W.T., 1976. Soft wheat quality of pre-ripe, harvested wheat. *Crop Sci.* 16: 572-575.

YAMAZAKI, W.T., DONELSON, J.T., 1983. Kernel hardness of some U.S. wheats. *Cereal Chem.* 60: 344-350.